FRREDSS Price Mechanism

Utilizing bioenergy siting and economic optimization tool to support long-term feedstock procurement price management

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Disclaimer: The numbers produced in this report were not intended to inform business plan development. Please exercise caution when interpreting final modeling results and verify costs with forest professionals in your area.

Abstract

The need to establish new infrastructure for biomass processing has been recommended by several state strategies for California to accomplish its carbon neutrality and forest health goals. However, without a long-term guaranteed supply contract, new facilities are not eligible for loans, debt servicing, or other financing strategies. In 2023, the Watershed Research and Training Center (WRTC) partnered with UC Davis on the use of the Forest Resource and Renewable Energy Decision Support System (FRREDSS)—an integrated optimization tool for least-cost feedstock procurement—to test its effectiveness as a tool to determine long-term feedstock contract prices in a spatial environment. Sensitivity analyses were conducted by summarizing the 20-year profit and loss (P&L) statement across silvicultural and harvest types, expansion factors, and inflation rates across six (6) site locations within Nevada, Placer, and El Dorado Counties. Site locations were modeled to test the feedstock costs for a 5 MW combined heat and power conversion system with a general average feedstock demand of 35,753 bone dry tons (BDT) per year. Input variables were updated to 2023 market rates across the modeling environment (i.e. diesel price, hauling rate, CPI, etc.). When comparing the average delivered feedstock cost over the 20-year period with reported contractor rates to the Ophir site location, we found that the model was unable to come within 10% of the reported rates. On a year by year basis, costs where consistently less than reported rates. It wasn't until Year 15 of the 20-year P&L statement that prices began to exceed reported contractor rates. For this reason, recommendations to improve the FRREDSS model focus on better representing logging constraints in a spatial environment, adding variables to estimate workforce capacity, adding variables to represent subsidies, and to develop an inflation-based index to better represent biomass economics. Ultimately, it is recommended that a new tool be built that is more customized to the end goals of long-term feedstock contract price management. Results developed in this report continue to support the basis for long-term feedstock pricing, but more development is required before cost estimates are within an acceptable range of accuracy to be applied in existing markets.

Overview

The need to establish new infrastructure for biomass processing has been recommended by several state strategies for California to accomplish its carbon neutrality and forest health goals (California Air Resources Board, 2022; Forest Climate Action Team, 2018; Forest Management Task Force, 2021). However, prospective wood product businesses face high barriers to market entry in California and often face a nearly insurmountable challenge in securing long-term feedstock supply contracts. Without a guaranteed supply contract, facilities are not eligible for loans, debt servicing, or other financing strategies (CLERE, 2021). Through the Governor's Office of Planning and Research (OPR), five regions throughout California were awarded funding to investigate the potential for new public entity business models to support the coordination of non-merchantable biomass from subsidized forest health projects. A component of this entity proposes that bundling many biomass contracts and establishing transparent, long-term brokering services for new facilities to satisfy lending requirements could drastically enable a new generation of biomass processing businesses to access large sums of capital (CLERE, 2023). To accomplish this, a publicly managed price mechanism could establish a common ground between buyers and sellers to enter a fair process for price negotiation.

In 2023, the Northeastern California (NE CA) OPR Pilot Project team partnered with UC Davis on the use of the Forest Resource and Renewable Energy Decision Support System (FRREDSS) to test its effectiveness as a tool to determine long-term feedstock contract price points. Developed in 2020, the FRREDSS model provides a multi-step framework for user-defined locations to site bioenergy facilities and calculates the 20-yr profit and loss (P&L) statements based on the full delivered price of forest-based feedstock.

Goal

The goal of this study is to validate FRREDSS feedstock price changes over time using a sensitivity analysis on location, different combinations of forest treatment and harvest system, inflation rate, and with various expansion factors. This study relied on a small stakeholder group of industry experts to determine the accuracy of the model and the potential for its incorporation into feedstock procurement plans.

Objectives

1. Understand the FRREDSS model inputs and outputs and identify specific results from the model that would be useful for developing long-term feedstock agreement.
2. Validate current FRREDSS output feedstock prices with existing feedstock contracts.
3. Identify the most sensitive parameters which will be the target parameters to toggle in model scenarios (i.e., under what conditions would warrant a feedstock agreement to be updated, modified, or re-written).
4. Recommend changes to the FRREDSS model to better service the goal of the study.

Introduction

During California's rise of bioenergy development in the aftermath of the 1973-1974 energy crisis, biomass procurement systems may have looked very different from today's supply chain. Between 1985 and 1990, 33 new biomass generating facilities were opened. During this time, some facilities may have been more vertically integrated by owning their own land, logging crews or chipping equipment (Morris, 2002; BioResource Management, 2012). Today, the forest product sector is more fragmented with landowners, operators, and wood product facilities often existing as separate entities. As such, feedstock contracts are either negotiated through long-term relationships with different landowners, negotiated with brokers or contractors, or are based on spot market purchases. Guaranteeing a constant feedstock supply over a long-term period (more than 10 years) thereby becomes a sophisticated exercise and can be a nearly insurmountable task for new facility development without ownership of their own forested land[1]. Without a long-term feedstock agreement, lenders will deem the project too risky for a loan thereby jeopardizing new development feasibility. More research on innovative contract designs for the wood procurement process could help provide a more informed discussion as California considers options for a circular bioeconomy.

The barriers to biomass utilization have been well documented throughout the West over the last two decades (Becker et al., 2011; Dysthe, 2021; Nicholls et al., 2018; Sanchez & Gilani, 2022). Price volatility of markets, increasing costs to operate, and the market capture of subsidies required to accomplish the new land management objectives of fuel reduction and forest resiliency are some of the variables which have exacerbated uncertainty in feedstock agreements in California today. Timing of wood delivery as well as workforce capacity have also been significant barriers. Managing these dynamics has been the responsibility of the receiving end-user's feedstock procurement manager, where large landowners offer the simplest process for multi-year contracts on a regular basis. However, there are timber dealers or feedstock brokers who can be hired to manage feedstock procurement across the scale from small to large landholdings.

Feedstock brokers were a common and relied upon aspect of the biomass market in the past and to a lesser extent today. It is still common for feedstock brokers to be hired by established facilities to fill in gaps of supply during key times of the year, although this type of profession has slowly dwindled as bioenergy facilities regularly employ feedstock procurement managers (Personal Communication with Industry Professional). Recreating a network of wood brokers to manage fiber flow to existing markets and bundle many smaller contracts for new facility developers to obtain a long-term feedstock agreement is a promising option. However, an entity of this sort must be highly receptive to the existing market conditions. Where there is current concern for existing supply chains to scale up to satisfy state goals, the question becomes: how to incentivize facilities and timber operators to feel safe when entering into an agreement that would otherwise be seen as risky?

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[1] The only operational facility under the BioMAT program is owned by Collins Pine who is also an industrial timber landowner. Burney Hat Creek would be the first without land ownership to operate if successful. They are currently under construction and are expected to be operational in 2025.

Prominent risks within a long-term feedstock agreement can be most acutely felt with price volatility or feedstock availability. In some cases, established supply chains may prefer more access to feedstock during the winter in order to maintain consistency. In the Northeastern OPR pilot region, stakeholders preferred to have their existing prices not be significantly altered because “it works”, adding that winter feedstock availability could be improved. Other regions may prefer more predictable prices over a long term to anchor financial cash flow projections. In the Central Sierra OPR pilot region, markets are still developing, and long-term price forecasting remains a prominent concern for business development. Other regions still may require both. However, biomass price prediction can be a complex process.

There are many factors which impact harvesting, processing, and mobilizing biomass to market. Final costs to operate are calculated on a project by project basis and therefore makes generalizations potentially misleading. Yet, the viability of mobilizing biomass to market frequently depends on the transportation distance (Berry, 2017). Consequently, the price of diesel (both for hauling and for timber operations) becomes one of the quickest estimations of biomass price volatility for the timber operator (BioResource Management et al, 2012). Additionally, the stumpage price of sawlogs can significantly impact the viability of feedstock supply by influencing landowner’s decision to operate (BioResource Management et al, 2012). Ultimately, there are a variety of pinch points within the biomass supply chain that can be exposed to risk and potential failure.

Table 1 summarizes the ways that feedstock contracts can manage various types of risk in addition to others. In California, many of these measures are already practiced. However, with the need for some facilities to manage upwards of 20 or 30 contracts at a time, simplicity is important. The simplest process, as stated earlier, is to work with a large landowner or otherwise develop forest projects with high-value sawlog harvesting to offset the costs to remove biomass.

Table 1: Summary of risk and uncertainty types, sources, and potential management measures. (Source: BioResource Management et al. 2012)

Risk / uncertainty type	Main sources	Potential for mitigation or management	Management measures
Production cost uncertainty	● Diesel fuel volatility ● Inflation	Low to moderate	● Build fuel cost 'pass through' provisions in biomass facility offtake agreements ● Petroleum/diesel fuel hedging

Risk / uncertainty type	Main sources	Potential for mitigation or management	Management measures
External demand uncertainty	- Demand (domestic and international) for renewable energy. - Demand for building products, such as oriented strand board, made from small diameter timber	Low to moderate	- Long-term supply agreements to secure needed quantities. - Land leases to generate dedicated biomass exclusively for the facility. - Diversification of biomass material types
Biomass Crop Risk	- Catastrophic events (fire, storm, pathogens) - Yield underperformance	Low (storms) to high (fire, yield)	- Good silvicultural management practices - Timberland insurance - Diversification of suppliers, material types, and geographic sources
Counterparty risk	- Exposure to production cost or other market volatility	Moderate to high	- Selection of stable and reliable suppliers - Sound contract construction (to avoid conditions leading to supplier default)
Regulatory uncertainty	- Dynamic nature of natural resource and renewable energy policy	Low to moderate	- Abide existing regulations. - Involvement in industry groups

Other ways to manage uncertainty can be through the long-term commitment of subsidies. It is hard to overstate the importance of both subsidies to guarantee power generation revenue from the biomass facilities and the subsidies for contractors to operate with preferred silvicultural treatments on priority landscapes. Subsidies close the gap between the timber operator production cost and the purchase price, thereby mobilizing biomass that would have originally been uneconomical.

Nevertheless, even with these management measures, there is still a perceived opportunity to innovate with long-term feedstock contracts and pricing. A key component of long-term contracts is the ability to identify a price and system for ongoing negotiation throughout the lifetime of the contract. Ideally, a mechanism of this sort would provide security to timber operators who can better forecast financial performance over the term of the contract, as well as benefit an end-user to prove a long-term commitment to feedstock (e.g. the last 10% of the total feedstock demand).

It's important to note that this type of supply uncertainty exists as a necessary risk in other sectors as well. For example, the energy market uses many sophisticated tools and mechanisms when developing long-term agreements for power purchases.

This analysis aims to evaluate the ability to generate a self-adjusting price contracting scheme to support the forest-biomass feedstock procurement process. Specifically, this paper reviews the application of the UC Davis Forest Resource and Renewable Energy Decision Support System (FRREDSS) model to validate its feasibility to support long-term feedstock contract prices during contract negotiations. If successful, the FRREDSS model can create a more transparent price negotiation and procurement process for all interested parties in contract negotiation. This includes potential lenders looking to invest in new biomass opportunities.

Decision Support System for long-term feedstock price mechanism

The FRREDSS is a web-based forest biomass-to-energy plant siting application that was developed by UC Davis under a project funded by the California Energy Commission (CEC). FRREDSS allows users to quickly assess preliminary forest feedstock availability as well as evaluate the economic feasibility and environmental impacts of potential wood-based bioenergy facilities in California. While the project aims to include biomass resources associated with extreme tree mortality, vegetation layers represent 2016 vegetation.

FRREDSS is intended to assist in identifying potential sources of feedstock for project development. FRREDSS currently has the capability to identify forest biomass resources in the Sierra Nevada region and their relationship to fire hazard zones and other attributes important to siting power generation and other types of biomass utilization facilities. In addition, the spatial analysis model of FRREDSS also has the capability to assess proximity of feedstock to infrastructure, e.g., access to landings and road networks, along with estimated delivered costs of feedstock at the facility and overall levelized cost of energy (LCOE).

FRREDSS currently uses forest biomass data produced from the F^3 modeling framework that integrates Forest Inventory and Analysis (FIA) data from the U.S. Forest Service (USFS), the Forest Vegetation Simulator (FVS), and the FastEmap (Field and SatelliTe for Ecosystem MAPping) to simulate spatiotemporal forest changes under natural succession and vegetation management (Huang, 2018). With support from the OPR, FRREDSS will structure the updated statewide biomass data

(LEMMA GNN dataset derived from FIA) currently used in the C-BREC model[2] for direct use with the FRREDSS and eventually with the overall online digital marketplace[3].

FRREDSS was developed using primarily open-source software and integrates user-defined inputs with a number of analysis modules representing the elements of a forest-based biopower supply chain including forest biomass harvesting cost evaluation adapted from the Fuel Reduction Cost Simulator (FRCS) (Fight et al., 2006), optimized feedstock transportation employing the Open Source Routing Machine (OSRM)[4] and a transportation cost estimator developed in association with the Advanced Hardwood Biofuels (AHB) project (Bandaru, 2015); comprehensive techno economic assessment (TEA) developed through the California Biomass Collaborative at UC Davis[5] to provide estimated levelized lifecycle cost of energy, and lifecycle inventory, accounting and assessment (LCI/LCA) to estimate criteria pollutant and greenhouse gas emission.

Methods and Parameters

The methods for examining the suitability of FRREDSS as a tool for long-term feedstock prices contains both a sensitivity analysis and consultation with stakeholders through a series of focus group meetings. The sensitivity analysis is explained in depth in the section. Our stakeholder focus group meetings were attended by two timber operators, one feedstock broker in California, and foresters. In addition, individual meetings were conducted with a variety of individuals including foresters, biomass power facility operators, and project managers throughout the process.

The purpose of this research is to investigate variable feedstock costs to inform long-term feedstock contracts and a potential rate structure. While this model does have a techno-economic analysis (TEA) component to determine the profit and loss (P&L) statement of a biopower facility, the model is built in such a way that the economics of the facility do not constrain the availability of feedstock or its price. As such, this effort looked exclusively at sensitivity analyses which only impact the feedstock cost. The scenarios are summarized below. Each scenario is labeled according to the analysis being performed and the scenario number. For example, scenarios dealing with forest treatment and harvest system combinations are labeled “S1” and each variation within this scenario is given a separate number (1-5). Scenarios dealing with the expansion factor are labeled “S2” and each variation within this scenario is given a number (1-3). Six site locations were chosen throughout the Tahoe Central Sierra.

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[2] California Biomass Residue Emissions Characterization (C-BREC) model provides a life-cycle assessment framework for the use of California forest residues for electricity generation.

[3] OPR has offered a joint award through an interagency agreement of $350,000.00 to UC Davis, Cal Poly Humboldt and Cal Poly San Luis Obispo, to finance the integration of existing forest management tools into a comprehensive feedstock aggregation and mapping tool.

[4] Project OSRM

[5] Energy Cost Calculator | California Biomass Collaborative

FRREDSS provides default assumptions for the model. This research updated the assumptions to reflect current market rates, as depicted in Table 2. Model runs were only conducted for updated assumptions. Once the input assumptions were updated, all other input variables were fixed except for the following:

1. **Forest Treatment/Forest Harvesting System Sensitivity Analysis** These combinations are intended to replicate the most common forest treatment and harvest method meant to be delivered to a biomass facility and associated with non-industrial timberland management. Land objectives are associated with stand improvement, fuel reduction, and general vegetation management from public agencies. Scenario labels are depicted in Table 2.

Table 2: FRREDSS forest treatment and harvest system combinations with sensitivity run combination identified

	Ground Mech Whole Tree (WT)	Ground Manual WT	Ground Manual Log	Ground Cut to Length (CTL)	Cable Manual WT/Log	Cable Manual WT	Cable Manual Log	Cable CTL	Heli-Manual Log	Heli-CTL
Clearcut										
Commercial Thin	S1-1									
Commercial Thin Chip Tree (CT)	S1-4									
Timber Salvage										
Timber Salvage CT										
Selection				S1-2						
Selection CT	S1-5									
10% Group Selection	S1-3									
20% Group Selection										
Biomass Salvage CT										

2. **Expansion Factor.** The expansion factor is an approach developed within FRREDSS to expand on the search region in each year of the analysis. As the expansion factors increase, the size of the woodbasket increases as well. However, biomass clusters are optimized within this larger radius to be the cheapest source of material, given the costs of the unique

forest treatment and harvest combination selected. This research examined the following expansion factors under a commercial thin prescription with small tree removal and whole tree harvest systems (“S1-1”, see Table 2) as the baseline.

    1. Expansion factor 3 (S2-1)
    2. Expansion factor 10 (S2-2)

3. **Location**. This analysis selected the following locations in the Tahoe Central Sierra region due to their affiliation with prospective biomass development sites. See Figure 1 for their spatial location. All facilities were modeled under a 5 MW feedstock demand assumption, with the exception of the South Lake Tahoe site.
    1. **Ophir, Auburn, Placer County.** Proposed 5 MW biomass facility being investigated by Placer County Water Agency located just outside the City of Auburn.
    2. **Camptonville, Town of Dobbins, Nevada County.** The Camptonville Community Partnership has been developing a 5 MW BioMAT compliant bioenergy facility.
    3. **Cabin Creek, Truckee, Placer County.** Proposed 5 MW Cabin Creek Biomass facility located along the HWY 89 Corridor to Tahoe City near the Eastern Regional Landfill being investigated by Placer County.
    4. **South Tahoe Refuse, City of South Lake Tahoe, El Dorado County**. Proposed small-scale 125 kW demonstration project at the Material Recovery Facility located within the City of South Lake Tahoe.
    5. **Medium to Large Wood Product Campus, Town of Camino, El Dorado County.** El Dorado County is looking to have a more informed discussion with SPI and other key stakeholders, including PG&E, Mountain Enterprises, SMUD, USFS, EDWA & Pioneer on a new 5 MW facility. SPI agreeable to sell or lease space at Camino site.
    6. **Grass Valley, Nevada County**. The City of Grass Valley is examining potential site locations for a 5 MW facility.
4. **Inflation Rate**. The default assumption for inflation is 2.1%. This number is eliminated in order to isolate the impacts to prices due from general model performance.

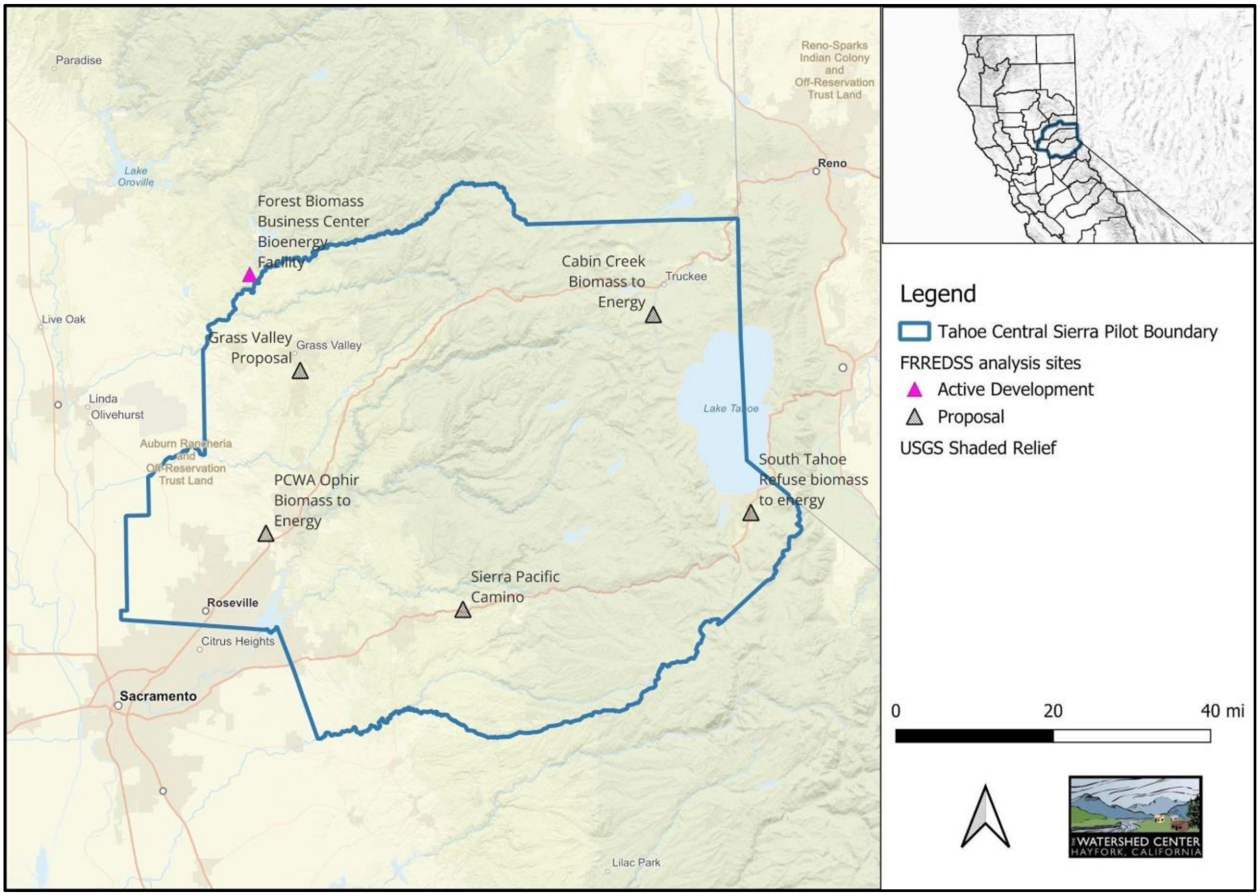


Figure 1: Site locations of FRREDSS analysis

The sensitivity analysis also updated assumptions on the feedstock cost inputs in the model. Inputs and updates to the input assumptions are shown in Table 3. Updates were developed through interviews with industry professionals or additional research. Diesel fuel price is determined by averaging the 2022-2024 CA diesel prices for Northern California using data from the US Environmental Information Agency (US EIA). Percent overhead and hourly hauling contractor rates are based on industry standards as communicated by professionals, in addition to Swezy (2021). Finally, electrical capacity of 5,000 kWe is selected in order to represent facilities which are compliant with the California Bioenergy Market Adjusting Tariff (BioMAT).

Table 3: Updated assumptions to customize in FRREDSS input selection

	Default	Updates
Expansion Factor	1	Sensitivity variable
Fuel Reduction Cost Simulator		
Diesel Fuel Price ($/gal)	$2.24	$5.41
Wage for Fallers ($/hr)	$35.13	Used default values

	Default	Updates
Wage for Other Workers ($/hr)	$22.07	Used default values
% benefits and overhead for operators	35%	20%
Current Producer Price Index	284.7	140.5
Residue Recovery from WT	80%	Used default values
Residue Recovery from CTL	50%	Used default values
Transportation		
Hourly Wage for Truckers ($/hr)	$24.71	$150.00
% benefits and overhead for truckers	67%	0%
Oil Cost ($/mi)	$0.35	Used default values
Techno-Econ Assessment		
Bioenergy generation type		
Generic Power	x	
Combined Heat and Gas		
Gasification Power		x
Net Electrical Capacity (kWe)	25,000	5,000
Capacity Factor	80%	Used default values
Moisture Content	50%	Used default values
Fuel Heating Value	18,608	Used default values
Inflation Rate	2.1	Used default values

Finally, we compare the outputs of the FRREDSS model under all scenarios to reported harvest rates collected in the region from contractors as documented by Swezy (2024). This will help benchmark the effectiveness of the model to calculate a general cost to deliver biomass.

Results

Sensitivity Analysis

Analysis results looked at average feedstock price across sensitivities and site locations. For a specific look at how prices changed across sensitivities, results focus on the Grass Valley site. Feedback from stakeholders and a comparison of prices to contractor rates supported model refinement based on the results of the analysis.

The Grass Valley feedstock price curve for each sensitivity variable is shown in Figure 2. All other facility locations followed a similar trajectory. Sensitivity S1-2 uses a cut to length harvesting system which inflates the overall cost to operate. Most of the harvest systems use whole tree logging and have an average delivered feedstock cost of $44 per BDT in the first year, rising to an average of $113 per BDT in year 20 when given fixed inflation rates and deterministic assumptions about the future of forest treatment availability. Generally, treatment prescription had less of an impact on prices than harvest type when assuming the most common type of harvest type within the region for biomass procurement.

Furthermore, the difference in expansion factors did not play a significant role in price forecasting. As a reminder the expansion factor is a variable to determine the spatial extent for the model to locate the least expensive biomass clusters. As the expansion factor continues to increase, it is assumed that the model will be more “optimized” to find the least expensive biomass. For images of how each expansion factor impacted the location of biomass around a site location please see “Appendix C: FRREDSS spatial outputs for each expansion factor scenario”.

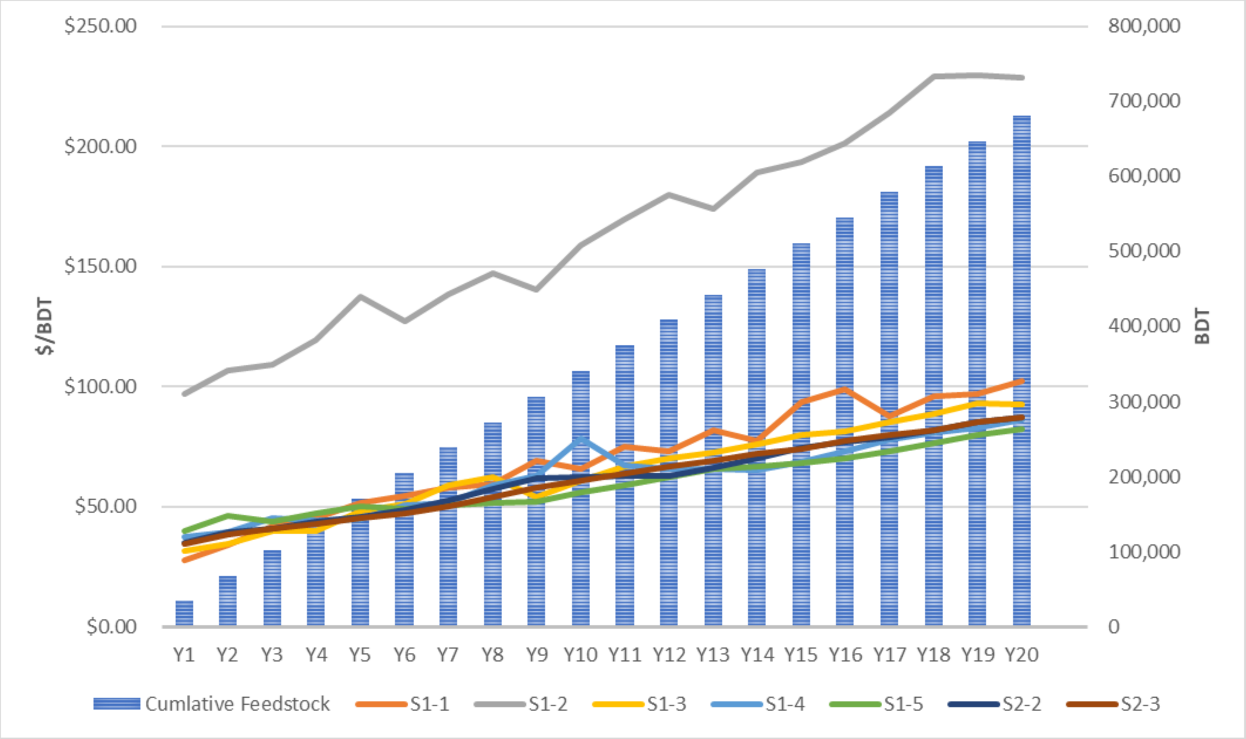


Figure 2: Delivered Price in Grass Valley across sensitivity variables

The FRREDSS model is built to assume that feedstock closest to the facility would be more favorable and is consumed first. As the size of the facility increases so will the feedstock demand. Due to the variability in harvest site locations, transportation costs are often the hardest cost to predict and can frequently be the most expensive aspect to delivering feedstock costs (Berry, 2017). Distances are calculated within the outputs of FRREDSS but can be easily derived using the $150 hourly hauling rate for contractors and transportation costs. As shown in Table 4, all site locations are able to find a potential feedstock availability supply within a 30-minute radius. Note that workforce availability, additional terrain characteristic constraints (e.g. distance from roads, protected activity centers, etc.), or road access is not considered within the model.

Table 4: Summary of time distance to procure feedstock over the lifetime of facility operations

Distance (minutes)	Y1	Y5	Y10	Y15	Y20	Average
Cabin Creek	6.29	11.14	21.65	23.80	26.39	18.36
Camino	4.83	11.67	18.04	23.27	28.89	17.70
Camptonville	4.28	10.55	14.90	19.81	24.21	15.77
Grass Valley	5.33	11.21	16.50	22.48	27.44	17.01
Ophir	11.03	16.21	19.30	23.49	28.85	20.39
South Tahoe	2.09	3.43	5.10	6.19	7.96	5.25

Figures 3 and 4 look at the average harvest and transportation costs across sensitivities per site location. Harvest costs are generally similar and range from $30 per BDT to $40 per BDT over the course of the facility life. Costs are increasing over the 20-year period due to inflation rates of 2.1%. This rate and other factors can be customized in the FRREDSS model if desired. There is a large increase in harvest costs after year 10 at the Cabin Creek site, located just outside of the Town of Truckee, that is not replicated for other site locations. Because Figure 3 represents only harvest costs (not transportation costs like Figure 4), the increase in transportation costs cannot explain this anomaly. The only variable that may be subject to this drastic change within the FRCS harvest calculation is the yarding distance for each pixel. Due to the facility’s location within a wildland-urban interface (WUI) environment, yarding distance may have been impacted. Notably, Grass Valley’s harvest cost curve remains more stable.

Consequently, a new class of questions is raised regarding the differences in schedule machine hour (SMH) and productive machine hour (PMH) with operations occurring in the built environment and WUI, versus the wildland. SMH and PMH are standard machine rate calculations developed by Miyata (1980).   The FRREDSS model does not currently operate with this granularity for user modification, although the FRCS module relies on the formulas developed by Miyata (1980) for individual machines and combines machines into systems by using the approach described in Hartsough and others (2001) to determine harvest cost (Fight, 2006).

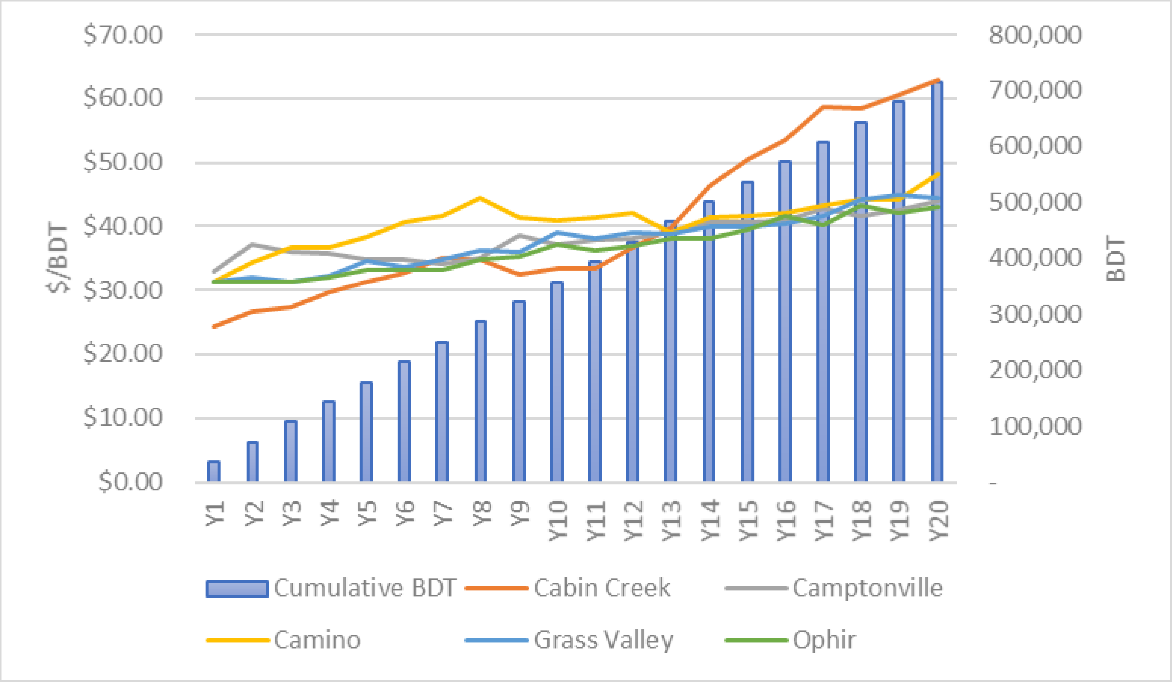


Figure 3: Average harvest cost across sensitivities per site location

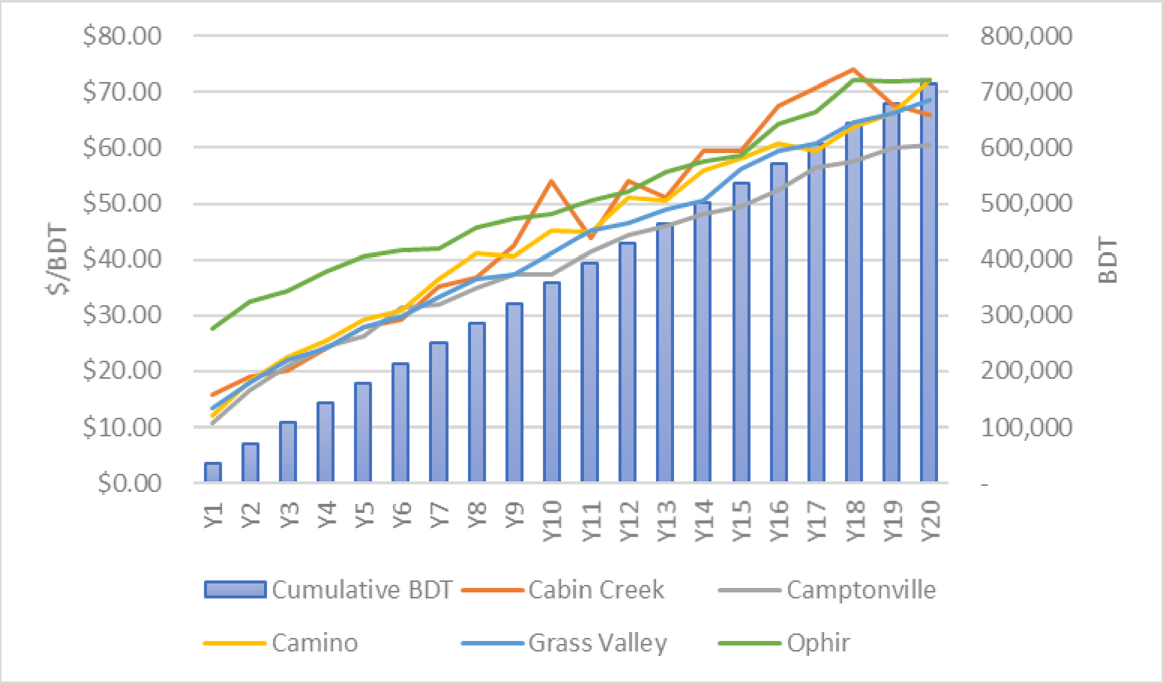


Figure 4: Average transportation cost across sensitivities per site location

The combined 20 year delivered feedstock price curve averaging all sensitivity variables per location is illustrated in Figure 5. Sensitivities include both the changes in treatment and harvest combinations, and the expansion factor. In other words, Figure 5 depicts a general trend for prices across various scenarios and distances using the FRREDSS model. Prices increase throughout the life of the project due to the priority for the model to harvest the closest feedstock first and due to general inflation.

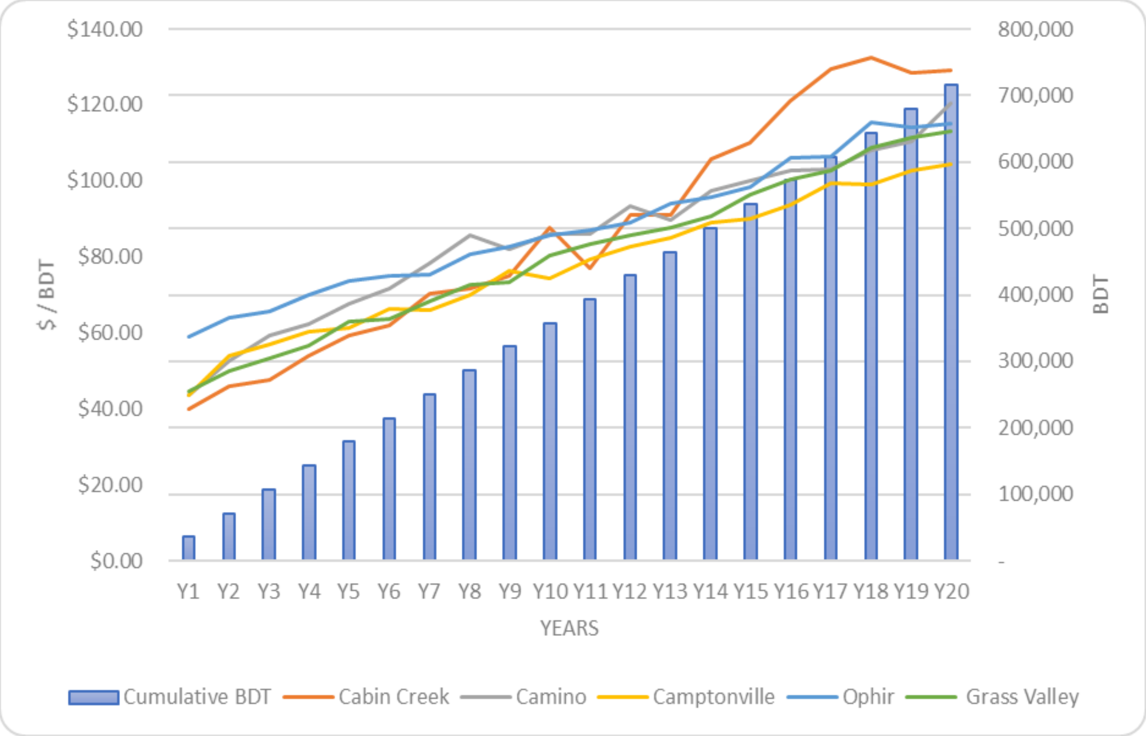


Figure 5: Total delivered feedstock cost per site location in Tahoe Central Sierra OPR region assuming a 5MW feedstock demand

Table 5 shows that costs rise from an average of $43 per BDT within the first year of operation under 2022 price assumptions and increase to $106 per BDT by year 20. This is a 147% increase in prices. On a year-to-year basis, prices increased from 4–7% depending on the site location. Overall, prices increased by 5% per year on average across all site locations.

Table 5: Cost summary table of harvest operations to cut, skid, deck, chip, and deliver biomass to a site location

Feedstock Cost	Y1	Y5	Y10	Y15	Y20	**Average**
Cabin Creek	$40	$59	$88	$110	$129	**$86**
Camino	$44	$68	$86	$100	$120	**$85**
Camptonville	$44	$61	$74	$90	$105	**$78**
Grass Valley	$43	$60	$78	$93	$110	**$78**
Ophir	$59	$74	$86	$98	$115	**$88**
South Tahoe	$30	$37	$43	$50	$58	**$44**
Average	**$43**	**$60**	**$76**	**$90**	**$106**	**$76**

Finally, in order to understand the magnitude default inflation rates of 2.1% had on price forecasting, S1-1 was modeled across each site location without inflation rates. Eliminating the inflation rate focuses attention on the impact transportation distance has on prices year over year. The results are represented in Figure 6. Without a year over year inflation rate of 2.1%, prices over a 20 year period remain more constant with a difference of $15 per BDT from year 1 to year 20. This is a 30% decrease in prices at year 20 when compared with inflation based prices. This graph illustrates that general inflation rates are more important than transportation distance when explaining prices changes under our assumptions. When thinking about price forecasting, general inflation rates or escalation factors will be a consequential component to making the tool identify appropriate prices within changing markets.

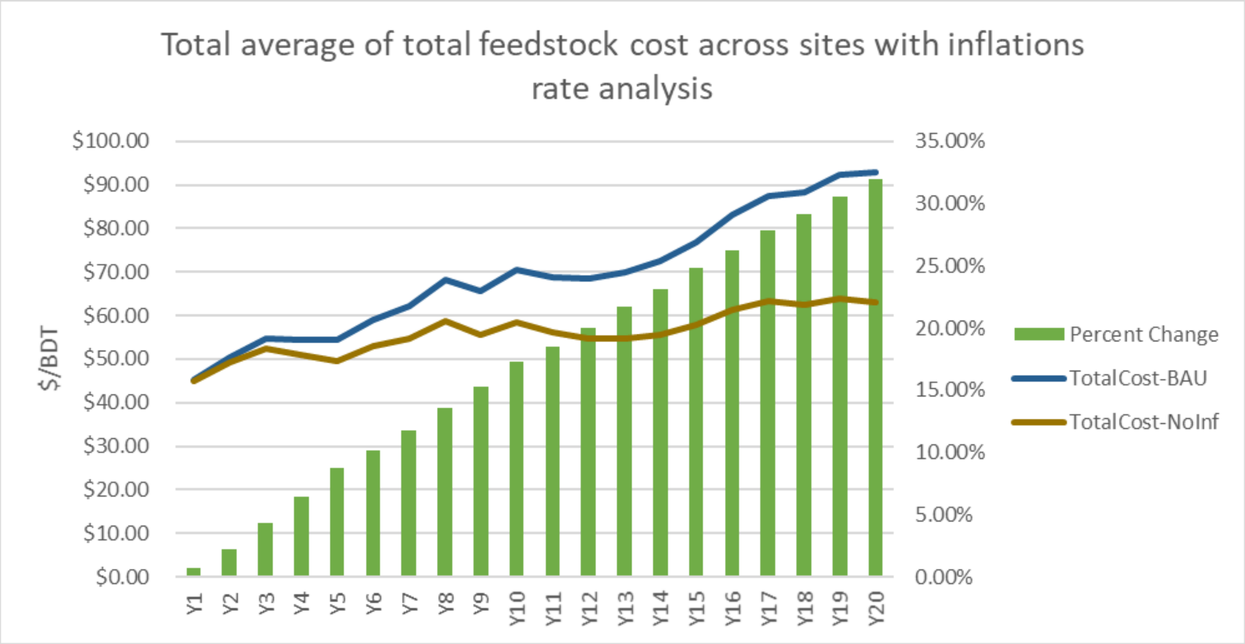


Figure 6: Total average delivered feedstock cost in Tahoe Central Sierra OPR region analysis with and without inflation rates assuming a 5MW feedstock demand.

Stakeholder comments

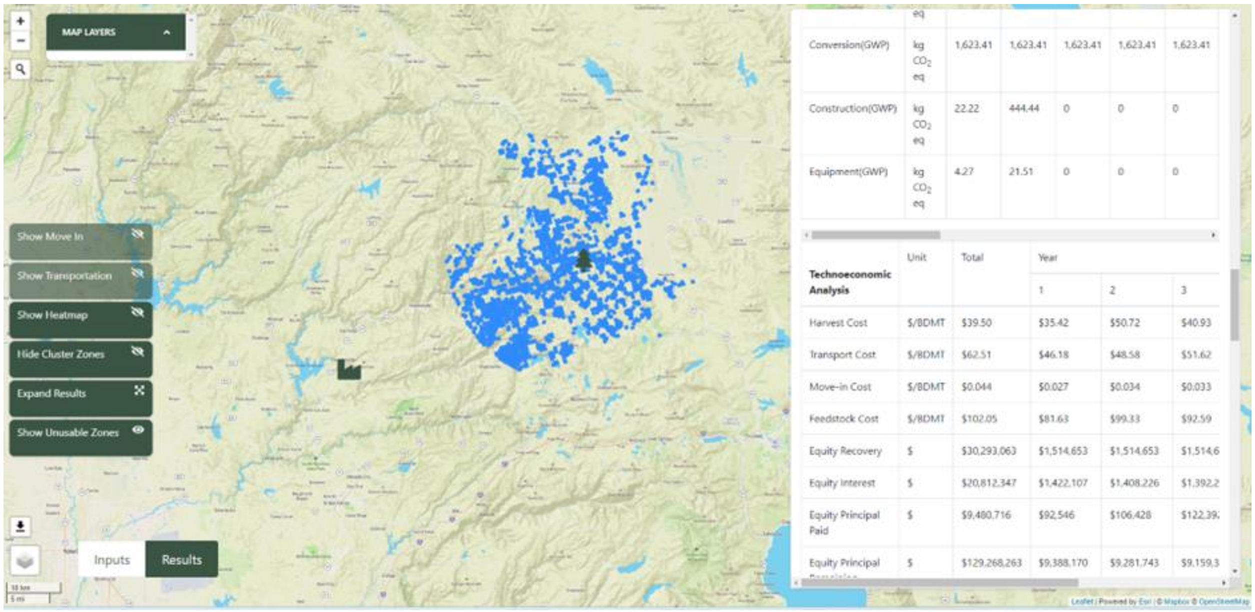
On September 19th, 2023, the project team held a stakeholder meeting to introduce the FRREDSS model to the participants and help them answer questions for an informed discussion on model effectiveness. During this presentation, we discussed the inputs and outputs of the model, participants impression biomass prices with preliminary model runs and opportunities for improvement. A list of questions was developed for the participants to respond to and are included in Appendix B. The meeting summary is below.

(1) **Model accuracy.** There is a general sense that the model was within an acceptable price range, although could be improved with more fine-tuning. One participant offered to have us tour one of his operations to get a better sense of the cost analysis.

(2) **Fully-load costs.** There is a need to calibrate the model to offer the option for fully loaded costs for operators and haulers. This will allow for practitioners to fill in their fair-market rate rather than having the model compute expected costs. Having the option for the model to calculate expected costs however will allow for transparency on costs, beneficial for both industry and non-industry users.

(3) **Satellite treatment locations.** There is the situation where a facility is not in the same location as where the actual treatments will occur. However, there is a place in the FRREDSS model where you can customize the location of the treatments. See Figure 6. The results would effectively increase hauling costs, providing a more realistic delivery estimate. In this scenario, the blue dots route directly to the conversion facility. They do not route to the tree icon before being delivered to the facility.

(4) **Subsidies.** There is a clear need to better understand how subsidies play out over a 10-year period and its utility in a model such as this. More thought is required on this subject. FRREDSS does have a technical advisory committee which has some great thinkers on biomass utilization in the state, and who may provide some additional thoughts on the matter.



	eq					
Conversion(GWP)	kg CO_2 eq	1,623.41	1,623.41	1,623.41	1,623.41	1,623.41
Construction(GWP)	kg CO_2 eq	22.22	444.44	0	0	0
Equipment(GWP)	kg CO_2 eq	4.27	21.51	0	0	0

Technoeconomic Analysis	Unit	Total	Year		
			1	2	3
Harvest Cost	$/BDMT	$39.50	$35.42	$50.72	$40.93
Transport Cost	$/BDMT	$62.51	$46.18	$48.58	$51.62
Move-in Cost	$/BDMT	$0.044	$0.027	$0.034	$0.033
Feedstock Cost	$/BDMT	$102.05	$81.63	$99.33	$92.59
Equity Recovery	$	$30,293,063	$1,514,653	$1,514,653	$1,514,6
Equity Interest	$	$20,812,347	$1,422,107	$1,408,226	$1,392,2
Equity Principal Paid	$	$9,480,716	$92,546	$106,428	$122,39
Equity Principal	$	$129,268,263	$9,388,170	$9,281,743	$9,159,3

Figure 7: Example of FRREDSS capability to model a satellite fuel yard or concentrated forest treatment location separate from facility location.

Comparison to Contractor Rates

Information collected by CLERE Inc in completion of a Biomass Supply Report for the Placer County Water Agency (PCWA) was developed in consultation with operators and project managers within the OPR Pilot boundary extent (Swezy, 2024). Operators provided a significant range of prices for delivered biomass, from $50/BDT to $112/BDT, up to $200/BDT for material from more distant locations. To pay for a full harvesting system of cutting, skidding, and processing biomass, the price ranges from $56-$64/BDT just to get a loaded truck. Trucking costs add $28 - $48/BDT, resulting in a grand total of $84-$112/BDT. This input is consistent with results from the Tahoe Central Sierra Initiative (TCSI) Restoration Wood Supply Assessment (Baribault, 2020), which suggested that the current market price of $40/ton (the industry standard in the TCSI region) is far too low to make forest restoration activities economically feasible.

Table 6 shows a comparison between reported contractor prices and the FRREDSS model outputs. Averages were taken from (1) the contractor estimates and the FRREDSS model outputs for prices to Ophir site location, (2) averages across all sites under 2.1% general inflation, and (3) averages across all sites without inflation. It shows that FRREDSS model outputs under our assumptions tend to be on the lower end of estimated prices, although, it is worth emphasizing again the short distance which biomass was procured within the FRREDSS model. The distance for the reported contractor rates is unclear. The largest difference in prices occurs within the costs to cut, skid, and load the material. As this calculation from the FRREDSS model is not subject to change across time as much as transportation distance, additional information will be needed to bring the FRREDSS model within range of real-world prices.

Table 6: Average $/BDT comparison between contractor operating price estimates and FRREDSS model outputs

	Average $/BDT				
TCSI contractor estimates to deliver to Ophir (Swezy, 2024)					
Cut, skid, load	$60.00				
Trucking	$38.00				
subtotal	**$98.00**				
FRREDSS price to Ophir	Y1	Y5	Y10	Y20	20yr Average
Cut, skid, load	$31.25	$33.24	$37.16	$43.02	$36.59
Trucking	$27.57	$40.52	$48.26	$72.12	$50.98
subtotal	**$58.82**	**$73.76**	**$85.41**	**$115.14**	**$87.56**
Average across sites with inflation	Y1	Y5	Y10	Y20	20yr Average
Cut, skid, load	$29.78	$34.05	$36.84	$48.47	$38.36
Trucking	$16.00	$29.93	$44.34	$66.32	$43.88
subtotal	**$45.78**	**$63.98**	**$81.17**	**$114.78**	**$82.24**
Average across sites without inflation	Y1	Y5	Y10	Y20	20yr Average
Cut, skid, load	$29.70	$29.51	$30.17	$29.16	$29.70
Trucking	$26.31	$20.12	$28.12	$33.88	$26.31
subtotal	**$56.01**	**$49.63**	**$58.29**	**$63.04**	**$56.01**

The column on the far right ("20yr Average") averages the price over the full 20-year P&L statement. Because the model is built to move further away from the facility each year of operation, the 20-year average is the same as calculating average costs across distance as well. When thinking about a long-term feedstock price, the 20-year average may be a useful number to base initial contract negotiations. However, the following table shows the difference between model results and contractor estimates. Average prices within a 30-minute radius around a facility never falls within a 10% range of accuracy to reported estimates.

Table 7: Difference between 20-year average delivered feedstock costs and reported contractor estimates by $/BDT and percent.

	Difference to contractors	
	$ / BDT	Percent (%)
FRREDSS price to Ophir		
Cut, skid, load	-$23.41	-64%
Trucking	+$12.98	+25%
subtotal	**-$10.44**	**-12%**
Average across sites with inflation		
Cut, skid, load	-$21.64	-56%
Trucking	+$5.88	+13%
subtotal	**-$15.76**	**-19%**
Average across sites without inflation		
Cut, skid, load	-$30.30	-102%
Trucking	-$11.69	-44%
subtotal	**-$41.99**	**-75%**

To explain this divergence, it is important to note that quoted costs from operators are likely padded to accommodate risk and profit margins. Additionally, the operations frequently performed by contractors in the region may not be entirely representative of the modeling work performed under this report. Contractors may work more on clearcut operations with cut-to-length harvest systems for example, when all model runs in this report are based uneven aged management with whole tree harvest systems. Future modifications of the FRREDSS model should provide the ability for contractors to apply their fully loaded rates.

Finally, reported contractor estimates may have timber operations concentrated in locations outside of the working circle derived from the FRREDSS model. Modeling unique harvest locations can be completed in FRREDSS at the moment as long as there is prior knowledge on where treatment intensity is highest on the landscape. Future research should identify where treatment locations are concentrated and for cost estimates to be based on a more robust analysis using the “separate biomass coordinates" feature.

Discussion

The FRREDSS model proved to be an effective tool to quickly calculate timber operator costs to deliver in-woods feedstock and within a logical distance from a site location. Programming a 20-year profit and loss statement with user-defined inputs has a strong potential to support contract negotiation prices in an open and transparent manner. The increase in prices on a year-to-year basis can represent a useful metric for determining rate structure within a contract, although more attention is needed to refine the tool. Further development of the model can be categorized by additional research that needs to be completed and modifications to the way the model is configured to more accurately simulate the biomass supply chain.

Additional Research

Next steps in development will require additional research on a variety of items. This research does not originally intend to alter the way the model is built, but rather provide more precision to how prices are determined.

First, the inflation rates were found to be the most influential factor impacting prices over time. At a rate of 2.1%, average prices changed by $69 per BDT. When compared to a zero-inflation rate scenario, prices over a 20 year period only changed $7 per BDT showing the importance of a constant escalation factor. Identifying the correct escalation factor will be the most important factor in determining a regular price increase. Due to the heavy influence diesel prices play on the supply chain, one suggestion is to tie escalation rates to the fluctuations in diesel listed on commodity markets (Solomon, 2017; Mason, 2023).

Second, the sensitivity analysis only looked at feedstock procurement within the immediate radius around each site location. However, the FRREDSS tool has the ability to identify different harvest locations than the immediate facility. Further research should incorporate this into another set of sensitivity analyses in order to have a more realistic picture of transportation distances and costs. Distance is discussed further in the following section.

Finally, more information needs to be provided to understand why harvest costs differed so greatly between reported prices by contractors and the FRREDSS model. There is a difference of $40 per BDT between reported prices and those calculated by FRREDSS. The FRREDSS model relies on the Fuel Reduction Cost Simulator (FRCS) which may need further research to know how to best remedy this divergence.

Model Configuration

This section refers to changes in the way the model is configured in order to better simulate the biomass supply chain. There is an itemized recommendations paper that was developed to further support the development of the FRREDSS model that is not included in this section. This summarizes limitations in the model and provides a basis for the recommendations paper.

Biomass prices and subsidies

The most notable aspect of the FRREDSS model is its assumption that a buyer (ie. bioenergy facilities) will accept the full delivery costs to procure biomass. The FRREDSS model projects the full cost to harvest, skid, and deliver biomass. This provides a cost estimate for sellers (ie. timber operators). Biomass prices rarely, if ever, cover the full costs to operate. Integrated harvesting– where operations offset costs with high value logs–provides a more reliable way of conducting biomass removal operations. As such, using the full delivery costs as an estimate for buyer prices only represents those situations where biomass is the main focus (a “biomass only sale”). The results illustrate the concern for operations to continue increasing in costs while market prices are stagnant, causing a larger and larger need for public intervention if acre targets are to be met and preferred silvicultural treatments are to be widely deployed.

Market price

The facility economics which determine the buyer's price (or "market price") for biomass is generally based on power production rates and business performance considerations like internal rates of return (ROR) or profit margins. While the buyer's price can be challenging to predict at times, they are a function of their revenue. Nevertheless, electricity rates have not changed enough to pay for the increasing costs to operate. There are very few times when the biomass spot market changed enough to accommodate larger haul distance for sellers. One of these periods was during the rise of bioenergy in the late 80s and early 90s (Morris, 2002). A 60% increase in price per BDT from 1988 to 1990 occurred, before it returned to 1988 prices by 1996 due to a sharp increase in facility development and feedstock competition. It only returned to 1988 prices because CPUC purchased and subsequently shut down one third of the operating capacity by 1994 (Morris, 2002). Another time was during the start of the Bioenergy Renewable Auction Mechanism (BioRAM) in 2016. Prices went from approximately ~$40 per ton to ~$60 per ton within two years for qualifying fuel sources due to the sharp increase in feedstock competition (MB&G 2019).

Recently, state mandates from SB 100 and SB 350 have required energy procurement within the state to increase renewable generation sources year over year, and have 65% of those renewables be under a 10+ year contract, respectively. Furthermore, resource adequacy requirements have placed more value in baseload power sources. In order to reduce stress on the grid during the transition between periods of high solar and wind generation, renewable baseload power sources like biomass to electricity have become more sought after to meet these stacking state mandates. As such, there is reason to believe that power purchase agreements (PPA) with bioenergy sources may increase, however, it is unclear if they will be able to keep up the pace of rising timber operation costs, or otherwise result in a higher market price without feedstock competition. Because of the importance competition plays on prices, more attention to how the model should account for feedstock competition should be given considering the growing interest in the sector.

In the meantime, subsidies to end-users through PPAs or to land managers for forest health treatments provide a meaningful service to fill this financial gap between electricity rates and in-woods fuel procurement. In context to developing long-term feedstock agreements, one interviewee said, "if you can guarantee me a subsidy, I can guarantee you feedstock". The FRREDSS model has the capability to include producer tax credits (PTC) as well as other additional credits (e.g. carbon credits), but is unable to represent subsidies for land management or power purchase agreements (PPA).

Applying subsidies to the model can be a simple calculation, however structuring the model to allow for users to input subsidy amounts over a 20 year period is challenging. One method to approach this is to apply a constraint on the "total revenue required" of the facility. By constraining the revenue to a known quantity as determined by electricity rates or PPAs, the model could hypothetically be retooled to define a breakeven distance for feedstock rather than the amount of money a facility would require if it purchased the full delivery cost of its feedstock. By adding subsidies to this version of the model (either by listing a PPA price or average CALFIRE grant award over a region), the facility would essentially be able to expand its woodbasket radius. Nevertheless, it is important to note the value of the current configuration of FRREDSS. Currently, the ability for the model to surpass breakeven distances is potentially a better way to *identify* additional subsidies needed to make the facility economics work. While additional ways to apply subsidies need more attention, other methods may best be done after processing.

Some individuals voiced reports of buyers gouging prices if they knew a timber operator was delivering biomass from a subsidized project. While there is inherent tension between buyers and sellers, they require a more dynamic relationship to make the supply chain work. To develop long-lasting relationships built on trust, they must be willing to work with each other. While this situation may have occurred, it may be an exception rather than the norm or otherwise a function of expected supply surplus.[6] For example, when BioRAM was first established, BioRAM compliant facilities were faced with a need to expand the supply chain infrastructure. In response, they provided financial assistance to contractors who were encountering cash flow issues. Contractors then entered an agreement to deliver the biomass from projects occurring on HHZ compliant lands. Facilities also leased equipment timber contractors were hesitant to purchase during this time (MB&G, 2018). This type of cooperation between the two parties shows how dependent they are on each other, and can act in more altruistic ways to support the benefit of land stewardship.

Feedstock quality and added value

As timber prices fluctuate, so do landowners' willingness to operate. Without favorable timber prices or subsidies, silvicultural treatments which target small-diameter, non-merchantable materials are not prioritized. As the FRREDSS model suggests, unless further intervention is implemented to improve the economics of forest biomass, the existing cost gap is expected to widen. It is because of this reason, attention on large-scale biomass utilization solutions often focus on the need to build additional revenue streams for end producers to afford a higher feedstock purchase price (Sanchez 2020). Presumably, this would encourage additional forest operations by increasing the market price for the product. While advanced technology solutions that would be able to take advantage of carbon credits or low-carbon fuel markets are promising, their technologies are still developing (Porter, 2020; Sanchez, 2020). Making additional technologies available within the techno-economic analysis module of FRREDSS may be useful. With the addition of new technologies other than combustion based facilities, feedstock quality will need to be considered due to system sensitivities to feedstock size and type.

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[6] Reports about this center on FEMA post-disaster relief for tree removal and hazard reduction.

Distance

The site of the biopower facility is provided by the user and the Open Source Routing Machine (OSRM) module within the FRREDSS model calculates the distance from every cluster to the biopower facility. For example, the first year of feedstock delivery costs in Grass Valley are expected to be around current market prices of $50/BDT. This would bring parity to both buyer and seller of the biomass, but it is not immediately clear the distance at which feedstock is procured from. We can see from Figure 4 that transportation costs are around $15/BDT and know that hauling rates are $150/hr. Therefore, we can calculate that the haul zone within the first year is about 4 minutes away from the facility. In other words, conducting forest thinning projects only makes economic sense if operations are within a 4-minute radius around the site location. Calculating time distance away for each year after processing is doable but can also be a low hanging fruit to program into the model for ease of use. This example also illustrates the hard reality of biomass economics. If one were to equate the model to real world situations, the FRREDSS model computes a relatively small woodbasket. It is uncommon for a 20-year supply of feedstock to be procured within a 30-minute haul distance of the site location as made evident in Table 4. This is due to workforce capacity, permitting restrictions, and road access conditions.

Workforce Capacity

Workforce capacity is hard to estimate within a spatial context. However, there are ways to approximate workforce capacity based on the limits to a county's volume or acre production level. The Board of Equalization releases timber volume estimates by county based on timber tax data. This could suffice for determining a threshold to operating capacity. The limitation to using this dataset is that it tracks sawlog volumes which is not the target feedstock for the facilities modeled under FRREDSS. Within the last several years, more spatial data has emerged to track forest treatment polygons approved under CAL FIRE and the Forest Service. Recently, the Spatial Informatics Group and Ascent Environmental entered into a contract to produce a spatial layer of all NEPA and CEQA approved lands which may be a suitable proxy for workforce availability and future biomass supply. A more exhaustive process of determining area production level thresholds per county could be completed on a semi-regular basis to improve accuracy to feedstock availability (Yeo et al., n.d.). Without the inclusion of workforce capacity, transportation times will be an unreliable approximation for contract price negotiations.

Vegetation Base Layer

Finally, the vegetation data is dated to 2016. There is a need to update this layer to current vegetation conditions including the removal of forest treatment polygons and wildfire scars (Yeo et al., n.d.). With the update to this vegetation layer, several new operational feasibility considerations can also be included as well, including: maximum distance from roads; and removing riparian areas, wildlife protected activity centers, and slopes above 40% from the vegetation layer. Furthermore, if salvage harvest systems are to be maintained within the model annual vegetation base layer updates will be required. The removal of post-fire material safely should be conducted within a maximum time interval of 5 years from ignition date. Due to salvage harvest's high maintenance needs to have the vegetation layer be updated every 3 to 5 years, it may not be a practical treatment option to include moving forward.

Conclusion

The biopower facility development faces several obstacles including a lack of security in long-term feedstock supply, permitting requirements, economic estimations, and uncertain technology performance for many new types of technologies, among other reasons. Without a supply chain, new prospective facilities are deemed risky to investors and are ultimately restricted from access to capital. The wicked problem of building new biomass infrastructure is therefore defined by a lack of consistent supply for a new facility to develop if the new facility doesn't already exist to offer a price for the biomass-generating projects. Investigating new ways to structure feedstock agreements may provide additional risk assurance and product security to encourage more markets to develop. Innovative ways to look at long-term feedstock supply contracts requires a look at long-term feedstock prices. The FRREDSS model is a useful tool but may not be able to serve as a contracting software. With further research on aspects like escalation rates, a more streamlined model may be easier to include changes to the vegetation base layer to better represent logging constraints, inclusion of workforce capacity considerations, incorporating variables for subsidies, clearer metrics like time-distance, and restructuring the model to better represent market dynamics through an index-based pricing formula. Recommendations are included in Appendix A of this document, as well as elaborated in Chapter 5 of Yeo et al.(n.d.).

Next Steps

The next steps for the price mechanism are to use these sensitivity analysis results and recommendations to update the FRREDSS model. Once updated, FRREDSS 2.0 can then be tested as a contracting software in a real market environment with iterative updates based on user feedback. Various stakeholders involved in this transaction will be contacted for their feedback. This includes industrial forest landowners, contractors, facility operators, and a range of project managers working in the biomass and workforce development space.

Additionally, a bioeconomy risk rating company, Ecostrat, will be contracted to review the model and provide comments on its use-ability for their own Bioeconomy Development Opportunity (BDO) Zone modeling. Finally, once comments from all parties have been received and applied to FRREDSS model updates, the new versions will be eligible for review with financial professionals and banks.

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Appendix A: Recommendations to support forest biomass pricing for long-term feedstock agreements through a decision support system

Please contact the Fall River RCD for access to this document.

Appendix B: Stakeholder Questionnaire

Overarching questions

- Identify key characteristics of successful feedstock contracts
- How should we be thinking of the impact of subsidies on price dynamics?
- How do we address the importance of timing? Are feedstock rates staggered depending on the season?
    - Summer season with high volumes = lower feedstock prices
    - Winter season with low volumes = higher prices
    - Peaker plant ramping during high grid stress = higher prices
- How to incorporate mixed feedstock procurement (eg. sawmill residue)?

Questionnaire

1. What is the average length of a harvest contract in your region? ________________________
2. Please rate the most important aspect of a feedstock contract for your company
    a. Contract length 1 2 3 4 5
    b. Time of year 1 2 3 4 5
    c. Feedstock quantity 1 2 3 4 5
    d. Feedstock quality 1 2 3 4 5
    e. Feedstock price 1 2 3 4 5
3. Please put an X for the top 3-5 forest treatment and harvest system combinations used in your region. Please add anything not listed here.

Forest Treatment	Clearcut	Commercial Thin	Commercial Thin Chip Tree (CT)	Timber Salvage	Timber Salvage CT	Selection	Selection CT	10% Group Selection	20% Group Selection	Biomass Salvage CT	Other:
Harvest System											
Ground Mech Whole Tree (WT)											
Ground Manual WT											
Ground Manual Log											
Ground Cut to											

Forest Treatment	Clearcut	Commercial Thin	Commercial Thin Chip Tree (CT)	Timber Salvage	Timber Salvage CT	Selection	Selection CT	10% Group Selection	20% Group Selection	Biomass Salvage CT	Other:
Length (CTL)											
Cable Manual WT/Log											
Cable Manual WT											
Cable Manual Log											
Cable CTL											
Helicopter Manual Log											
Helicopter CTL											
Other:											

4. What basal area is commonly removed from thinning contracts in your region?
    a. 20%
    b. 40%
    c. 60%
    d. 80%
    e. Other (please specify):

5. Operators – Please fill out the following (are any of these items negotiable?)
    a. Diesel Fuel Price ($/gal)____
    b. Wage for Fallers ($/hr)____
    c. Wage for Other Workers ($/hr)____
    d. % benefits and overhead for operators___________________________________
    e. Hourly Wage for Truckers ($/hr)____
    f. % benefits and overhead for truckers ___________________________________

6. Facilities – Please fill out the following (are any of these items negotiable?)
    a. Moisture content ____

b. Fuel ash concentration ____

c. Feedstock type ____

d. Source of feedstock ____

e. Feedstock composition ____

f. How is ash disposed of or managed? ____________________________________

g. Ash disposal cost? ____

h. Labor costs ____

i. Maintenance cost ____

j. Insurance ____

k. Utilities ____

l. Management ____

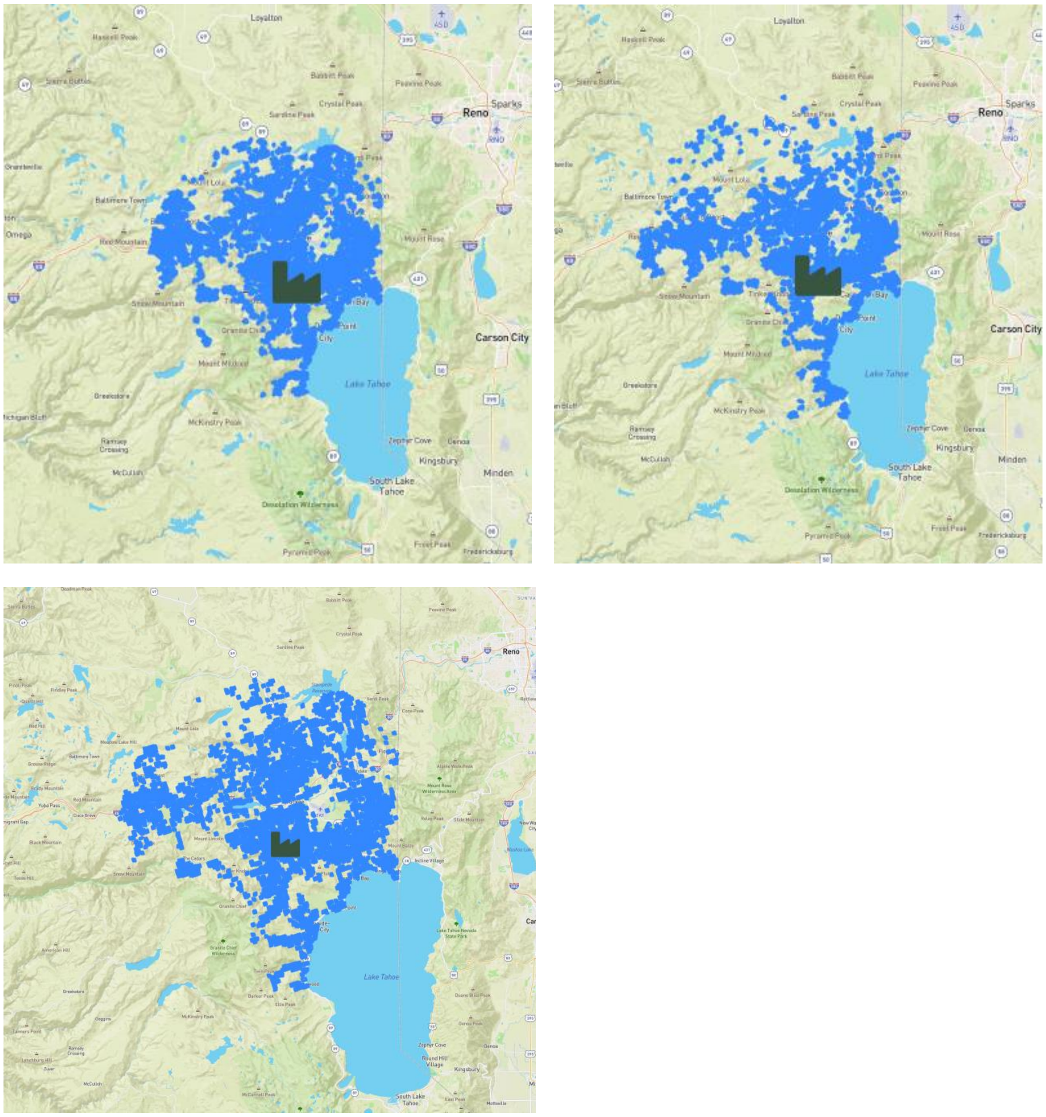
m. Other operating expenses ____

n. Escalation rate ____

o. % benefits and overhead for facilities __________________________________

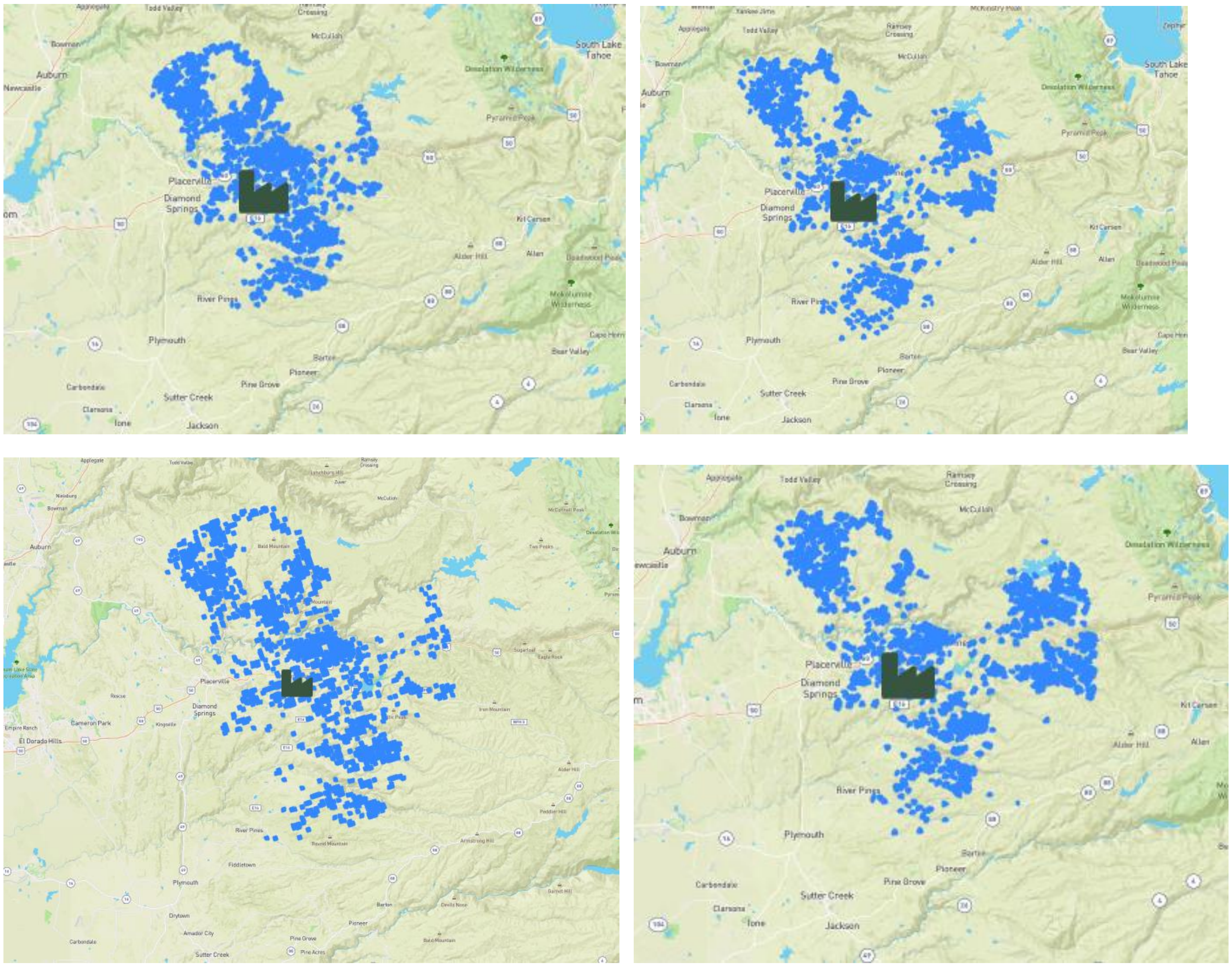
Appendix C: FRREDSS spatial outputs for each expansion factor scenario

Cabin Creek



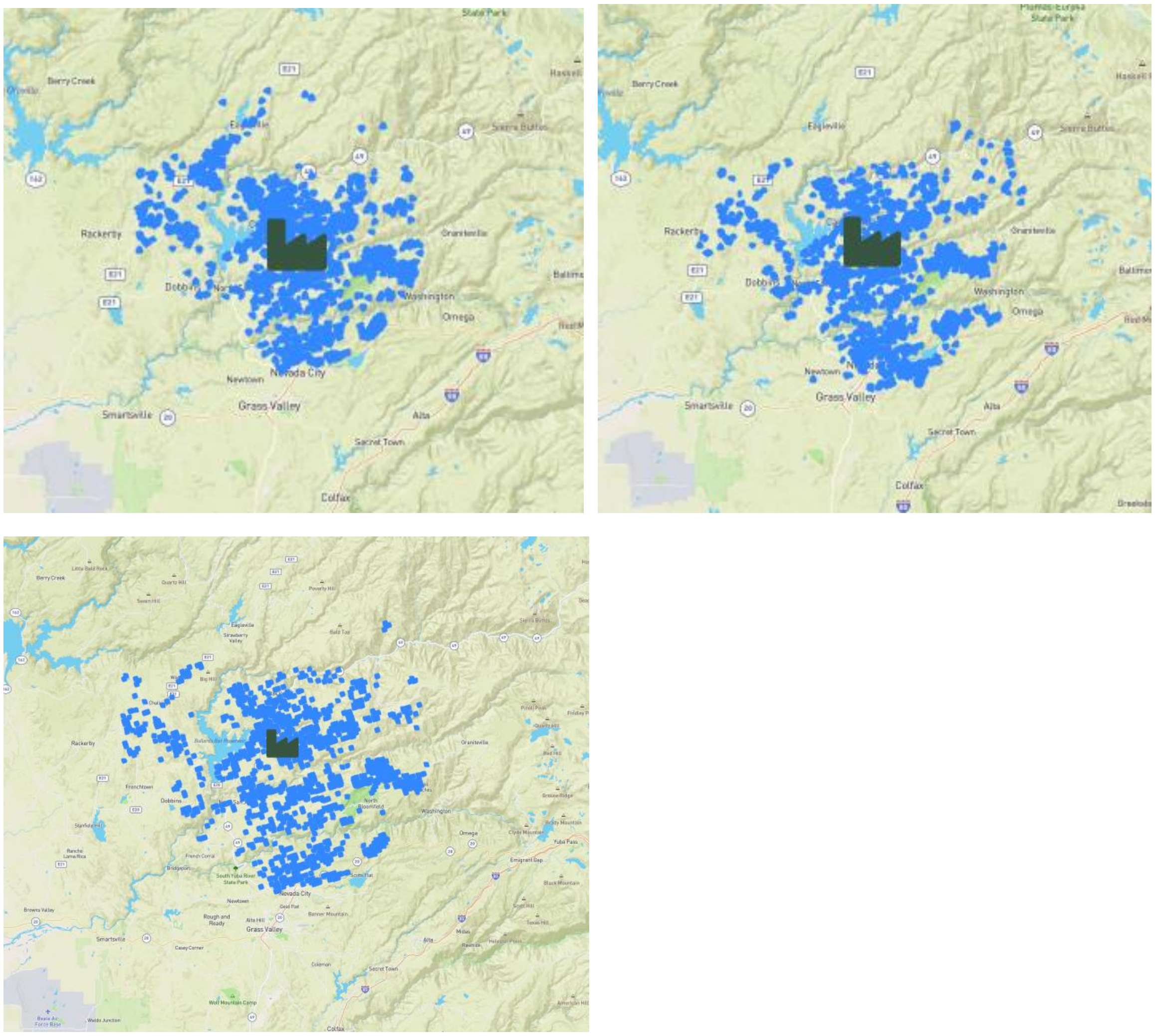
Cabin Creek at expansion factor 1 (left) and expansion factor of 10 (right). Zero inflation rate (Bottom left).

Camino



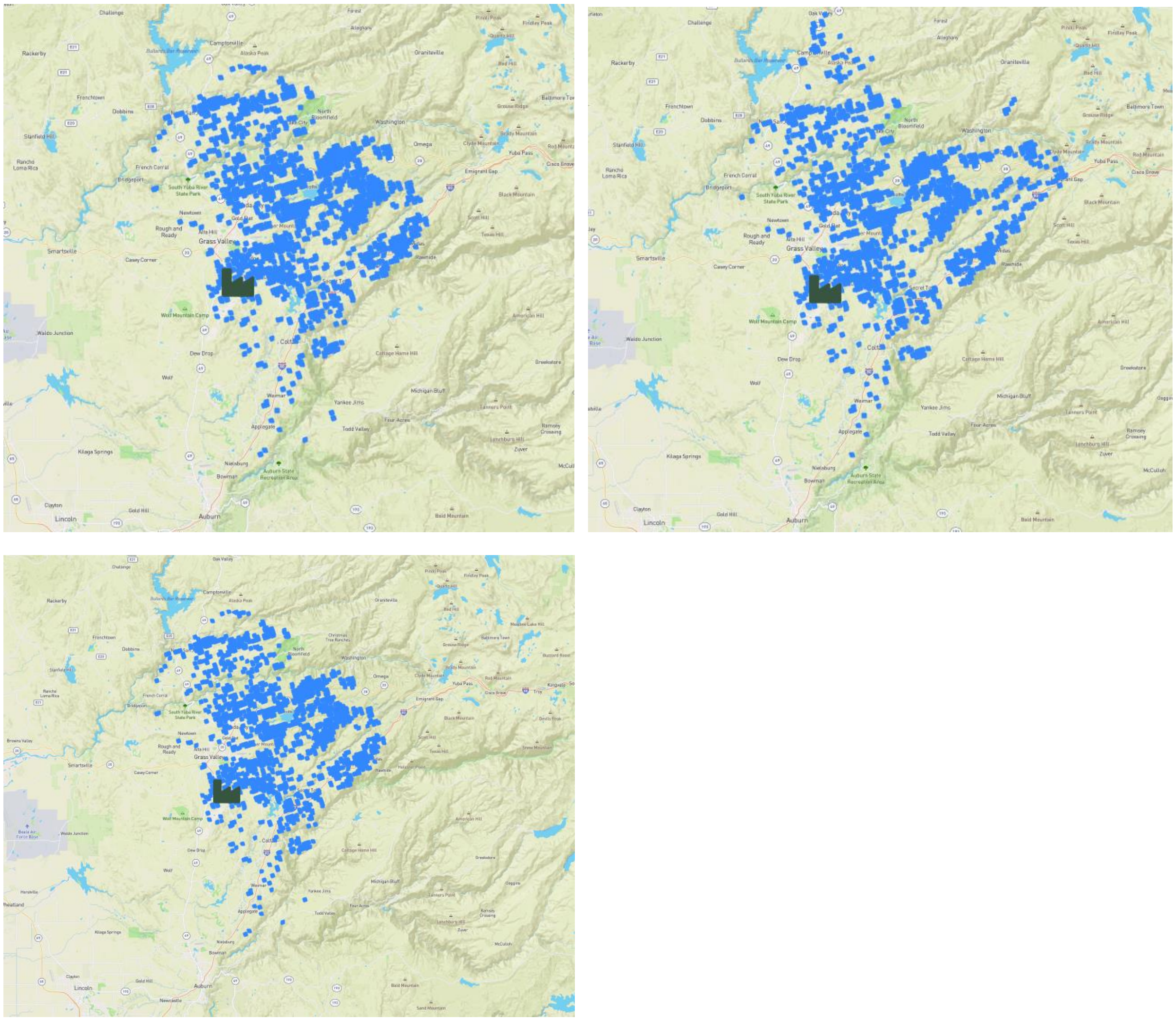
Camino at expansion factor 1 (left) and expansion factor of 10 (right). Zero inflation rate (Bottom left). Camino at expansion factor 20 (bottom right).

Camptonville



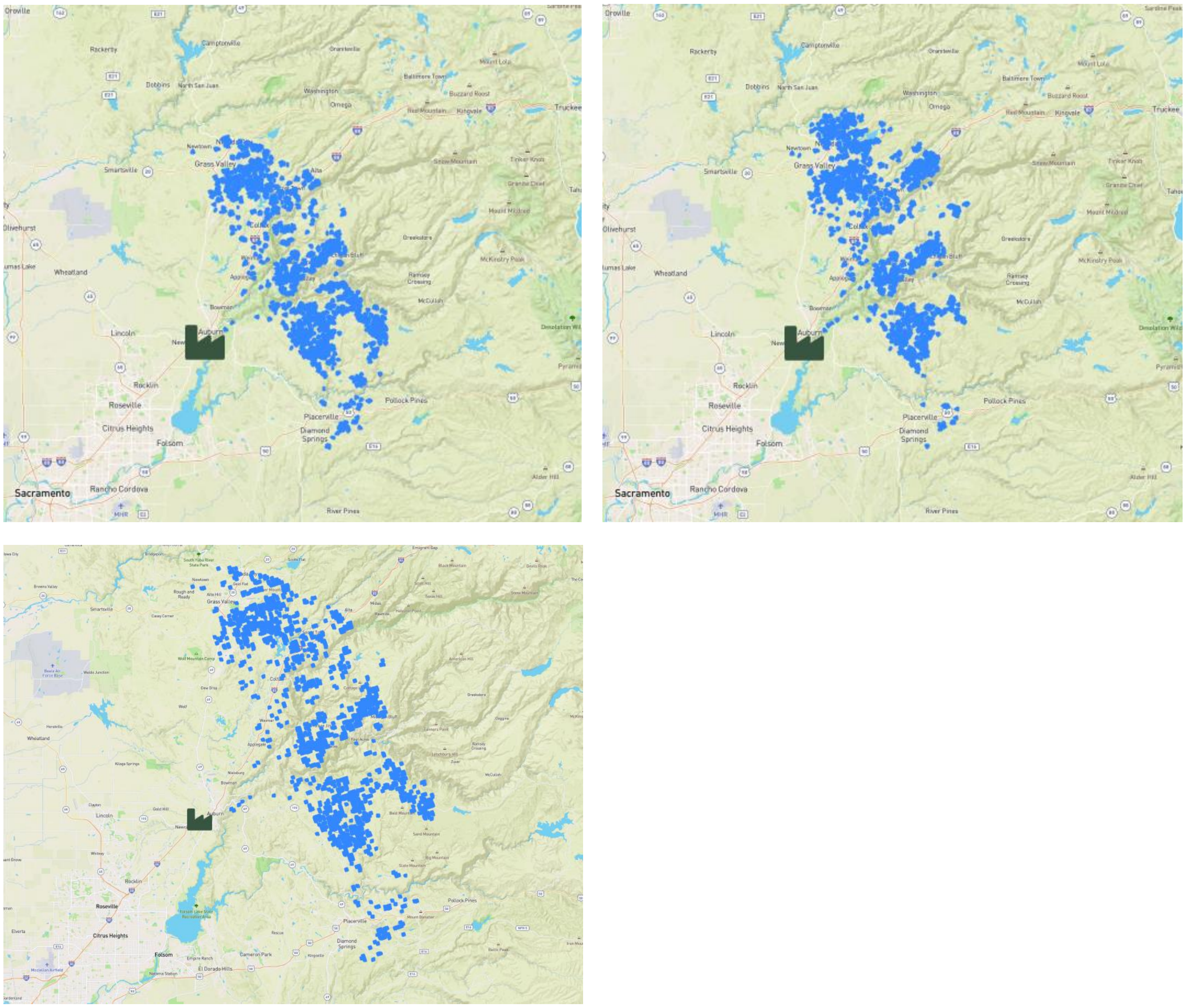
Camptonville at expansion factor 1 (left) and expansion factor of 10 (right). Zero inflation rate (Bottom left).

Grass Valley



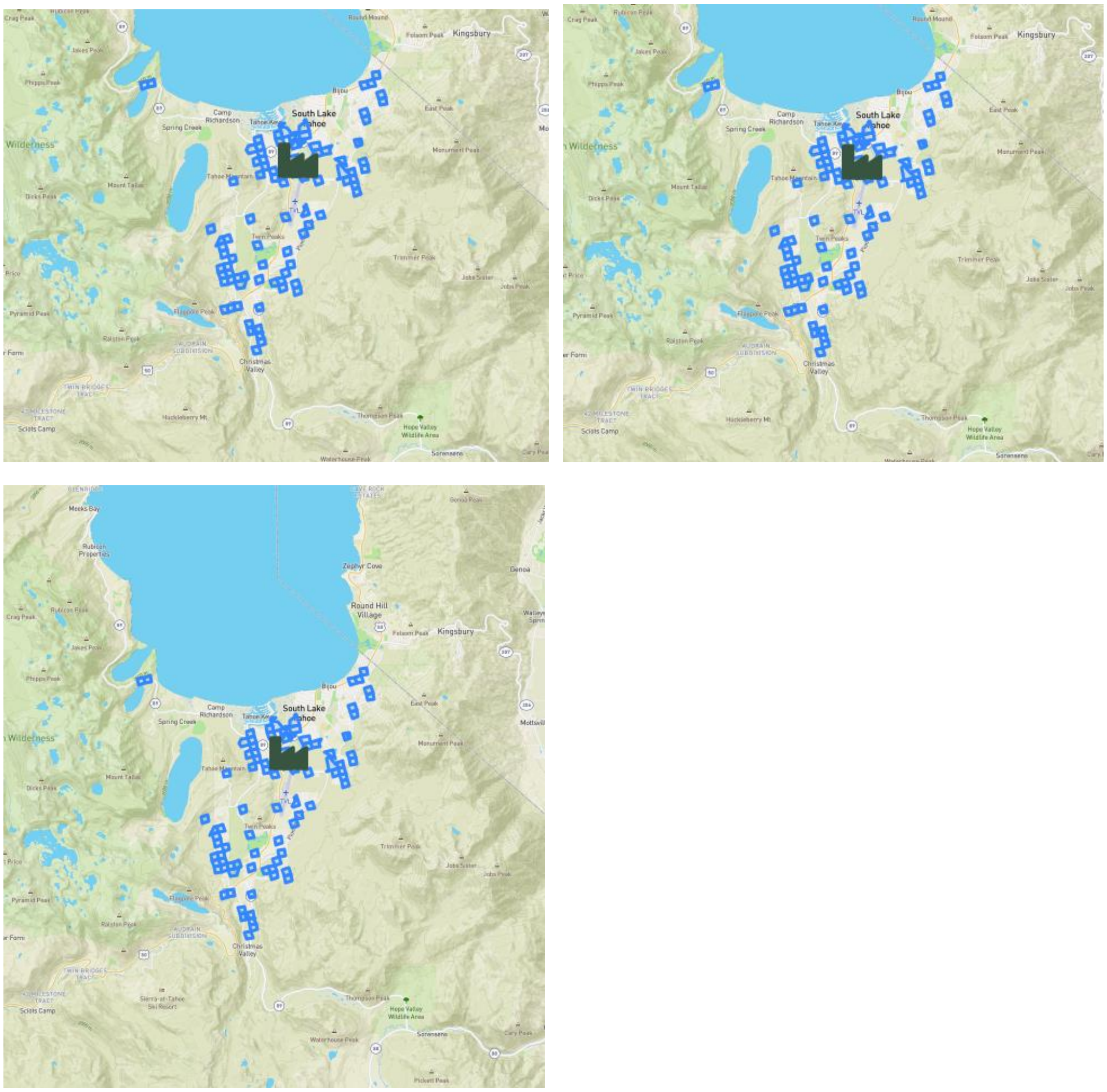
Grass Valley at expansion factor 1 (left) and expansion factor of 10 (right). Zero inflation rate (Bottom left).

Ophir



Ophir Site at expansion factor 1 (left) and expansion factor of 10 (right). Zero inflation rate (Bottom left).

South Lake Tahoe



South Tahoe Refuse at expansion factor 1 (left) and expansion factor of 10 (right). Zero inflation rate (Bottom left).