Propensity of Sawmills to Produce Structural Sawn Wood in Chile

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Abstract

The goals of Chile's forest policy regarding the use of wood in construction are far from being achieved. Chile is the ninth-largest global producer of sawn softwood and has an industry with numerous sawmills; however, structural sawn wood (SSW) represents less than 1 percent of the industry's total production, which is insufficient to address large-scale construction programs with wood. Therefore, policy instruments are needed to lead to an increase in the volume of SSW production. This research aimed to design a typology of sawmills that facilitates the definition and implementation of these policy instruments to ensure attainment of the 2035 goal of the forest policy. Multiple linear regression and multiple logistic regression were used to assess the impact of various variables on SSW production; variable selection was done using stepwise regression. The number of clusters was determined using the gap method, and sawmill clusters were determined using *k* means. The result is a typology with five categories of sawmills based on their propensity to produce SSW. The most significant variable was the quality of the supply, so it is suggested to prioritize the management of *Pinus radiata* plantations. With this result, a map for the application of policy instruments was created, proposing an intervention pathway. The proposed typology will stimulate decisions to provide direct support to the sawmill industry, thereby increasing SSW production.

In Chile, there is a Forest Policy (CONAF 2015) that, in its Impact Objective 2.5, declares the intention to make wood one of the main construction materials, although goals for the year 2020 were not met (INE 2022). The goals for 2025, wherein 30 percent of materials in housing, industry, and public infrastructure make intensive use of wood, are unlikely to be achieved, but there is hope for meeting the targets set for 2035, given the recent strong interest in increasing the use of wood in construction. This interest, rooted in economic, social, and environmental considerations (Ramage et al. 2017, CIM-UC 2018, CNP 2020, Terraza et al., 2020, Gysling et al., 2021), is evident in the activities of numerous public and private institutions related to both the forestry sector and the construction sector.

Why have the goals of the forest policy not been met, despite Chile having substantial wood volumes (Büchner et al. 2022), being a global producer in various forest products (FAO 2022), and explicit recognition by many stakeholders of the multiple benefits that wood construction could bring to the country's development and population's well-being (Gysling et al. 2021)? The reasons are diverse, with one notable factor being the low volume of structural sawn wood (SSW), classified as such, offered by the country's sawmills (0.4% of national production; Álvarez et al. 2022b). This article proposes a typology of sawmills to facilitate the design and implementation of policy instruments aimed at increasing the supply of SSW to progress toward achieving the forest policy's goal for 2035.

Sawmill industry in Chile

The supply of wood for construction comes from the national sawmill industry, considering that imports of this product are not significant (Poblete 2022). Therefore, the role of this industry is crucial as a provider of sawn wood for both

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structural and nonstructural use. However, the industry's supply has limitations for widespread use in the construction sector.

Chile ranks ninth globally in the production of sawn softwood, with a 2.4 percent share; as an exporter, it holds the 10th position, also at 2.4 percent, while its role as an importer is not relevant (FAO 2022). The per capita consumption of sawn softwood (0.27 m^3 per inhabitant) places Chile sixth in the world, following Austria, Sweden, Finland, Belgium, and Canada, just ahead of the United States and Germany, where the sawmill and wood construction industries have a vast history.

In 2021 (Álvarez et al. 2022a), the industry comprised 1,233 sawmills, of which 74.8 percent were in operation, while the remaining 25.2 percent were inactive. Of the 922 sawmills that operated that year, 87.2 percent (804 plants) were small sawmills (annual production less than 10,000 m^3), and among these, 59 percent were mobile (sawmills that, due to their design, can move from one place to another in search of wood supply). Permanent sawmills (established in a fixed location) that operated in 2021 were 448 plants, and they contributed 97.8 percent to national production.

The sawmill industry's structure reflects the fundamental features of the economic development model prevailing in Chile over the last four decades, where productivity gaps between large and small units are substantial (Infante and Sunkel 2009). In 2021, large sawmills (with annual production of sawn wood exceeding 100,000 m^3) represented 2.1 percent of operational units, generated 55.8 percent of the total sawn wood produced in the country, employed 29.7 percent of the workforce in the industry, exported 76 percent of the total volume of sawn wood sent abroad, and remanufactured 64.7 percent of the total volume of remanufactured sawn wood in sawmills. Regarding physical productivity, large sawmills achieved an average productivity of 1,026 m^3 per person employed, while in medium-sized sawmills (production between 10,000 and 100,000 m^3), average productivity was 496 m^3 per person employed, and in small sawmills (annual production less than 10,000 m^3), it was only 210 m^3 per person employed (Álvarez et al. 2022a).

The low productivity of medium and small sawmills, which supply over 75 percent of the available sawn wood in the national market, is compounded by long-standing issues, including: lack of operator training, limited qualifications of entrepreneurs and employees, unawareness of commercial prospects, low raw material efficiency, poor product quality, lack of standards, limited investment, high income irregularity, unstable employment, and serious technological deficiencies (Gysling and Soto 2016, Fernández Parra et al. 2019). These characteristics become evident when observing the operations of small- and medium-sized sawmills, which struggle to obtain sawlogs in the quantity and quality needed for a stable supply of sawn wood for construction. This is reflected in the lack of market demands for product standardization and quality certification. According to figures from the Forest Institute (Álvarez et al. 2022b), it can be concluded that the production of classified SSW does not exceed 0.5 percent of the national sawn wood production, representing less than 10 percent of the sawn wood marketed by sawmills for structural use but not classified as such.

Public policy

Public policy is defined as a set of actions, decisions, and measures taken or not taken by governments to achieve a public objective or address a specific problem or challenge in society (Irarrázaval et al. 2020). These policies are designed to achieve goals and targets in various areas of activity, such as housing construction, for example. Policy instruments are defined as mechanisms and techniques for implementing public policies and generally take the form of laws, quotas, awards, sanctions, permits, prohibitions, access, and restrictions (Sarthou 2015). In the field of wood construction, there are numerous examples of public policies that can be adapted to the realities of each case (Leszczyszyn et al. 2022, Tori et al. 2022, Wiegand and Ramage 2022).

Chile has a forest policy called the Forest Policy of Chile 2015–2035 (CONAF 2015). In line with United Nations Sustainable Development Goal 11 (ONU 2020, CEPAL 2023), this policy includes among its impact objectives (CONAF 2015, p. 40): "To make wood one of the main components of construction materials in the country, substantially increasing its use in housing, industry, and public infrastructure, based on a standardized and certified product by the wood industry." To achieve this objective, the policy sets partial goals for the years 2020 and 2025, while the goal for 2035 is to "Double the proportion of wood in the construction of housing, industry, and public infrastructure," based on an initial situation (2015) where "the proportion of wood use in buildings in Chile is 18%." However, in 2020, the use of wood as the predominant material for walls in the total authorized surface area for new residential and nonresidential construction reached only 10.6 percent (Álvarez et al. 2022b). This indicates a significant setback, far from progressing toward the proposed goal, highlighting the absence of appropriate instruments.

Achieving the forest policy's goal requires the sawmill industry to advance to higher stages of development to produce wood for construction in the quantity and quality required by construction projects that enhance wood's contribution in this sector. Therefore, an in-depth analysis of the characteristics of the sawmill industry to understand its operation in relation to the supply of sawn wood for construction is needed. From this analysis, key elements of a public policy that significantly and sustainably improves the timber sector's contribution to reducing the housing deficit in Chile can be inferred (FAO 2020, Wiegand and Ramage 2022). The significance of acquiring information about the forestry industry is also recognized as a requirement to understand its impact on communities that depend on forests and to understand the forests themselves (Hyde et al. 2022).

The sawmill industry must be a priority actor in public policy. This conviction is rooted in the idea that, as Mazzucato (2017) suggests, an "entrepreneurial state" is not just a corrector of market failures but also a creator of wealth and a driver of innovation. Moreover, the path to productive convergence in different sectors of the economy, such as the forestry sector and the construction sector, requires a state that plays a central role in implementing public policies that increase the productivity of small- and medium-sized enterprises (Judt 2011).

A public policy could bring together the sawmill industry with the construction sector, making a significant contribution to the well-being of the population in line with sustainable development (Gysling et al. 2021). This aligns with the concept of industrial symbiosis, allowing traditionally separate entities and companies to cooperate, sharing resources and contributing to increased sustainability with environmental, economic, and social benefits (Neves et al. 2020).

Multiple linear regression

Multiple linear regression is a statistical modeling technique that allows the analysis of the relationship between a dependent variable (Y) and two or more independent variables ($X_1, X_2, \ldots, X_n$; Lind et al. 2012). The goal of multiple linear regression is to find a linear function that relates the independent variables to the dependent variable. The general formula for multiple regression is:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n + \varepsilon \tag{1}$$

where

Y is the dependent variable (quantity of wood for structural use),

$X_1, X_2, \ldots, X_n$ are the independent variables,

b_0 is the intercept,

$b_1, b_2, \ldots, b_n$ are the regression coefficients, and

ε is the random error term.

This statistical technique has various applications. In the industry, it is used to determine the effect of certain variables on the production characteristics of a good, especially regarding factors that determine yields in the production process (Camacho-Vera et al. 2017). It has also been employed to anticipate or predict changes in certain climate phenomena, such as floods due to excessive rainfall in areas heavily affected by climate change (Sreehari and Srivastava 2018). In the health field, numerous studies use multiple linear regression to understand the relationship between a patient's risk factors and an indicator of disease, such as blood pressure (Zapata 2021).

Multiple logistic regression

Multiple logistic regression is a statistical analysis technique used to predict the probability of a categorical outcome from a set of predictor variables (Dayton 1992). This technique assumes a logistic relationship between the outcome and predictor variables. Multiple logistic regression is used to describe the behavior of a categorical (binary) dependent variable based on one or more risk factors. The mathematical representation of multiple logistic regression is:

$$P(Y = 1|X_1, X_2, \ldots, X_n) = \frac{1}{1 + e^{(-b_0 - b_1X_1 - b_2X_2 - \ldots - b_nX_n)}} \tag{2}$$

where

$P(Y = 1|X_1, X_2, \ldots, X_n)$ is the probability of the outcome Y being 1 given the values of predictor variables $X_1, X_2, \ldots, X_n$,

b_0 is the intercept, and

$b_1, b_2, \ldots, b_n$ are the regression coefficients.

Multiple logistic regression finds applications in various fields. In forestry, it has been used to analyze the factors determining deforestation, so that decision-makers can predict the geographical areas that will be subject to this phenomenon and anticipate corrective measures (Bavaghar 2015). Multiple logistic regression is also used in various economic studies that employ surveys to obtain information, ranging from investigating the probability of a respondent selecting one option or another in multiple-choice questions to studying the factors influencing a positive or negative decision on a proposal (Tapasco and Giraldo 2016).

Cluster analysis

K-means clustering is a clustering algorithm used to divide a data set into *k* clusters (Hartigan and Wong 1979). The algorithm assigns data points to the nearest centroid and then recalculates centroids to minimize the distance between assigned points and centroids. This process is repeated until centroids do not change significantly. The number of clusters, *k*, is predefined and can be determined through techniques such as the elbow method, silhouette method, and gap method (Tibshirani et al. 2001). This analysis allows for the classification of companies into subclusters based on certain characteristics or variables.

Various clustering algorithms based on distance measures exist, with *K*-means and hierarchical clustering (Charu and Chandan, 2014) being the most popular (Capece et al. 2009, Kramarić et al. 2018, Akay 2023). In this research, *K*-means clustering was chosen primarily because it aligns with the volume of available sawmill data and the complexity of the typology to be determined. Additionally, each data point belongs to a specific cluster, facilitating the interpretation of results.

Materials and Methods

Data

The database used was formed from the sawmill database maintained by the Forest Institute (INFOR), Santiago, Chile, wherein data are collected through an annual sampling of the industry, a practice this institution has been carrying out for 40 years. In total, 517 permanent sawmills were considered (Álvarez et al. 2022a), of which 448 units correspond to the total number of permanent sawmills that operated in 2021. Additionally, 39 sawmills did not operate in 2021 but did in the three or more years prior, and 30 sawmills did not operate in 2020 and 2021 but did in the three or more years prior to that. The selection of units that did not operate in 2021 was based on considerations related to the instability of those years caused by the coronavirus disease 2019 pandemic, with the estimation that these sawmills meet conditions to resume operations after the crisis.

The variables entered into the model, for both multiple linear regression and multiple logistic regression, are presented and described in Table 1.

Methodology

Effect of variables on sawn wood production.—Given that the production of SSW classified according to standards (INN 2005) takes place in a very limited number of sawmills, with an average production volume for the period 2018 to 2021 below 29,000 m^3 annually (Álvarez et al. 2022b), the analysis here was conducted for the variable of sawn wood for structural use. This is the precursor to the production of SSW, as it involves sawn wood not classified according to standards, declared by sawmills for structural use based on their own experience.

Two methods of statistical analysis were employed to assess the impact of different variables on the production of sawn wood for structural use. Multiple linear regression was used to

Table 1.—Variables considered in the statistical analysis.

Variable	Description
Continuity of production	CTVi: Permanent sawmills that produced continuously until 2021. DISCT: Sawmills that produced sporadically in the period, with years of no production and years with production. CTNOVi: Sawmills that produced continuously for a number of years in the period but did not do so in 2021.
Years of production	Number of years from 2006 to 2021 during which the sawmill has been in production
Nregion	Name of the region where the sawmill is located
Ntype_saw perm	Type of permanent sawmill: permanent sawmill, permanent sawmill with processing, permanent sawmill with remanufacturing
Production_M3	Production of sawn wood in m^3
Export_Total	Percentage of production exported
Prod_Minterno	Percentage of production for the domestic market
Reprocess	Percentage of production for reprocessing
Total Drying	Percentage of production undergoing drying process
Volume_M3	Volume of log supply in m^3
Vol_Bpropio	Percentage of supply from own forest
Total_Same_Region	Percentage of log supply from the same region as the plant
Knot-Free	Percentage of knot-free quality log supply
Industrial	Percentage of industrial quality log supply
Commercial	Percentage of commercial quality log supply
MR Classified	Percentage of metro ruma classified log supply
Unclassified	Percentage of unclassified log supply
L244	Percentage of log supply with length 2.44 m
L32	Percentage of log supply with length 3.2 m
L36	Percentage of log supply with length 3.6 m
L4	Percentage of log supply with length 4 m
L5	Percentage of log supply with length >5 m
D16	Percentage of log supply with diameter <16 cm
D1620	Percentage of log supply with diameter 16 to 20 cm
D2030	Percentage of log supply with diameter 20 to 30 cm
D30	Percentage of log supply with diameter >30 cm
Interest_Produce SSW	Interest in producing SSW: YES = Interested, NO = Not interested, NR = No response
Interest_Train	Interest in training personnel in SSW classification: YES = Interested, NO = Not interested, NR = No response
Total_Personnel	Employees working in the last year of industry sampling
Main_L1	Type of saw on the main production line: CC = chipper canter, CD = circular double, CH = circular horizontal, CS = circular simple, CV = circular with flyer, HCC = band with chipper canter, HH = band horizontal, HI = band with inclined carriage, HM = band multiple, HP = band parallel, HVC = band vertical with carriage
M1: Increase production	Percentage of responses that indicated M1 as the main goal in the analyzed period
M2: Maintain production	Percentage of responses that indicated M2 as the main goal in the analyzed period
M3: Increase exports	Percentage of responses that indicated M3 as the main goal in the analyzed period
M4: Diversify products	Percentage of responses that indicated M4 as the main goal in the analyzed period
M5: Train personnel	Percentage of responses that indicated M5 as the main goal in the analyzed period
M6: Improve productivity	Percentage of responses that indicated M6 as the main goal in the analyzed period
M7: Invest in forest resources	Percentage of responses that indicated M7 as the main goal in the analyzed period
M8: Invest in sawmilling	Percentage of responses that indicated M8 as the main goal in the analyzed period
M9: Invest in processing	Percentage of responses that indicated M9 as the main goal in the analyzed period
M10: Invest in chippers, shredders	Percentage of responses that indicated M10 as the main goal in the analyzed period
M11: Invest in drying	Percentage of responses that indicated M11 as the main goal in the analyzed period
M12: Invest in treatment	Percentage of responses that indicated M12 as the main goal in the analyzed period
M13: Change business, close	Percentage of responses that indicated M13 as the main goal in the analyzed period
P1: Lack of supply	Percentage of responses that indicated P1 as the main problem in the analyzed period
P2: Low sale price of sawn wood	Percentage of responses that indicated P2 as the main problem in the analyzed period
P3: Low demand for sawn wood	Percentage of responses that indicated P3 as the main problem in the analyzed period
P4: Increase in energy costs	Percentage of responses that indicated P4 as the main problem in the analyzed period
P5: Shortage of trained labor	Percentage of responses that indicated P5 as the main problem in the analyzed period
P6: Lack of financing and capital	Percentage of responses that indicated P6 as the main problem in the analyzed period
P7: Force majeure	Percentage of responses that indicated P7 as the main problem in the analyzed period

evaluate the proportion of sawmill production dedicated to sawn wood for structural use, and multiple logistic regression was used to evaluate the dichotomous variable indicating whether the sawmill produces ($y = 1$) or does not produce ($y = 0$) sawn wood for structural use. By analyzing the significance of the variables in these models, it is possible to identify those variables that contribute significantly to explaining the variance of variable Y. The stepwise technique was used for selecting variables entered into the model, implemented through the Akaike information criterion (AIC) indicator (Venables and Ripley 2002). These statistical analyses were conducted using the R-Studio statistical analysis program, with a confidence level of 95 percent. The P value to decide the significance of the variables was $P < 0.05$.

Sawmill typology.—To generate the typology of sawmills, a cluster analysis was performed using the *k*-means method (Hartigan and Wong 1979). Categorical variables were transformed into dichotomous variables, generating one for each level of the variable. Subsequently, all variables used were normalized to standard normal to homogenize the data for comparability (equal weighting) and eliminate potential biases in subsequent analyses.

To apply the *K*-means clustering algorithm, the gap method was used to determine the maximum number of clusters that could be formed based on the variables. This statistical technique identifies the point at which a break in the data pattern occurs, indicating the optimal number of clusters. Clusters were generated using *K*-means, and the sawmills within them were characterized based on the relevant variables obtained in the linear and logistic regression analyses, allowing for the identification of patterns and similarities among them.

Once the six sawmill clusters and their characteristics were determined, the sawmill typology was organized around what was termed "propensity for SSW production," rating the clusters from A to F based on the actual value they had for each variable. If the variable had a positive relationship with the propensity for SSW production, then the highest value was rated as A; if the variable had a negative relationship with the propensity for SSW production, then the A rating went to the cluster where the corresponding variable had the lowest value.

Next, each cluster was organized in relation to its ratings. Their ordering according to the cluster's propensity to produce SSW and its description constitute the proposed sawmill typology in this article. Finally, a visual ordering of the cluster ratings was carried out, designing an intervention map for the application of specific public policy instruments.

Results

Number of clusters

The gap method concluded that up to a total of 14 sawmill clusters can be formed (Fig. 1). Considering that the objective of this technique was to find a balance in creating significantly distinct clusters, it was decided to form six sawmill clusters, maintaining greater homogeneity of the clusters in relation to the number of units they contained while avoiding clusters formed by a single sawmill. Thus, the 517 sawmills involved in the statistical analysis were subdivided into six clusters (Fig. 2), determining a sawmill typology wherein the central axis was the propensity to produce SSW.

Selected variables

In the multiple linear regression where the proportion of sawmill production intended for sawn wood for structural use was evaluated, the variables selected by the stepwise method from the total entered into the model are presented in Table 2. In the multiple logistic regression where the dichotomous variable indicating whether a sawmill produces ($y = 1$) or does not produce ($y = 0$) sawn wood for structural use was evaluated, the variables selected by the same method are presented in Table 3.

The 12 independent variables involved in the multiple linear regression model recorded different levels of significance. The most significant variable is the proportion of knot-free quality sawlogs in the total supply of the sawmill, which is directly related to the volume of SSW that can be produced in the sawmill. However, with a lower level of significance, other qualities of logs inferior to knot-free quality also stand out, such as MR classified and industrial-quality logs, from which a lower volume of SSW can be obtained, but for which a lower price is paid. It is also important to consider that knot-free wood is intended for high-value manufactured product niches, where the competitiveness of SSW is likely to be very restricted; in contrast, in medium-priced product ranges, SSW can compete successfully, and the sawmill can offer a broader product mix than clear wood allows.

Regarding the main production line saws that stand out as significant variables, it should be noted that currently, the vertical band saw, with or without a carriage, is the most commonly used in small sawmills (production of sawn wood

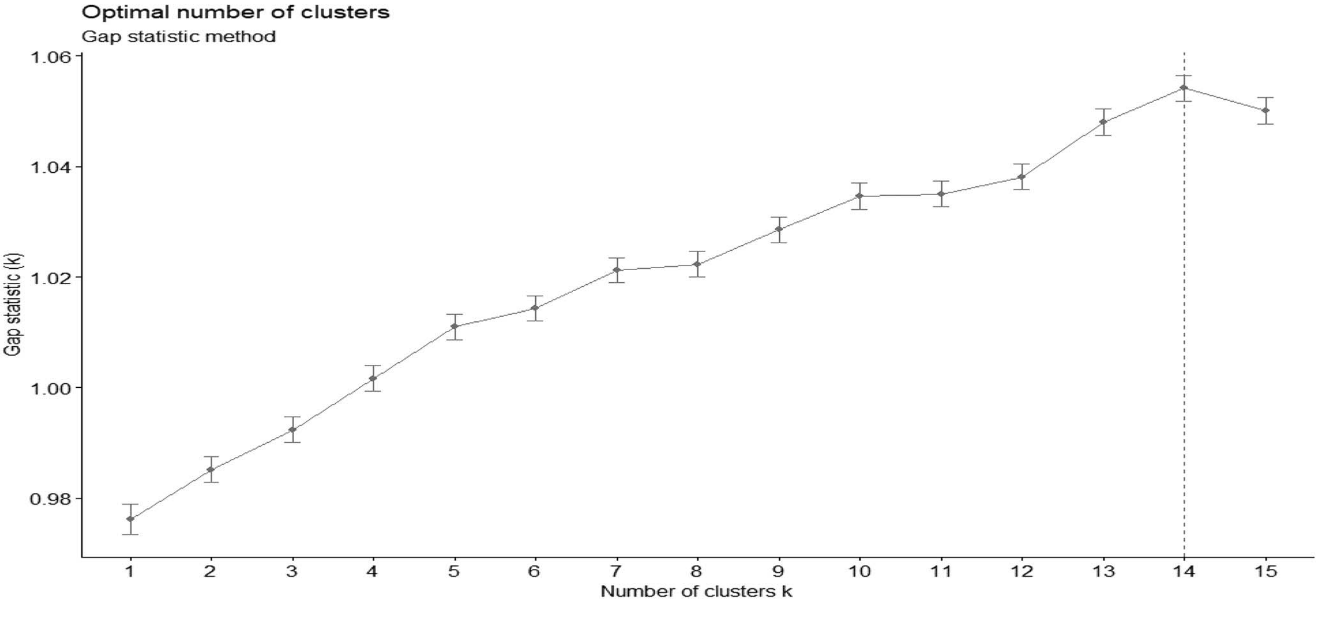


Figure 1.—Gain of the GAP statistic (k), according to the number of formed clusters.

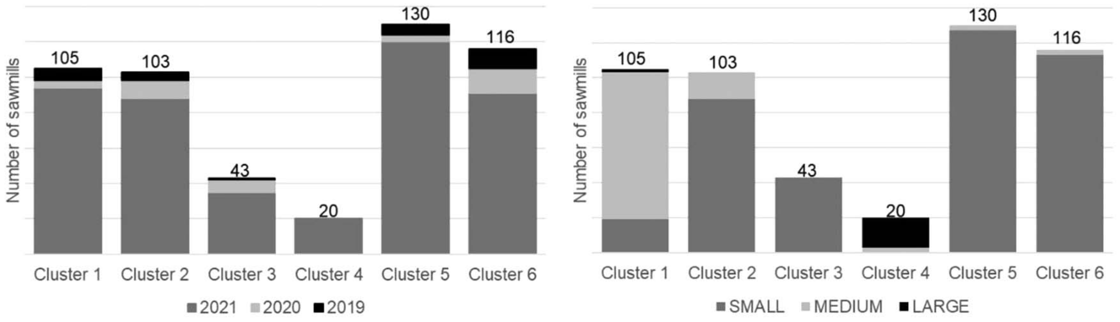


Figure 2.—Number of sawmills in each cluster, according to the last year of operation and size.

$<$10,000 m^3/yr) and medium-sized sawmills (10,000–100,000 m^3/yr), where there are significant challenges in producing SSW. On the other hand, the use of the double circular saw is concentrated in medium-sized sawmills. This could be an indicator that the majority of sawmills do not have the machinery suitable for producing SSW.

If we compare the results of the multiple linear regression with the results of the multiple logistic regression model, we can conclude that the supply quality, from the highest quality to the lowest, is a very significant variable for the volume of SSW production, and it is significant, but to a lesser extent, for the decision to produce SSW or not.

The volume of sawn wood production is the most significant variable, with a positive connotation that is quite evident, indicating that a higher production volume increases the probability of producing SSW. Two other variables, length of pieces (3.2 m) and administrative region (Maule), also showed great significance, representing two variables with a high participation in the sawmilling industry. The first is because the majority of *Pinus radiata* logs are marketed in 3.2 m length, while the Maule region stands out for the large number of medium-sized sawmills.

The significance of the type of saw in the main production line was manifested similarly in both regression models, confirming its importance in the decision to produce SSW and in the volume to be produced. However, in the case of the decision to produce SSW, the probability of occurrence was lower.

The contribution of dry sawn wood to the total production of the sawmill is fundamental for the production of SSW, as one of the four legal requirements of SSW is that its moisture content must be below 19 percent, according to the requirements established by the General Ordinance of Urbanism and Construction (MINVU 1992).

Sawmill typology

The typology of sawmills based on their propensity to produce SSW considers the six clusters of sawmills determined in the cluster analysis, characterized by 24 variables that included all those highlighted by the regression results, plus others considered by the authors to be of great interest for SSW production. In each of the 24 variables, the clusters were categorized based on their contribution to SSW production. The results by variable and cluster are presented in Figure 3. The variables of the country region where the sawmill is located and the size of the sawmills were not included in the propensity analysis to produce SSW but are presented as a notable feature of them.

By sorting the characteristics of each sawmill cluster into those that, with their behavior, make the sawmills more prone to the production of SSW to those that make them less prone, the following typology was determined:

Sawmills highly prone to produce SSW (Cluster 4).—This cluster mainly consists of large sawmills (sawn wood production greater than 100,000 m^3/yr), with 10 characteristics that place them in the best conditions in the sawmilling industry to produce SSW. These characteristics are related to their size, technological capabilities, the type of supply, and their stability and experience in the activity. However, these favorable characteristics coexist with others, also numerous, located at the other end of the propensity bar,

Table 2.—Variables selected by the stepwise method in the multiple linear regression.

Variable	Estimate	Standard error	*t* value	*P* value	Significance[a]
Quality of sawlog timber supply: KNOT-FREE	0.19504	0.04101	4.756	2.58e−06	***
Quality of sawlog supply: MRCLASSIFIED	0.12316	0.04112	2.995	0.00288	**
Quality of sawlog supply: INDUSTRIAL	0.14899	0.05163	2.886	0.00407	**
Main saw: PRINCIPAL L1_CD double circular	0.11009	0.04214	2.612	0.00927	**
Main saw: PRINCIPAL L1_HVC vertical band saw with carriage	0.11397	0.04382	2.601	0.00957	**
Length of sawlog supply: L32_M	0.11176	0.04351	2.569	0.01050	*
Quality of sawlog supply: COMMERCIAL	0.10946	0.04747	2.306	0.02153	*
Administrative region: NREGION_Ñuble	0.09803	0.04295	2.283	0.02287	*
Continuity of production from 2006–2021: CTVi	0.08471	0.04105	2.063	0.03958	*
Sawn wood production: PRODUCTION_M3	−124.907	0.64193	−1.946	0.05223	•
Sawlog consumption: VOLUME_M3	125.425	0.64848	1.934	0.05365	•
Administrative region: NREGION_Maule	0.08812	0.04634	1.902	0.05776	•

[a] *** Correspond to the most significant variables; • results closer to 0.05.

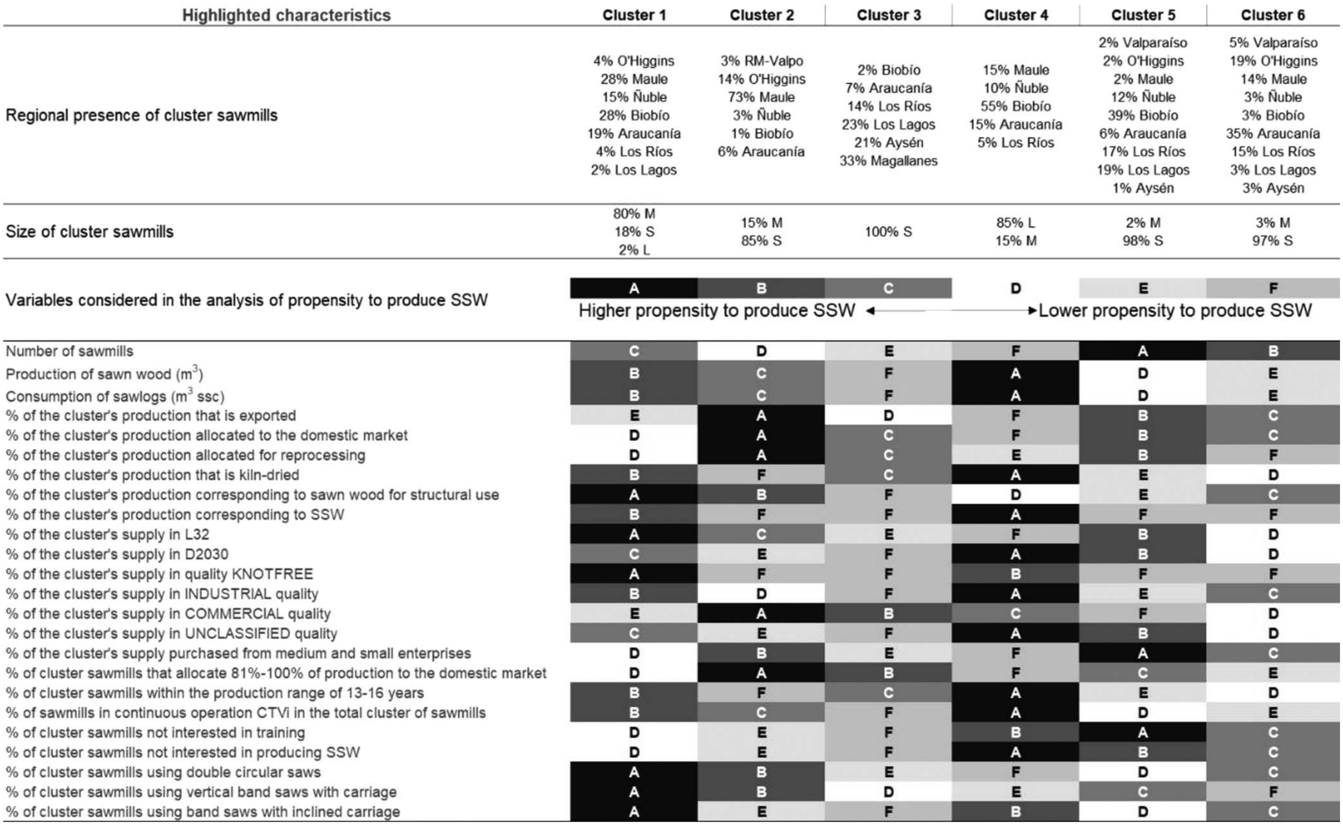
Table 3.—Variables selected by the stepwise method in the multiple logistic regression.

Variable	Estimate	Standard error	*t* value	*P* value	Significance[a]
(Intercept)	−31.571	0.2969	−10.635	<2e−16	***
Sawn wood production: PRODUCTION M3	0.6956	0.1483	4.692	2.7e−06	***
Length of sawlog supply: L32_M	10.302	0.2754	3.741	0.000183	***
Administrative region: NREGION_Maule	0.7159	0.1992	3.593	0.000326	***
Main saw: PRINCIPAL_L1_CD circular double	0.3849	0.1235	3.116	0.001836	**
Main saw: PRINCIPAL_L1_HVC vertical saw with carriage	0.5062	0.1685	3.005	0.002655	**
Production of dried sawn wood: TOTAL_DRYED_M3	0.4927	0.1782	2.765	0.005685	**
Years of production in the period 2006–2021: Work years	0.4322	0.1782	2.425	0.015311	*
Continuity of production in the period 2006–2021: CTVi	0.6046	0.2608	2.319	0.020410	*
Administrative region: NREGION_Araucania	0.4297	0.1923	2.235	0.025422	*
Quality of sawlog supply: COMMERCIAL	0.4298	0.2012	2.136	0.032674	*
Quality of sawlog supply: KNOT-FREE	0.4901	0.2496	1.964	0.049577	*
Production of sawn wood for reprocessing: PROD_REPROCESO_M3	−0.4449	0.2288	−1.945	0.051797	•
Quality of sawlog supply: MRCLASSIFIED	0.2578	0.1429	1.804	0.071160	•
Main saw: PRINCIPAL_L1_HI band saw with inclined carriage	0.2201	0.1281	1.718	0.085727	•

[a] *** Correspond to the most significant variables; • results closer to 0.05.

mainly related to the export-oriented nature of these productive units, leaving them relatively little space for the local market, which supplies the construction industry. They produce relatively low volumes of sawn wood for structural use and relatively high volumes of SSW. The activity of this cluster is concentrated in the major *P. radiata* wood-producing regions: Maule, Ñuble, Biobío, and Araucanía.

Sawmills prone to produce SSW (Cluster 1).—This cluster is dominated by medium-sized sawmills (sawn wood production between 10,000 and 100,000 m^3/yr), with six characteristics that make them highly prone to the production of SSW, only two characteristics in the opposite position, and the rest of the variables in intermediate positions (B, C, and D), suggesting a low level of difficulties for the production of SSW. Among those variables contributing to a higher propensity are stability and experience in the industry, and variables related to their greater focus on the domestic market. Some sawmills in this cluster produce industrial sawn wood for structural use and SSW, but the volumes are low. They are present in all regions of the central-southern part of



Highlighted characteristics	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Regional presence of cluster sawmills	4% O'Higgins 28% Maule 15% Ñuble 28% Biobío 19% Araucanía 4% Los Ríos 2% Los Lagos	3% RM-Valpo 14% O'Higgins 73% Maule 3% Ñuble 1% Biobío 6% Araucanía	2% Biobío 7% Araucanía 14% Los Ríos 23% Los Lagos 21% Aysén 33% Magallanes	15% Maule 10% Ñuble 55% Biobío 15% Araucanía 5% Los Ríos	2% Valparaíso 2% O'Higgins 2% Maule 12% Ñuble 39% Biobío 6% Araucanía 17% Los Ríos 19% Los Lagos 1% Aysén	5% Valparaíso 19% O'Higgins 14% Maule 3% Ñuble 3% Biobío 35% Araucanía 15% Los Ríos 3% Los Lagos 3% Aysén
Size of cluster sawmills	80% M 18% S 2% L	15% M 85% S	100% S	85% L 15% M	2% M 98% S	3% M 97% S
Variables considered in the analysis of propensity to produce SSW	A	B	C	D	E	F
	Higher propensity to produce SSW ←			→ Lower propensity to produce SSW		
Number of sawmills	C	D	E	F	A	B
Production of sawn wood (m^3)	B	C	F	A	D	E
Consumption of sawlogs (m^3 ssc)	B	C	F	A	D	E
% of the cluster's production that is exported	E	A	D	F	B	C
% of the cluster's production allocated to the domestic market	D	A	C	F	B	C
% of the cluster's production allocated for reprocessing	D	A	C	E	B	F
% of the cluster's production that is kiln-dried	B	F	C	A	E	D
% of the cluster's production corresponding to sawn wood for structural use	A	B	F	D	E	C
% of the cluster's production corresponding to SSW	B	F	F	A	F	F
% of the cluster's supply in L32	A	C	E	F	B	D
% of the cluster's supply in D2030	C	E	F	A	B	D
% of the cluster's supply in quality KNOTFREE	A	F	F	B	F	F
% of the cluster's supply in INDUSTRIAL quality	B	D	F	A	E	C
% of the cluster's supply in COMMERCIAL quality	E	A	B	C	F	D
% of the cluster's supply in UNCLASSIFIED quality	C	E	F	A	B	D
% of the cluster's supply purchased from medium and small enterprises	D	B	E	F	A	C
% of cluster sawmills that allocate 81%-100% of production to the domestic market	D	A	B	F	C	E
% of cluster sawmills within the production range of 13-16 years	B	F	C	A	E	D
% of sawmills in continuous operation CTVi in the total cluster of sawmills	B	C	F	A	D	E
% of cluster sawmills not interested in training	D	E	F	B	A	C
% of cluster sawmills not interested in producing SSW	D	E	F	A	B	C
% of cluster sawmills using double circular saws	A	B	E	F	D	C
% of cluster sawmills using vertical band saws with carriage	A	B	D	E	C	F
% of cluster sawmills using band saws with inclined carriage	A	E	F	B	D	C

Figure 3.—Characterization and categorization of sawmill clusters according to their propensity for the production of structural sawn wood (SSW).

the country but are more concentrated in the *P. radiata* regions. This cluster, which has good characteristics for producing SSW, declares little interest in producing it and in training for visual wood classification.

Sawmills with difficulties to produce SSW (Cluster 2).—Sawmills in this cluster are mainly characterized as small (sawn wood production less than 10,000 m^3/yr), but there is also the presence of medium-sized sawmills. They have 13 characteristics at higher propensity levels, compared to 11 at lower propensity levels. They are present in six regions of the central-southern zone, but 73 percent of these sawmills are located in the Maule region. Here, their low level of production of sawn wood destined for exports and reprocessing stands out, favoring their relative presence in the local market and, therefore, increasing their chances of supplying the construction sector. They produce sawn wood for structural use but not SSW and declare no interest in producing it or training for visual classification.

Sawmills with significant difficulties to produce SSW (Cluster 5 and Cluster 6).—These two clusters have been combined for typology purposes because they have great similarities. They are basically composed of small sawmills characterized by low volumes of production and consumption of wood pieces, but they do not export and process smaller volumes. Their relative participation in the domestic market is important. They have access to low-quality supply. They declare producing very low levels of sawn wood for structural use and do not produce SSW, but the paradox is that they are interested in producing it and in training for visual classification. With the exception of the vertical band saw with a carriage, the other saws they use were not selected by statistical regressions as the most significant for the production of SSW. They are distributed from Valparaíso to Patagonia, but while Cluster 5 sawmills are concentrated in the Biobío Region, Cluster 6 sawmills are concentrated in La Araucanía.

Sawmills with very few conditions to produce SSW (Cluster 3).—These sawmills are 100 percent small in size. They have 18 out of 24 characteristics with low or very low propensity to produce SSW. They constitute the southernmost cluster, with 54 percent of the sawmills in the Aysen and Magallanes regions. In this cluster, there are the few permanent sawmills that work with exotic species other than *P. radiata* or native species. They have a high domestic market orientation, but they do not produce sawn wood for structural use or SSW. They also have no interest in producing it or training for classification. The type of supply they access suggests that they have better opportunities in sawn wood for nonstructural uses.

Areas of intervention for public policy instruments

By organizing the ratings of the variables for each cluster from those with the highest propensity to produce SSW to those with the lowest propensity, an intervention map for the application of public policy instruments was obtained (Fig. 4).

Discussion

The importance of building with wood to mitigate the effects of climate change, thereby reducing CO_2 emissions, is widely researched and demonstrated by numerous studies (Himes and Busby 2020, FPInnovations 2021, Peralta 2022, Pramreiter et al. 2023). However, some studies consider it essential to understand the conditions under which construction with wood constitutes an environmental contribution (Ramage et al. 2017, Pramreiter et al. 2023). This environmentally positive connotation of wood construction led the Chilean Forest Policy Council to define goals for wood use in construction (CONAF 2015), the first of which (2020) was not achieved, and the second of which (2025) is

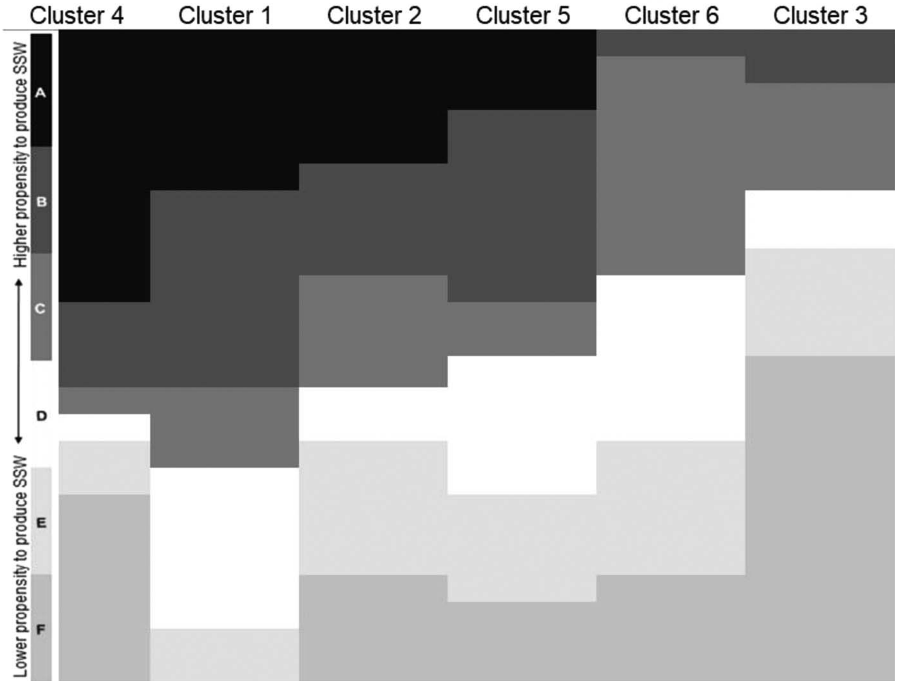


Figure 4.—Intervention map for the application of public policy instruments.

unlikely to be achieved, leaving the entire task for the year 2035, the final year of the mentioned policy horizon.

At the same time, Chile urgently needs to address its estimated housing deficit of around 600,000 homes, for which the Ministry of Housing (MINVU) is promoting the participation of industrialized construction, where sawn wood plays a fundamental role (MINVU 2022). These challenges require the production of SSW, which the sawmilling industry currently does not provide in the volumes and qualities required (Álvarez et al. 2022b). Some policymakers propose that this limitation can be addressed with a new subsidy for *P. radiata* plantations, generating a significant increase in sawlog volume in the medium term (Ugarte 2019, Gilabert and Ugarte 2023). However, the 1974 Decree Law and its extensions have critics, both economically and socially due to the sectoral development model it generated (González 2017), and environmentally, as monocultures are attributed to loss of native forests, loss of biodiversity, and a questionable contribution to reducing CO_2 emissions (Heilmayr et al. 2020, Lara 2023).

This research was conducted with the conviction that an increase in SSW production will only be achieved if direct support instruments are generated for sawmills. Considering the low level of classification of the structural grade of sawn timber highlighted in the "Effect of variables on sawn wood production" section here, a fundamental aspect is to encourage this classification, considering that currently only three or four sawmills are using machines to classify the structural grade of wood, which is a common practice in North America. For this purpose, a typology of this industry based on its propensity to produce SSW and an intervention map of policy instruments are proposed. Along with this, it will also be necessary to stimulate the management of *P. radiata* plantations with the aim of producing SSW (Regmi et al. 2022).

The methodology employed allowed precise and reliable results to be obtained, considering both the use of stepwise regression for the selection of input variables to the model (Roque 2021) and multiple regressions to identify the most significant variables. Also noteworthy is the use of *k*-means clustering to generate typologies (Maggi et al. 2020), in this case, a typology of sawmills.

The results are relevant for those responsible for implementing policy instruments that incentivize the production of SSW. Therefore, discussion on how the government can support sawmills should be initiated promptly.

Conclusions

The decisions of sawmills to produce or not produce SSW and in what volumes are related to numerous variables, representing great complexity when deciding which actions to take to generate a significant impact on production volume.

This research provides a statistically validated typology of sawmills so that decision-makers can address the problem of low SSW production volumes in sawmills, considering the goals of forestry policy and the country's urgency to reduce the housing deficit.

Based on the intervention map for the application of public policy instruments (Fig. 4), it is recommended that the selection and application of policy instruments for the sawmilling industry begin based on the determining variables of the intermediate clusters in the typology. This means that areas to intervene should be prioritized in the central zone of the intervention map, advancing in successive stages towards the periphery.

The methodology used allowed precise and reliable results to be obtained, which can be used to improve decision-making in the sawmilling sector in Chile, but also in other countries and other industrial sectors.

To the best of the authors' knowledge, this study is the first study to conduct a typology of sawmills in Chile and suggests direct support from public policy for the sawmilling industry.

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