forests

MDPI

Article

Operational and Regulatory Feasibility of Whole-Tree Hauling Using a Modified Log Trailer for Biomass Recovery in the Southeastern United States

Aihua Yu [1], Mandira Pokharel [2,*], Marissa "Jo" Daniel [2], John Lancaster [3], Tom Gallagher [2], Tim McDonald [4] and Dana Mitchell [5]

[1] Department of Forest Engineering, College of Civil Engineering, Nanjing Forestry University, 159 LongPan Road, Nanjing 210037, China; yuer@njfu.com.cn
[2] College of Forestry, Wildlife and Environment, Auburn University, 602 Duncan Dr, Auburn, AL 36849, USA; mzd0060@auburn.edu (M.J.D.)
[3] Midsouth Forestry Services, 25034 US-82, Gordo, AL 35466, USA
[4] Department of Biosystems Engineering, Auburn University, Corley Bldg and Agricultural Engineering Annex, Auburn, AL 36849, USA
[5] Bioenergy Technologies Office, Department of Energy (Retired), 15013 Denver W Pkwy, Golden, CO 8040, USA
* Correspondence: map0208@auburn.edu

Abstract

Growing demand for renewable energy from biomass has prompted exploration of timber transportation concepts. This study evaluated the operational and regulatory boundaries of whole-tree hauling using a modified log trailer in the southeastern United States. Two designs, a swinging gate and an extendable bolster, were developed to accommodate full-length, unprocessed loblolly pine (*Pinus taeda*) and contain tree crowns. The swinging gate was selected for field testing due to its lower cost, lighter weight, and structural reliability. Field testing included nine loads evaluated under unprocessed, trimmed, and delimbed trees. Axle weights and net payloads were evaluated with tandem and tridem axle regulations. The modified trailer increased biomass recovery, while processed biomass represented 14% of total load weight. However, the mean trimmed loads exceeded tandem-axle allowances reviewed for the eleven southeastern states considered. Pulpwood-sized timber required less trimming and allowed better crown containment than chip-and-saw timber. Overall, the modified trailer can improve biomass recovery, but practical implementation is strongly constrained by timber characteristics, axle configuration, and state-specific weight regulations.

Keywords: biomass transportation; trailer modification; extendable bolster; swinging gate design; timber transportation; whole-tree hauling; axle weight; gross trailer weight; loblolly pine

Academic Editors: Rodolfo Picchio, Grzegorz Trzciński and Kazuhiro Aruga

Received: 25 September 2026
Revised: 29 October 2026
Accepted: 2 November 2026
Published: 5 November 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Growing concerns over fossil fuel use have increased interest in renewable energy sources in the United States. Scientists and engineers have explored renewable resources as a means to supplement fossil fuel consumption and extend the longevity of diminishing reserves [1,2]. Recent studies emphasize that transitioning to renewable energy systems is not only essential for energy security but also critical for achieving carbon neutrality goals [3–5].

One promising renewable energy source is biomass derived from forest residues and short-rotation woody crops, such as fast-growing pine or poplar species [6–8]. Wood has received increasing attention as an energy source because timber can be regrown within a relatively short time. Modern silvicultural practices, including improved planting stock, irrigation, competition control, and fertilization, can increase tree growth and shorten the time needed to produce usable biomass [9–11]. Unlike fossil fuels, which require extensive geological time to form and are non-renewable, timber produced under short-rotation intensive culture can grow into usable biomass fuel material for energy production within 1 to 15 years, depending on the species [12,13].

In recent years, increasing attention has been given to improving the logistics and supply chain of woody biomass, which significantly influences the economic feasibility and sustainability of bioenergy production [14–16]. Building on this focus, the recent literature has begun to analyze the efficiency of different truck and trailer configurations for transporting forest biomass. For example Howitt and Ghaffariyan [17] identified key factors influencing biomass transport efficiency, material density, moisture content, hauling distance, legal weight limits, and payload capacity, and compared different configuration options across regions. In addition, Derochers et al. [18] compared raw-forest products trucking and general commercial trucking in the U.S. South, highlighting how weight limits, trailer configurations, and operational constraints shape the feasibility and economics of timber transport under current regulations. Moreover, case studies from southern U.S. log-truck operators show that existing gross vehicle weight (GVW) limits for log trucks are among the lowest in timber-producing regions; a survey in Georgia found that the majority of loggers and industry representatives consider the current GVW limits too restrictive for efficient hauling [19]. These findings signal that regulatory context, especially axle-weight limits, plays a decisive role in transport feasibility, not just the vehicle design itself.

One proposed system to enhance the amount of renewable biomass available for use is a timber processing depot, where limbs and crowns are processed at a centralized facility rather than at the harvesting site. This system aims to optimize biomass yield and minimize the amount of recoverable material left in the field. Centralized processing can also reduce contamination and ash content, thereby improving the energy quality of biomass fuel [20,21].

However, the success of such depots depends on the efficient and safe transportation of whole trees or partially processed stems from forest stands to the depot. The current timber transportation system is designed for fully processed logs [9,22,23]. The envisioned application focuses on chip-and-saw (CNS)-sized southern yellow pine, a mid-diameter timber class suitable for both lumber and wood chips; however, hauling such unprocessed trees on traditional double bunk log trailers leaves crowns uncontained, posing safety and compliance issues [24]. To mitigate this risk, haulers sometimes trim the crowns with pole saws after loading, but this practice reduces payload and discards a substantial portion of potentially valuable biomass that could otherwise serve as fuel material. Lancaster et al. [24] demonstrated that even modified log trailers struggle to safely transport whole-stem southern yellow pine, highlighting the logistical and regulatory challenges of using conventional timber transportation systems for unprocessed wood biomass supply chains.

Therefore, the objective of this study is to evaluate the operational and regulatory feasibility boundaries of whole-tree transportation systems designed for depot-based processing in the U.S. South. The main goal of the design process was to modify an existing log trailer so that it retained its versatility, avoiding the need for loggers to purchase a specialized, purpose-built trailer that could tie up limited capital in underutilized equipment. To achieve this, two modified trailer designs, the swinging gate and the extendable bolster, were conceptualized, fabricated, and field-tested to assess their structural performance, loading characteristics, and compliance with legal axle weight limits. By identifying the constraints and opportunities associated with hauling unprocessed loblolly pine

(*Pinus taeda*), this study provides practical insights into how equipment modification, transportation regulations, and operational conditions collectively shape the feasibility of implementing timber processing depots at a regional scale.

2. Materials and Methods

2.1. Study Conceptualization and Field Setup

Transportation laws and regulations were reviewed for eleven southeastern U.S. states where loblolly pine (*Pinus taeda*) naturally occurs to establish constraints for the trailer modification design and evaluate the feasibility of the transportation method across individual states. Semi-truck and trailer dimensional restrictions (length, height, and width), allowable load overhang, state and federal gross vehicle weight limits, and allowable axle weights were reviewed. The allowable gross vehicle weight across the region was mostly consistent at 80,000 lbs (36,287 kg), with tolerance varying among states from 0 to 15%. State-specific dimensional limits and timber transportation exemptions are summarized in Appendix A.1, and GVW, applicable tolerances, and axle weight restrictions are presented in Appendix A.2.

Loblolly pine trees were felled at Auburn University's Mary Olive Thomas Demonstration Forest and skidded to a loading deck. Trees were loaded onto the modified trailer, which was donated to this project, without deliberate limb or crown removal until the stacked height reached the front standard height, ensuring maximum trailer volume utilization without overloading. Six trailer loads consisted of CNS-sized timber, and three loads consisted of pulpwood (PWD)-sized timber.

2.2. Trailer Modifications

Two trailer modifications were designed: a swinging gate and an extendable bolster, both mounted on a Pitts LT40-8L double-bunk log trailer (Pitts Trailers, Pittsview, AL, USA), chosen for its similarity to commercially available log trailers. ASTM A36 mild low-carbon steel was selected for construction due to its availability, low cost, and adequate mechanical properties.

The swinging gate design uses a crosshatched metal gate (Figure 1) mounted on the rear bunk of the log trailer. The gate is attached only to the two rear standards (vertical steel stakes) and does not connect to the front pair. These rear standards are modified so they can rotate 180 degrees, allowing the gate to move from the closed position shown in Figure 1 to the new open position shown in Figure 2. When opened to the rear of the trailer, the gate helps contain the limbs and crown material that extend beyond the trailer and would otherwise need to be trimmed before transport on a standard trailer. The modification can be removed by lifting the rear standards and gate assembly from the trailer and sliding the gate off the standards.

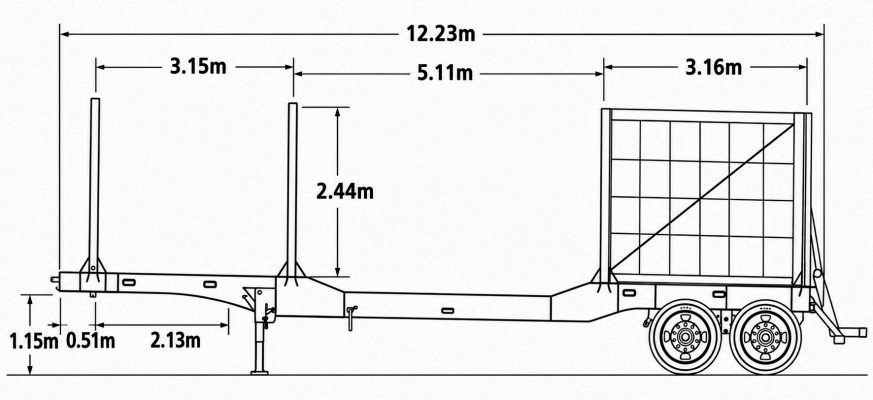


Figure 1. Swinging guide design-closed position for unloaded transportation.

https://doi.org/10.3390/f17111326

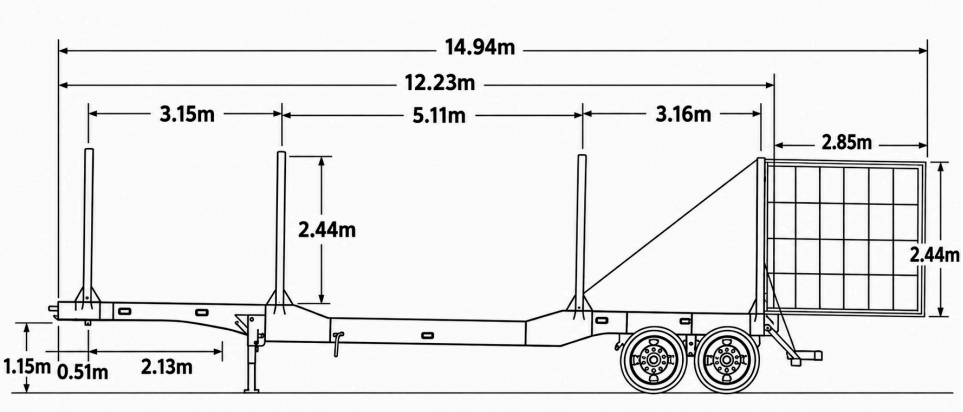


Figure 2. Swinging guide design-opened position for loaded transportation.

The extendable bolster design uses an additional bolster with two standards that can be extended from its collapsed position next to the rear bolster (Figure 3) to an extended position behind the trailer. In the extended position, the bolster supported and contained tree crowns extending beyond the rear of the trailer (Figure 4). Two square steel tubes passed through slots cut into the existing trailer bolsters and act as sliding rails for the modification. Stoppers were installed on the forward ends of the tubes to limit how far the bolster can extend.

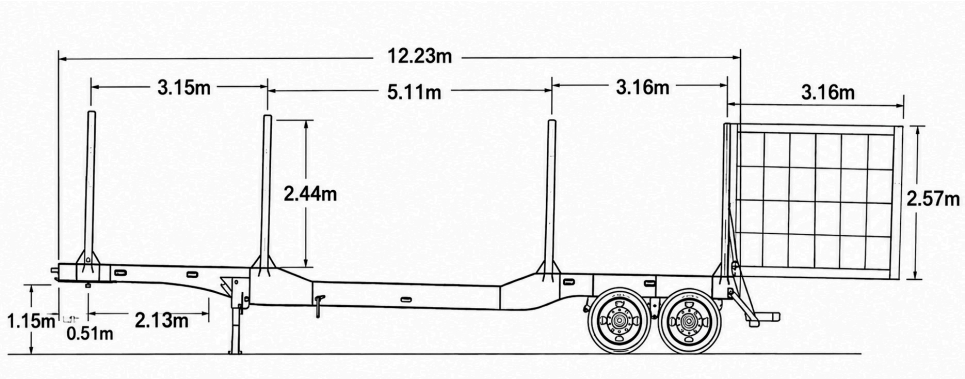


Figure 3. Extendable bolster design- collapsed.

Two crosshatched chain nets were installed along the sides of the trailer between the rear trailer standards and the standards of the extendable bolster. As the bolster was extended, the chain nets became taut and helped contain the tree crowns (Figure 4). When the bolster was returned to its collapsed position, the nets also collapsed, reducing the overall size of the modification and making it easier to maneuver. To remove the modification from the trailer, the stoppers could be detached, allowing the steel tubes to slide out through the pre-cut slots in the bolsters.

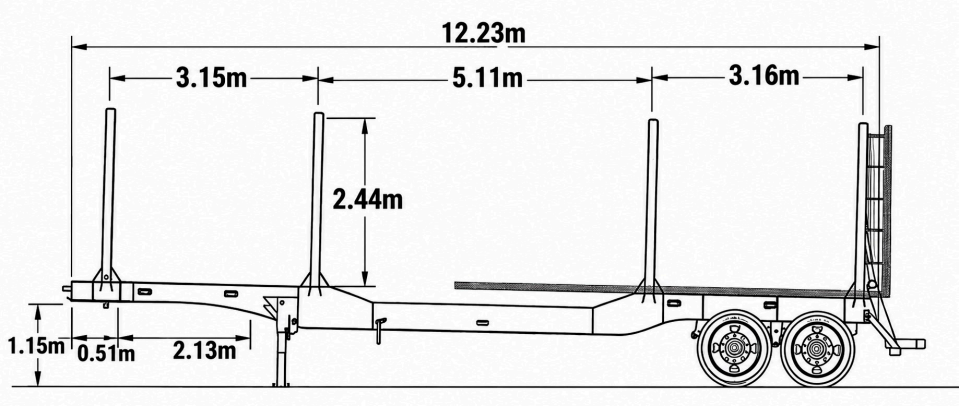


Figure 4. Extendable bolster design-extended.

2.3. Structural Analysis

Potential locations of structural failure due to yielding were identified for both modification designs, and the forces and bending moments acting at these locations were calculated. Yield strength represents the stress threshold at which a material begins to deform plastically. All structural calculations were performed under static loading assumptions and the sum-of-forces method.

After identifying potential failure locations, static load analyses were performed by applying known weights representing the modification mass and the biomass material the design would support. The calculated bending moments at critical locations were then compared with the yield capacity of the corresponding structural members to evaluate the structural adequacy of each design.

2.4. Swinging Gate Structural Analysis

For the swinging gate design, the critical stress point was located on each rear standard directly below the collar where the gate was attached. Each gate weighed 577 lb (261 kg), generating a bending moment of 2867 lbf.ft (pound-feet) or 3.89 kN·m (kilonewton-meters) at this location. The standards of the Pitts LT40-8L trailer [25] are manufactured from steel with an estimated yield strength of 70,000 psi (pounds per square inch) or 482.63 MPa (megapascals). A moment of 50,283 lbf.ft (68.18 kN·m) would be required to reach this yield threshold. The applied moment therefore represented approximately 6% of the calculated yield capacity, indicating adequate structural capacity under the assumed static load.

To verify these calculations, a force analysis was performed on the donated trailer used for prototype installation. The constructed gates weighed slightly less (558 lb or 253 kg), generating a moment of 2798 lbf.ft (3.79 kN·m) at the critical location. The rearmost bolster, constructed of 3/8-inch (0.95 cm) thick steel tubing with a diameter of 6.72 in (17 cm), was conservatively assumed to have a yield strength comparable to ASTM A36 steel, 36,300 psi (250.26 MPa). Calculations indicated that a moment of 33,986 lbf.ft (46.08 kN·m) would be required to plastically deform the standards well above the applied moment, confirming structural adequacy.

2.5. Extendable Bolster Structural Analysis

For the extendable bolster design, the location most likely to experience structural failure was on the support beams just beyond the point where they passed through the slots in the rearmost bolster, where bending stresses are maximized. The modification required supporting both its own weight (estimated 1384 lb or 628 kg) and the additional crown biomass left on the stems (estimated 13,365 lb or 6062 kg). Under a conservative worst-case scenario in which the biomass weight was assumed to act entirely on the

modification as a point load, each of the two support beams experienced a bending moment of 78,538 lbf.ft, equivalent to 106.5 kN·m.

The biomass estimate was computed using green weights of 45 hypothetical loblolly pine trees with a diameter at breast height (DBH) of 30.5 cm and a height of 18.3 m. Total tree green weight was compared to the 15.24 cm merchantable top green weight using published values from Clark and Saucier [26].

Under a conservative worst-case assumption that the entire biomass load acted on the modification as a point load, each of the two support beams experienced a bending moment of 78,538 (lbf.ft), equivalent to 106.5 kN·m.

ASTM A36 steel has a yield strength of 36,300 psi, equivalent to 250.26 MPa. A hollow tubing beam with dimensions 4 × 3 × 0.5 in (10.16 × 7.62 × 1.27 cm) could withstand a maximum bending moment of 10,588 lbf.ft (14.36 kN.m) before yielding, so the applied moment exceeded its capacity by a factor of 7.5. Replacing the tubing with a solid 4 × 3 in (10.16 × 7.62 cm) beam increased capacity to 13,613 lbf.ft (18.46 kN·m), yet the applied moment still exceeded the yield threshold by a factor of 5.8. Under this intentionally conservative loading assumption, the extendable bolster did not provide sufficient structural capacity and was therefore rejected from further consideration.

2.6. Design Selection and Fabrication

After completing the static load analysis for both designs, material densities and unit costs were compiled to estimate total weight and fabrication cost of each modification. Because the modifications were intended for installation on existing trailers, the selection criteria included lowest total cost, minimal added weight, and sufficient structural integrity to avoid any risk of failure under load. Keeping the modification weight low was a concern, since any added trailer weight reduces the amount of timber that can be hauled within the legal vehicle and axle weight limits. These criteria were intended to minimize additional financial burden on loggers while allowing as much payload weight as possible to remain available for timber.

Based on these criteria, the swinging gate design was selected for prototype construction because it had a lower estimated material cost and weight than the extendable bolster design and its structural performance exceeded safety requirements. Engineering drawings were delivered to a local machinist, and the design was successfully fabricated and installed on a trailer donated specifically for the project. The fabricated swinging-gate modification had an estimated material cost of $1737.85.

2.7. Trial Load Testing

Once the unprocessed timber was loaded, weight measurements were taken for all five axles of the truck and modified log trailer. Trees were felled and loaded on the same day, so the weight reflects green (freshly harvested) wood. Weight measurements were collected using four Intercomp PT300 portable truck scales (Intercomp Company, Medina, MN, USA) with an accuracy of ±1%. Scheuter [27] states that gross vehicle weight is not affected when weighing is performed on level ground with less than a 5% longitudinal slope. For this reason, all weight measurements were taken on level ground with less than a 5% slope to minimize possible measurement error.

After the initial weighing, crowns and any limbs extending beyond the modification were trimmed so that the load met transportation regulations, and all five axles were weighed again. A knuckleboom loader and trailer-mounted delimber were then used to unload the trees and process them to a merchantable top. Once processed, the trees were reloaded onto the trailer and weighed a third time. Finally, the trees were unloaded, and the truck and empty modified trailer were weighed to obtain the tare weight.

Net load weights were calculated by subtracting the unloaded truck-and-trailer weight from the corresponding loaded weight. This approach was used to account for

potential variability in scale measurements over the duration of the loading tests, assuming that similar measurement variability affected both loaded and unloaded weights.

2.8. Axle-Group Weight Analysis

The axle weight measurements were summarized for the truck tandem driver axles and the modified trailer tandem axles. These weights were compared with the legal tandem-axle weight provisions identified for the southern states included in the regulatory review (Table A2).

The measured axle-group weights were also reviewed against applicable tridem-axle limits to assess whether the additional axle capacity could improve the feasibility of the transportation method.

2.9. Statistical Analysis

Recorded axle-weight measurements from each trial load were entered into Microsoft Excel for Microsoft 365 (Microsoft Corporation, Redmond, WA, USA) and summarized to calculate net load weights for the untrimmed, trimmed, and processed load conditions. The difference between the untrimmed and trimmed load weights represented the amount of material removed to meet transportation requirements. The difference between the untrimmed and processed load weights represented the additional biomass transported when trees were hauled unprocessed instead of processed chip-and-saw timber. These weight differences were calculated for each trial load and summarized using descriptive statistics.

Right-tailed *t*-tests were used to compare untrimmed and trimmed loads, trimmed and processed loads, and untrimmed and processed loads. A two-tailed *t*-test was also performed to compare the load-weight differences between CNS and PWD product classes.

3. Results

3.1. Trial Load Testing Results

Modified trailer loads of unprocessed whole trees were examined by product class. Figure 5 presents the average adjusted trailer load weights for PWD, CNS, and all loads combined.

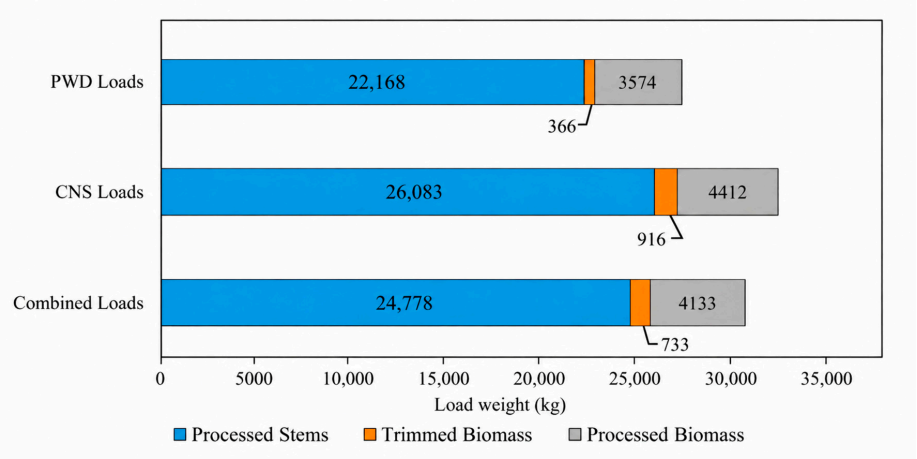


Figure 5. Modified trailer load weight averages for PWD, CNS, and combined loads.

Modified trailer loads (n = 9) averaged 9111 lb (4133 kg) (±1481 lb [672 kg], 95% CI) of processed biomass when product class was ignored. CNS loads (n = 6) averaged 9727 lb (4412 kg) (±1868 lb [847 kg], 95% CI) of processed biomass, while PWD loads (n = 3) averaged

7880 lb (3574 kg) (±1645 lb [746 kg], 95% CI). This processed biomass represents material that would remain attached to the stem during transport and become available to the timber processing depot rather than being removed during conventional processing.

The trimmed CNS loads, which are the loads that would actually be hauled to the timber processing depot, still extended well past the rear of the modified trailer. A large portion of the crown and biomass material remained beyond the reach of the swinging gates when they were opened (Figure 6a). This limited the effectiveness of the modification for CNS timber, even though the loads contained nearly 9700 lb/4400 kg of additional biomass. Shortening the stems, such as by bucking a 16-ft (4.9 m) saw log from the stem, could reduce the overall tree length and bring more of the crown within reach of the swinging gates. In comparison, a larger portion of the crowns (biomass material) on the trimmed PWD loads remained within reach of the gates because the PWD trees were shorter than the CNS trees (Figure 6b). Statistical testing ($\alpha = 0.05$) did not detect a significant difference between the distributions of CNS loads and PWD loads (Table 1), although the small sample size ($n = 9$) limited the power to detect potential differences.



Figure 6. (**a**) CNS timber load and (**b**) PWD timber load on the modified trailer after trimming to comply with transportation regulations.

Table 1. Mann–Whitney–Wilcoxon test results for differences between product classes.

Biomass Type	CNS Average (kg)	PWD Average (kg)	*p*-Value
Trimmed Biomass	916	366	0.1667
Processed Biomass	4412	3574	0.1667

Figure 7 presents the same load components as percentages of total net load weight, allowing comparison of their relative contributions across product classes. Trimmed biomass accounted for a relatively small proportion of total load weight, averaging 1% for PWD loads, 3% for CNS loads, and 2% for all loads combined. In contrast, processed biomass accounted for approximately 14% of total load weight across PWD, CNS, and combined loads. Because only three PWD loads were evaluated, the PWD estimates should be interpreted cautiously, as reflected by the wider confidence intervals for this product class.

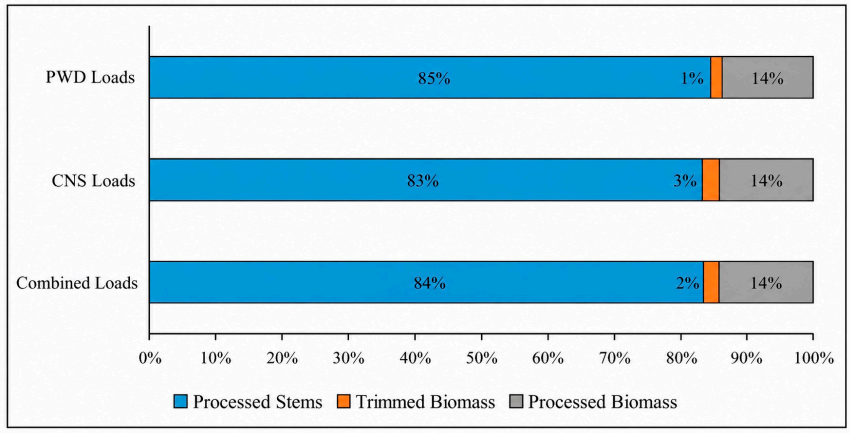


Figure 7. Modified trailer load weight averages as a percentage of the net load weight.

Although no statistically significant difference was detected between PWD and CNS loads (Table 1), practical differences were observed in their transportation characteristics. PWD loads averaged 7880 lb (3574 kg) of additional biomass, only 0.92 tons (0.83 tonnes) less than CNS loads, while requiring less trimming on average. The amount of biomass removed during trimming was statistically significant, and PWD loads averaged 2 percentage points less trimmed material than CNS loads. Together with the greater proportion of crown material contained by the swinging gates, these results indicate that a larger proportion of the whole-tree load could be delivered to the depot when hauling PWD rather than CNS trees.

3.2. Axle-Group Weight Results

Tandem axle weights from all nine loads were examined for the truck and trailer under the untrimmed, trimmed, and processed load conditions. All samples, regardless of product class, were included in this analysis because no statistically significant difference was detected between CNS and PWD load weights.

The truck tandem axle weights averaged 35,802 lb (16,239 kg) (±2892 lb [1311 kg], 95% CI), 35,913 lb (16,289 kg) (±2753 lb [1248 kg], 95% CI), and 38,853 lb (17,623 kg) (±2698 lb [1223 kg], 95% CI) for the untrimmed, trimmed, and processed loads, respectively (Figure 8). The modified trailer tandem axle weights averaged 54,180 lb (24,575 kg) (±4419 lb [2004 kg], 95% CI), 52,500 lb (23,813 kg) (±4152 lb [1883 kg], 95% CI), and 40,327 lb (18,292 kg) (±2953 lb [1339 kg], 95% CI), respectively.

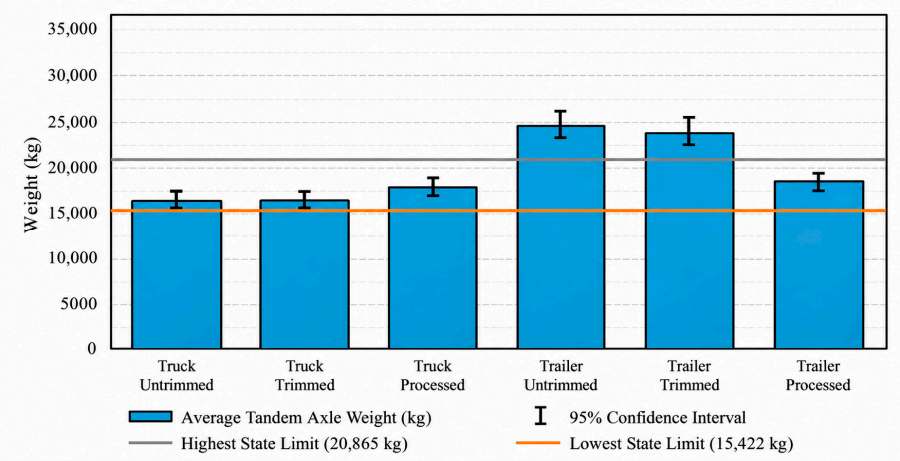


Figure 8. Average tandem axle weights.

Comparisions with the state regulations reviewed in this study (Table A.2) showed that the mean trimmed trailer tandem axle weight of 23,813 kg exceeded the tandem-axle allowances identified for the southern states evaluated.

4. Discussion

This study evaluated the operational feasibility of transporting unprocessed whole trees, including stems and crowns, to a centralized timber processing depot using a modified standard log trailer. The swinging-gate modification effectively captured limbs, increasing the amount of wood available for bioenergy, while feasibility varied by timber size. CNS timber presented challenges due to high crowns and extensive branch trimming, causing most loads to exceed tandem-axle regulations, whereas PWD timber was more compatible with the modified trailer, requiring less trimming and achieving higher transport efficiency. The modified trailer retained approximately 4412 kg of additional biomass per CNS load and 3574 kg per PWD load compared with conventionally processed loads. Assuming five loads per day, this would represent approximately 22,060 kg and 17,870 kg of additional biomass per day for CNS and PWD loads, respectively. Although CNS loads provide slightly more biomass per load, they require additional labor for trimming and handling (estimated at 20–40 min per load) and may pose safety concerns. In contrast, PWD loads are more manageable and safer to transport. The swinging-gate modification costs approximately $1737.85 and weighs 253 kg per gate, providing a cost-effective and structurally safe solution. Regulatory feasibility also varied considerably by state, particularly when tandem and tridem axle weight limits were considered.

4.1. Regulatory Context and Axle Weight Limits

The axle-group weights measured during the field trials indicate that transportation regulations are an important constraint on the use of the modified trailer. The mean trailer tandem-axle weight for the trimmed loads was 52,500 lb (23,813 kg), which was above the tandem-axle allwoances reviewed for the states included in this study. In Alabama, for example, the non-Interstate tandem-axle limit is 36,000 lb (16,329 kg), with a 10% enforcement tolerance increasing this value to 9,600 lb (17,962 kg) (Table A.2). The corresponding tridem-axle value is 42,000 lb (19,051 kg), or 46,200 lb (20,956 kg) when the same tolerance is considered (Table A.2). These values remain below the average trimmed trailer axle-group weight measured during the field trials.

Georgia provides higher allowable axle weights for some forest-products movements. Qualifying forest-produce vehicles may operate with tandem-axle weights of 46,000 lb (20,865 kg), with additional variance available under specified conditions. Even with these provisions, the average trimmed trailer axle-group weight measured in this study remained relatively high compared with the tandem-axle allowances reviewed.

The regulatory comparison therefore indicates that the feasibility of whole-tree hauling depends not only on the measured axle-group weights, but also on the specific weight provisions available in each state, including tolerances, permits, and axle configurations [19] Because additional axles can increase allowable gross vehicle weight while distributing the load over more axles [19], tridem or other multi-axle configurations may improve the feasibility of transporting heavier trimmed whole-tree loads where such configurations are permitted. Across the eleven southern states considered, additional axle capacity was available in some cases through tridem-axle configurations, forestry exemptions, tolerances, or overweight permits. These provisions could improve the feasibility of transporting trimmed whole-tree loads, but their applicability would depend on the specific vehicle configuration, route, and operating conditions. This regulatory constraint may become increasingly important if southern timber loads continue to increase in weight over time [28].

4.2. Timber Size and Operational Suitability

Timber size strongly influenced the operational suitability of the swinging-gate modification. The greater height of the CNS trees resulted in a large portion of the crowns extending beyond the reach of the swinging gates. Although the modification helped contain limbs and crown material within the width of the trailer, it did not address the excessive tree length and resulting rear overhang. Therefore, additional trimming was required for some CNS loads to meet transportation regulations. In contrast, the shorter PWD trees allowed more crown material to remain within the area contained by the swinging gates, reducing the amount of trimming required.

Although CNS loads retained a greater weight of additional biomass, PWD loads retained a larger percentage of the original whole-tree load after trimming. This indicates that PWD-size trees may be better suited for transportation using the swinging gate modification. Previous studies conducted in the U.S. and Europe [24,29–32] also identified tree diameter, stem length, and crown characteristics such as branch distribution and crown density as factors affecting whole-tree transportation. Therefore, the feasibility of this transportation method depends not only on the ability of the modification to contain crown material, but also on the size and characteristics of the trees being transported. Smaller-diameter trees with shorter crowns may be more suitable for this method because more crown material can be contained while reducing the trimming required to meet transportation regulations.

4.3. International Experience and Transport Optimization

Global experience underscores that efficient transport of unprocessed or partially processed forest biomass demands an integrated approach encompassing truck and trailer configurations, payload density optimization, and stringent regulatory compliance to balance economic viability, safety, and environmental impacts [30,33,34]. In Europe, particularly in Nordic countries like Finland and Sweden, higher gross vehicle weight (GVW) allowances, often exceeding 76 tonnes for multi-axle configurations, facilitate safe and cost-effective long-distance hauling of tree-length logs and biomass residues, enabling up to 20–25% higher payload capacities compared to standard setups [30,35]. Similarly, select regions in North America, such as the Pacific Northwest and parts of Canada, permit elevated GVW limits (up to 63.5 tonnes or more under provincial exemptions) for specialized log trailers with extended bunks or stakes, which support overlength energywood transport while minimizing roadside trimming [18,33]. These allowances not only reduce transportation costs per cubic meter but also enhance supply chain resilience against fluctuating fuel prices and road conditions.

Mechanized harvesting and loading systems further amplify these benefits by increasing payload density, which in turn boosts loading efficiency and curtails CO_2 emissions per unit of biomass transported—studies report reductions of 10–15% in emissions through optimized truck-trailer pairings [30,35]. However, challenges persist in handling low-density or irregular biomass forms, such as tree crowns and limbs, which are prone to shifting loads, increased downtime for securing, and elevated logistics costs due to suboptimal vehicle utilization [34]. For instance, in Finnish operations, irregular slash loads can inflate fuel consumption by 20% and extend idle times by up to 15% of total haul cycles, highlighting the need for modular attachments like telescoping racks or netting systems to contain overhang without compromising GVW limits [30].

Collectively, these international studies affirm that vehicle modifications, such as the swinging gate design evaluated here, cannot stand alone as a panacea for transport feasibility; they must be synergized with adaptive operational strategies, evolving regulatory frameworks, and trailer optimizations tailored to regional contexts [35,36]. A prominent alternative in both North American and European practices is partial bucking or

delimbing at the landing site, which shortens crowns to comply with length regulations and averts axle overloads but incurs higher upfront labor costs (15–25% increases in site processing time) and potential biomass losses if residues are not immediately collected [18,34]. In the U.S. South, where double-bunk trailers predominate, on-site interventions such as partial bucking, delimbing, or topping at the landing are commonplace to comply with length and weight regulations [37]. However, these practices frequently result in 5–10% lower biomass recovery rates compared to the integrated whole-tree transport systems widely used in Scandinavia, where modular containment devices (e.g., telescopic gates, high-strength nets, or extendable racks) routinely enable 18–25% of total payload to be delivered as recoverable crown and limb biomass [20,30].

The findings of the present study are consistent with this broader experience. The swinging-gate modification increased biomass recovery, with processed biomass representing approximately 14% of total load weight, but the benefits of the modification were strongly influenced by tree size, crown position, axle-load distribution, and state-specific weight limits. Thus, trailer modification alone does not determine the feasibility of whole-tree transportation. Effective implementation would require matching the trailer configuration and timber characteristics with appropriate loading practices and the regulatory conditions of the jurisdiction in which the system operates.

4.4. Study Limitations and Practical Considerations

Several limitations of this study should be considered when interpreting the results. Field testing was limited to nine trailer loads, including six CNS and three PWD loads. The number of trial loads was limited by the availability of the harvesting equipment and suitable timber during the study. Because of the small sample size, the statistical comparisons should be interpreted with caution, and additional field testing would help confirm the consistency of the observed patterns across a wider range of operating conditions.

Wood moisture content was not measured during the study. Trees were felled and loaded on the same day and were therefore weighed in a freshly harvested, green condition. The biomass weights reported in this study represent green mass as it relates to transportation and axle loading. Differences in moisture content among seasons, sites, and individual trees could affect both transported weight and the amount of recoverable dry biomass. Future studies could include moisture-content measurements to better quantify these effects.

The modified trailer was tested only under the conditions available during the field trials (dirt road) and was not operated on paved or gravel public roads. Therefore, the effects of the increased axle loads on pavement condition, including rutting or other road surface damage, were not evaluated. The study also did not assume that existing transportation regulations would be changed. Instead, the tandem and tridem axle analyses were used to determine how the feasibility of the transportation method would vary under existing state-specific axle-weight limits.

The study also did not include a complete economic analysis. The estimated material cost of the swinging gate modification was used as one of the design-selection criteria. However, commercial hauling costs, delivered wood prices, operating and maintenance costs, and revenues from recovered biomass were not evaluated.

5. Conclusions

This study evaluated the operational and regulatory boundaries of whole-tree hauling using a modified trailer in the U.S. South. Two modification designs were developed and evaluated, and the swinging gate design was selected for field testing due to its lower cost, lighter weight, and structural reliability. Trial load testing showed that the modified trailer could transport additional biomass, with about 14% of the load consisting of material that would otherwise be removed during conventional processing and could be

available for bioenergy use. Axle-weight analysis showed that the mean trimmed trailer tandem-axle weight exceeded the tandem-axle allowances reviewed for the southern states considered in the study. Additional axle capacity available through tridem configurations, forestry provisions, tolerances, or permits may improve transportation feasibility in some states, but the applicability of these provisions depends on the vehicle configuration, route, and state-specific regulations.

Overall, the study demonstrates that while modified trailers can enhance biomass recovery, practical implementation is primarily constrained by transportation weight regulations. The concept appears more suitable for pulpwood-sized material, where less trimming was required and crown material was more effectively contained by the swinging gates, and for regions with more flexible axle-weight policies. The framework developed here provides a quantitative basis for defining the operational and legal boundaries of whole-tree hauling in the U.S. South and can support decision-making for depot-based transportation systems.

Author Contributions: Conceptualization, J.L. and T.G.; methodology, A.Y., M.J.D., J.L. and T.G.; software, A.Y., M.P. and J.L.; validation, A.Y., M.J.D., T.G., T.M., D.M. and M.P.; formal analysis, A.Y. and J.L.; investigation, M.J.D., J.L. and T.G.; resources, T.G.; data curation, A.Y. and J.L.; writing—original draft preparation, A.Y., M.P. and M.J.D.; writing—review and editing, M.J.D. and M.P.; visualization, A.Y. and M.P.; supervision, T.G., T.M. and D.M. and M.P.; project administration, J.L. and T.G.; funding acquisition, T.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the U.S. Department of Energy, grant number DE-EE0006639.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: We thank Caterpillar Inc. and the Auburn University Agricultural Land and Resource Management Group for providing the equipment essential to this research. Resource Management Group provided the donated trailer but had no role in the study design, data collection and analysis, interpretation of results, preparation of the manuscript, or the decision to publish. We are grateful to David Crouch and Robert Sanders for their time and exceptional skill in operating the equipment and loading the modified trailer.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Appendix A.1

Table A1. State-specific vehicle dimensions and timber transportation length exemptions across 11 southeastern United States (2026).

State	Trailer/Semitrailer Length	Maximum Height	Maximum Width	Trailer Length and Overhang Exceptions for Timber/Forest Products
Alabama	17.37 m (57 ft)	4.11 m (13 ft 6 in)	2.59 m (102 in)	Poles, logs, lumber, and timber exempt from ordinary length limits.
Arkansas	16.31 m (53 ft 6 in)	4.11 m (13 ft 6 in)	2.59 m (102 in)	7.62 m (25 ft) rear overhang measured from center of rear tandem axle.
Florida	14.63 m (48 ft) standard; up to 17.37 m (57 ft) conditionally	4.11 m (13 ft 6 in)	2.59 m (102 in)	22.86 m (75 ft) maximum combined vehicle-and-load length for tree-length unprocessed logs; daytime operation and rear flags required.
Georgia	16.15 m (53 ft) standard; up to 22.86 m (75 ft) for qualifying extendable semitrailers	4.11 m (13 ft 6 in)	2.59 m (102 in)	30.48 m (100 ft) general combination limit on non-Interstate/NHS roads; rear projection beyond 1.22 m (4 ft) requires warning light and flags.
Louisiana	18.14 m (59 ft 6 in)	4.11 m (13 ft 6 in)	2.59 m (102 in)	20.11 m (66 ft) maximum forest-product load length; up to 6.09 m (20 ft) rear overhang beyond rear of bed or rear tire for natural-state products; daylight operation and flag required.

Mississippi	16.15 m (53 ft)	4.11 m (13 ft 6 in)	2.59 m (102 in)	8.53 m (28 ft) rear overhang beyond rear axle for natural-state forest/agricultural products.
North Carolina	16.15 m (53 ft)	4.26 m (14 ft)	2.59 m (102 in)	Forestry products exempt from general 4.26 m (14 ft) rear-overhang limit; flags/lights required beyond 1.21 m (4 ft).
South Carolina	16.15 m (53 ft)	4.11 m (13 ft 6 in)	2.59 m (102 in)	Poles/logs on qualifying pole or longwood trailers exempt from standard length limits; permit required for logs/poles exceeding 24.38 m (80 ft).
Tennessee	15.85 m (52 ft) kingpin-to-rear; axle-spacing conditions apply	4.11 m (13 ft 6 in)	2.59 m (102 in)	22.86 m (75 ft) maximum combined vehicle-and-load length for single-piece poles, logs, or timber; permit required above this limit.
Texas	17.98 m (59 ft)	4.26 m (14 ft)	2.59 m (102 in)	27.43 m (90 ft) vehicle-and-load limit for qualifying timber vehicles, excluding truck-tractor combinations; rear-overhang exemption applies.
Virginia	16.15 m (53 ft)	4.11 m (13 ft 6 in)	2.59 m (102 in)	19.81 m (65 ft) general length threshold; longer combinations allowed with semitrailer ≤16.15 m (53 ft) and kingpin-to-rear-axle spacing ≤12.49 m (41 ft); overlength tree-log permits available.

Notes: Values were compiled from state transportation statutes and Department of Transportation (DOT) regulations and guidance applicable in 2026 [38–48]. Dimensions are presented in SI units, with original U.S. customary units in parentheses. SI conversions were rounded down to avoid exceeding the original statutory limits. Timber-specific exceptions are subject to applicable operating conditions, route restrictions, and permit requirements. Extended length and overhang exceptions for unmanufactured forest products typically restrict travel to daylight hours only and mandate the use of regulatory warning flags, lights, or escort vehicles depending on the rear projection distance. NHS = National Highway System.

Appendix A.2

Table A2. Gross vehicle weight and axle-group weight limits for timber transportation across 11 southeastern U.S. states (2026).

State	Standard GVW, kg (lb)	Timber Allowance	Maximum Timber GVW, kg (lb)	Tandem Axle, kg (lb)	Tridem Axle, kg (lb)
Alabama	36,287 (80,000)	10% non-Interstate tolerance	39,916 (88,000)	16,329 (36,000) base at ≤8 ft spacing; 17,962 (39,600) with tolerance	19,050 (42,000) standard; 20,955 (46,200) including non-Interstate 10% statutory enforcement tolerance
Arkansas	36,287 (80,000)	Five-axle forest-product allowance; non-Interstate	38,555 (85,000)	15,422 (34,000) standard; 16,556 (36,500) forestry	19,050 (42,000) standard; 22,679 (50,000) including non-Interstate state-route allowance; 27,215 (60,000) including standard routine overweight permit allowance
Florida	36,287 (80,000)	Designated-route overweight permit	39,916 (88,000)	19,958 (44,000), including tolerance	19,050 (42,000) standard; 20,955 (46,200) including non-Interstate 10% standard scale tolerance
Georgia	36,287 (80,000)	10% qualifying forestry variance; non-Interstate	39,916 (88,000)	20,865 (46,000) for forestry	19,050 (42,000) standard; up to 27,215 (60,000) with routine overweight permit
Louisiana	36,287 (80,000)	Timber Harvest Season Permit; non-Interstate	41,730 (92,000)	16,782 (37,000) forestry base; 18,143 (40,000) with permit	19,050 (42,000) standard; 20,411 (45,000) including non-Interstate enforcement margin
Mississippi	36,287 (80,000)	2% GVW tolerance without harvest permit; 10% with permit	39,916 (88,000)	15,422 (34,000) standard; 18,143 (40,000) forestry base; 19,958 (44,000) with permit tolerance	19,050 (42,000) standard; 19,277 (42,500) including standard scale tolerance; 20,955 (46,200) including non-Interstate harvest permit allowance
North Carolina	36,287 (80,000)	Special forest-product exemption; non-Interstate	40,823 (90,000)	17,236 (38,000) standard; up to 19,958 (44,000) for qualifying combinations	No separate tridem cap; individual axles up to 11,793 (26,000) for qualifying combinations
South Carolina	33,239 (73,280)	15% forest-product tolerance; separate bulk-agricultural permit	38,225 (84,272) with 15% tolerance; 40,820 (90,000) with qualifying permit	16,329 (36,000) standard; 18,778 (41,400) with 15% tolerance	No separate tridem cap; individual axles limited to 10,432 (23,000)
Tennessee	36,287 (80,000)	10% enforcement margin for logging trucks; non-Interstate	39,916 (88,000)	15,422 (34,000) standard; 16,964 (37,400) including logging margin	19,731 (43,500) at 10 ft under Interstate bridge formula; state-road treatment differs

Texas	36,287 (80,000)	Annual Timber Permit; designated counties and routes	38,101 (84,000)	15,422 (34,000) standard; 19,958 (44,000) with permit	19,050 (42,000) general triple-axle cap, subject to spacing
Virginia	36,287 (80,000)	Forest-products overweight permit	40,823 (90,000)	15,422 (34,000) standard; 18,143 (40,000) with permit	22,679 (50,000) with forest-products permit

Note: Values were compiled from state transportation statutes, Department of Transportation regulations, and timber-hauling permit provisions applicable in 2026 [49–59]. Weights are presented in kilograms (kg), with original statutory values in pounds (lb) in parentheses. SI conversions were rounded down to the nearest whole unit to avoid exceeding the original statutory limits. In case of discrepancy, the original U.S. customary values govern. Maximum timber Gross Vehicle Weight (GVW) includes applicable exemptions, tolerances, and permits. Tridem axle limits reflect forestry-specific provisions where available; otherwise, general axle-group limits are reported. Allowable weights are subject to vehicle configuration, axle spacing, highway classification, and permit conditions. Forestry-specific weight extensions and variances typically apply only to non-Interstate state and county routes. All operations remain subject to local bridge weight postings and seasonal restrictions where applicable.

References

1. Trømborg, E.; Solberg, B. Forest Sector Impacts of the Increased Use of Wood in Energy Production in Norway. *For. Policy Econ.* **2010**, *12*, 39–47. https://doi.org/10.1016/j.forpol.2009.09.011.
2. Zhang, S.; Gilless, J.K.; Stewart, W. Modeling Price-Driven Interactions between Wood Bioenergy and Global Wood Product Markets. *Biomass Bioenergy* **2014**, *60*, 68–78. https://doi.org/10.1016/j.biombioe.2013.10.027.
3. *World Energy Transitions Outlook 2023*; The 1.5 °C Climate Pathway and Progress in the Energy Transition; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2025.
4. Stokes, D. Renewable Energy Federalism. *MinnLRev* **2022**, *106*, 1757. https://doi.org/10.24926/265535.4365.
5. Yu, A.; Daniel, M.J.; Chasuk, L.; Gallagher, T.; Pokharel, M.; Cristan, R.; Mitchell, D.; Parajuli, M. Forest Biomass Harvesting Operations' Costs and Production Rates in the Florida Coastal Plain: A Case Study of Two Sites. *Int. J. For. Eng.* **2026**, *37*, 366–374. https://doi.org/10.1080/14942119.2026.2686907.
6. McEwan, A.; Marchi, E.; Spinelli, R.; Brink, M. Past, Present and Future of Industrial Plantation Forestry and Implication on Future Timber Harvesting Technology. *J. For. Res.* **2020**, *31*, 339–351. https://doi.org/10.1007/s11676-019-01019-3.
7. McKendry, P. Energy Production from Biomass (Part 1): Overview of Biomass. *Bioresour. Technol.* **2002**, *83*, 37–46. https://doi.org/10.1016/S0960-8524(01)00118-3.
8. Kline, K.L.; Dale, V.H.; Rose, E.; Tonn, B. Effects of Production of Woody Pellets in the Southeastern United States on the Sustainable Development Goals. *Sustainability* **2021**, *13*, 821. https://doi.org/10.3390/su13020821.
9. Tuskan, G.A. Short-Rotation Woody Crop Supply Systems in the United States: What Do We Know and What Do We Need to Know? *Biomass Bioenergy* **1998**, *14*, 307–315. https://doi.org/10.1016/S0961-9534(97)10065-4.
10. Dickmann, D.I. Silviculture and Biology of Short-Rotation Woody Crops in Temperate Regions: Then and Now. *Biomass Bioenergy* **2006**, *30*, 696–705. https://doi.org/10.1016/j.biombioe.2005.02.008.
11. Barrette, J.; Achim, A.; Auty, D. Impact of Intensive Forest Management Practices on Wood Quality from Conifers: Literature Review and Reflection on Future Challenges. *Curr. For. Rep.* **2023**, *9*, 101–130. https://doi.org/10.1007/s40725-023-00181-6.
12. Drew, A.; Zsuffa, L.; Mitchell, C. Terminology Relating to Woody Plant Biomass and Its Production. *Biomass* **1987**, *12*, 79–82.
13. Moya, R.; Tenorio, C.; Oporto, G. Short Rotation Wood Crops in Latin American: A Review on Status and Potential Uses as Biofuel. *Energies* **2019**, *12*, 705. https://doi.org/10.3390/en12040705.
14. Helal, M.A.; Anderson, N.; Wei, Y.; Thompson, M. A Review of Biomass-to-Bioenergy Supply Chain Research Using Bibliometric Analysis and Visualization. *Energies* **2023**, *16*, 1187. https://doi.org/10.3390/en16031187.
15. Van Der Ven, H.; Bear, K. Sustainable Supply Chains in the Forest Bioeconomy: A Systematic Review. *Sustainability* **2025**, *17*, 9738. https://doi.org/10.3390/su17219738.
16. Gc, S.; Thapa, I.; Pokharel, R.; Alward, G.; Lamsal, B.; Poudel, J.; Dahal, R.; Joshi, O.; Parajuli, R.; Wagner, J.; et al. A Methodological Framework for Decomposing the Value-Chain Economic Contribution: A Case of Forest Resource Industries of the Lake States in the United States. *Forests* **2024**, *15*, 305. https://doi.org/10.3390/f15020305.

17. Howitt, C.; Ghaffariyan, M.R. Truck Configurations for Efficient Transportation of Forest Biomass: A Short Literature Review. *Silva Balc.* **2025**, *26*, 23–31. https://doi.org/10.3897/silvabalcanica.26.e138435.
18. Derochers, J.; Conrad, J.L.; Bolding, M.C.; Smidt, M.; Da Silva, B. Trucks-to-Trucks: A Comparison of the Raw Forest Products Transportation Industry and Other Forms of Commercial Trucking in the US South. *Int. J. For. Eng.* **2025**, *36*, 167–177. https://doi.org/10.1080/14942119.2024.2448936.
19. Conrad, J.L. Perceptions of Log Truck Weight Regulations Among Loggers and Forest Industry in Georgia, USA. *For. Sci.* **2022**, *68*, 53–62. https://doi.org/10.1093/forsci/fxab052.
20. Spinelli, R.; Visser, R.; Björheden, R.; Röser, D. Recovering Energy Biomass in Conventional Forest Operations: A Review of Integrated Harvesting Systems. *Curr. For. Rep.* **2019**, *5*, 90–100. https://doi.org/10.1007/s40725-019-00089-0.
21. Kuchler, C.; Schön, C.; Kuptz, D.; Dietz, E.; Zimmermann, D.; Rist, E.; Mack, R.; Riebler, M.; Blum, U.; Borchert, H.; et al. Fuel Upgrade and Soil Contamination Effects on Wood Chip Quality and Combustion Behaviour. *Biomass Bioenergy* **2024**, *183*, 107150. https://doi.org/10.1016/j.biombioe.2024.107150.
22. Ghaffariyan, M.R. Predicting Productivity of Timber Loading Operations: A Literature Review. *Silva Balc.* **2021**, *22*, 81–90. https://doi.org/10.3897/silvabalcanica.22.e69240.
23. Lamsal, B.; Poudel, J.; Pokharel, R. Regional Economic and Employment Impacts of Industrial Decline in the Forest Sector: Evidence from Sawmill Closures in Michigan. *For. Policy Econ.* **2025**, *178*, 103601. https://doi.org/10.1016/j.forpol.2025.103601.
24. Lancaster, J.; Gallagher, T.; McDonald, T.; Mitchell, D. Whole Tree Transportation System for Timber Processing Depots. In *Proceedings of the 2017 Council on Forest Engineering Meeting, "Forest Engineering, from Where We've Been, to Where We're Going"*; Southern Research Station: Asheville, NC, USA, 2017; Volume 807, pp. 1–7.
25. Pitts Trailers LT40-8L: Recessed Center Logging Trailer Available online: https://pittstrailers.com/wp-content/uploads/2022/04/LT40_8L_2022-1.pdf (accessed on 1 November 2026).
26. Clark, A., III; Saucier, J.R. *Tables for Estimating Total-Tree Weights, Stem Weights, and Volumes of Planted and Natural Southern Pines in the Southeast*; Research Division, Georgia Forestry Commission: Dry Branch, GA, USA, 1990.
27. Scheuter, F. *General Guide for Accurate Weighing with Portable Wheel Load Scales*; Loadometer Corporation: Timonium, MA, USA, 2008.
28. Pokharel, M.; Daniel, M.J.; Chappell, J. Are Trees Heavier Today? Re-Evaluating 1974 Transportation Weight Limits in the Context of Modern Forest Allometry. *Forests* **2026**, *17*, 815. https://doi.org/10.3390/f17070815.
29. Spinelli, R.; Magagnotti, N.; De Francesco, F.; Kováč, B.; Heger, P.; Heilig, D.; Heil, B.; Kovács, G.; Zemánek, T. Cut-to-Length Harvesting Options for the Integrated Harvesting of the European Industrial Poplar Plantations. *Forests* **2022**, *13*, 1478. https://doi.org/10.3390/f13091478.
30. Kalle, K.; Seuri, M.; Bradley, A.; Röser, D.; Pinto, C.; Dian, W.; Pandur, Z.; Dvořák, J.; Jørgensen, M.T.; Muiste, P.; et al. Overview of Global Long-Distance Road Transportation of Industrial Roundwood. *Croat. J. For. Eng.* **2024**, *45*, 217–236. https://doi.org/10.5552/crojfe.2024.2286.
31. Mușat, E.C.; Abutnăriței, G.L.; Hogea, D.D.; Miu, L.D.; Avram, V.N.; Saicu, Ș.; Derczeni, R.A. Loading Round Wood in Forestry Trucks and Forestry Platforms: A Case Study for Romania. *Forests* **2024**, *15*, 1646. https://doi.org/10.3390/f15091646.
32. Stoilov, S.; Zumbo, A.; Ustabasciev, C.; Angelov, G.; Papandrea, S.F.; Proto, A.R. Performance Evaluation of Long-Distance Road Transportation of Roundwood in Mountainous Conditions. *Forests* **2025**, *16*, 781. https://doi.org/10.3390/f16050781.
33. Malinen, J.; Nousiainen, V.; Palojärvi, K.; Palander, T. Prospects and Challenges of Timber Trucking in a Changing Operational Environment in Finland. *Croat. J. For. Eng.* **2014**, *35*, 91–100.
34. Trzciński, G.; Tymendorf, Ł. Axle Load of Round Wood Transport Vehicles in Relation to Wood Assortment. *Environ. Sci. Proc.* **2022**, *22*, 12.
35. Anttila, P.; Ojala, J.; Palander, T.; Väätäinen, K. The Effect of Road Characteristics on Timber Truck Driving Speed and Fuel Consumption Based on Visual Interpretation of Road Database and Data from Fleet Management System. *Silva Fenn.* **2023**, *56*, 10798. https://doi.org/10.14214/sf.10798.
36. Morneau-Pereira, M.; Alavi, M.A.; Gaudreault, J.; Nourelfath, M.; Ouhimmou, M. An Optimization and Simulation Framework for Integrated Tactical Planning of Wood Harvesting Operations, Wood Allocation and Lumber Production. In Proceedings of the 10th International Conference on Modeling, Optimization and Simulation, Nancy, France, 5–7 November 2014.
37. Han, S.-K.; Han, H.-S. Productivity and Cost of Whole-Tree and Tree-Length Harvesting in Fuel Reduction Thinning Treatments Using Cable Yarding Systems. *For. Sci. Technol.* **2020**, *16*, 41–48. https://doi.org/10.1080/21580103.2020.1712264.
38. 2025 Code of Alabama, Title 32, Chapter 9, Article 2, Section 32-9-20: Schedule of Restrictions. Available online: https://law.justia.com/codes/alabama/title-32/chapter-9/article-2/section-32-9-20/ (accessed on 20 October 2026).

39. 2026 Florida Statutes, Title XXIII, Chapter 316, Section 316.515: Maximum Width, Height, Length. Available online: https://www.leg.state.fl.us/Statutes/index.cfm?App_mode=Display_Statute&URL=0300-0399/0316/Sections/0316.515.html (accessed on 14 October 2026).
40. Code of Arkansas Rules, Title 27, Chapter V, Subchapter C, Part 111, Subpart 2, Section 111-208: Log Truck Exemption. Available online: https://codeofarrules.arkansas.gov/Rules/Rule?levelType=section&titleID=27&chapterID=224&subChapterID=274&partID=1006&subPartID=3917&sectionID=24176 (accessed on 16 October 2026).
41. 2025 Mississippi Code 1972, Title 63, Chapter 5, Section 63-5-19: Vehicle Length Limitations; Generally. Available online: https://law.justia.com/codes/mississippi/title-63/chapter-5/section-63-5-19/ (accessed on 4 October 2026).
42. 2025 Code of Georgia, Title 32, Chapter 6, Article 2, Section 32-6-24: Length of Vehicles and Loads. Available online: https://law.justia.com/codes/georgia/title-32/chapter-6/article-2/section-32-6-24/ (accessed on 4 October 2026).
43. Louisiana Revised Statutes, Title 32, Section 382: Length; Special Length Limits. Available online: https://www.legis.la.gov/legis/Law.aspx?d=88319 (accessed on 16 October 2026).
44. North Carolina General Statutes, Chapter 20, Section 20-115.1: Limitations on Tandem Trailers and Semitrailers on Certain North Carolina Highways. Available online: https://www.ncleg.gov/EnactedLegislation/Statutes/PDF/BySection/Chapter_20/GS_20-115.1.pdf (accessed on 20 September 2026).
45. 2025 South Carolina Code of Laws, Title 56, Chapter 5, Section 56-5-4070: Length of Vehicles; Limitations on Vehicle Combinations. Available online: https://law.justia.com/codes/south-carolina/title-56/chapter-5/section-56-5-4070/ (accessed on 22 September 2026).
46. 2025 Tennessee Code, Title 55, Chapter 7, Part 2, Section 55-7-202: Maximum Width and Height. Available online: https://law.justia.com/codes/tennessee/title-55/chapter-7/part-2/section-55-7-202/ (accessed on 20 September 2026).
47. 2025 Texas Statutes, Transportation Code, Title 7, Subtitle E, Chapter 621, Subchapter C, Section 621.204: Maximum Length of Semitrailer or Trailer. Available online: https://law.justia.com/codes/texas/transportation-code/title-7/subtitle-e/chapter-621/subchapter-c/section-621-204/ (accessed on 19 October 2026).
48. Virginia Department of Motor Vehicles Virginia's Size. *Weight and Equipment Requirements for Trucks, Trailers and Towed Vehicles*; Virginia Department of Motor Vehicles Virginia's Size: Richmond, VA, USA, 2024; p. 28.
49. Code of Alabama, Title 32, Chapter 9, Article 2, Section 32-9-20: Schedule of Restrictions. Available online: https://alison.legislature.state.al.us/code-of-alabama?section=32-9-20 (accessed on 20 October 2026).
50. 2025 Arkansas Code, Title 27, Subtitle 3, Chapter 35, Subchapter 2, Section 27-35-203: Single and Tandem Axle Load Limits—Definition. Available online: https://law.justia.com/codes/arkansas/title-27/subtitle-3/chapter-35/subchapter-2/section-27-35-203/ (accessed on 17 October 2026).
51. 2026 Florida Statutes, Title XXIII, Chapter 316, Section 316.535: Maximum Weights. Available online: https://www.flsenate.gov/Laws/Statutes/2026/316.535 (accessed on 17 October 2026).
52. 2025 Code of Georgia, Title 32, Chapter 6, Article 2, Section 32-6-26: Weight of Vehicle and Load. Available online: https://law.justia.com/codes/georgia/title-32/chapter-6/article-2/section-32-6-26/ (accessed on 13 October 2026).
53. *Louisiana Revised Statutes, Title 32, Section 386: Weight*. Available online: https://legis.la.gov/Legis/LawPrint.aspx?d=88325 (accessed on 20 October 2026).
54. 2025 Mississippi Code 1972, Title 63, Chapter 5: Size, Weight and Load. Available online: https://law.justia.com/codes/mississippi/title-63/chapter-5/ (accessed on 3 November 2026).
55. 2025 North Carolina General Statutes, Chapter 20, Article 3, Section 20-118: Weight of Vehicles and Load. Available online: https://law.justia.com/codes/north-carolina/chapter-20/article-3/section-20-118/ (accessed on 4 October 2026).
56. South Carolina Code of Laws, Title 56, Chapter 5: Uniform Act Regulating Traffic on Highways. Available online: https://www.scstatehouse.gov/code/t56c005.php (accessed on 16 October 2026).
57. 2025 Tennessee Code, Title 55, Chapter 7, Part 2, Section 55-7-203: Maximum Weight per Axle or Group of Axles Allowed—Exemptions for Heavy-Duty Tow and Recovery and Emergency Fire Suppression Vehicles. Available online: https://law.justia.com/codes/tennessee/title-55/chapter-7/part-2/section-55-7-203/ (accessed on 16 October 2026).

58. 2025 Texas Statutes, Transportation Code, Title 7, Subtitle E, Chapter 621: General Provisions Relating to Vehicle Size and Weight. Available online: https://law.justia.com/codes/texas/transportation-code/title-7/subtitle-e/chapter-621/ (accessed on 18 October 2026).
59. Code of Virginia, Title 46.2, Chapter 10, Article 18, Section 46.2-1148.1: Overweight Permit for Hauling Forest Products. Available online: https://law.lis.virginia.gov/vacode/title46.2/chapter10/section46.2-1148.1/ (accessed on 4 October 2026).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.