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Strategic asymmetry in a contractor-mediated forest biomass supply chain: Evidence from Central Slovakia

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Abstract: A reliable forest-biomass supply requires alignment among resource owners, processing contractors and energy users. This study examined governance and actor-specific strategic positions in a central Slovak chain comprising the state forest enterprise LESY SR, the contractor WorldWood and the Zvolen district-heating plant. Four management informants were interviewed using pre-tested semi-structured guides; the resulting factors were rated for impact (1–5) and importance (1–3), triangulated with documentary and operational evidence, and converted into weighted SWOT-TOWS coordinates. LESY SR ($x = 16$; $y = -61$) and the heating plant ($x = 36$; $y = -26$) occupied the strength-threat quadrant. WorldWood had a strong internal position ($x = 57$), but its external coordinate was boundary-sensitive: y ranged from −3 to 3 across the permitted importance weights for one corrected item. The chain was contractor-mediated and weakly integrated; principal system-level risks included seasonal mismatch, short-horizon tendering, price volatility, fuel-quality variability, and transport and storage costs. The contribution is to demonstrate that strategic asymmetry, rather than a lack of technical capacity, constrains coordination. Rolling volume forecasts, risk-sharing framework contracts, quality-based payment, regional inventory planning and interoperable traceability records are recommended. The study provides a replicable actor-level diagnostic for early-stage biomass-chain evidence.

Keywords: district heating; expert weighting; seasonal inventory; sustainability certification; tender procurement; TOWS analysis

Forest biomass can support renewable heat and regional bioeconomies, but its sustainability and competitiveness depend on more than feedstock availability. Origin, quality, moisture, transport distance, storage losses, conversion efficiency, and procurement rules jointly determine economic and environmental performance (Pandey, Erbaugh 2024; Palátová et al. 2022; Manrique et al. 2023). This interdependence is especially important for harvesting residues and low-grade wood, which are spatially dispersed and costly to handle.

Biomass logistics are subject to temporal and organisational uncertainty. Access to harvesting and residue generation does not necessarily coincide with winter heat demand, while variability in moisture content and particle size affects delivered en-

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ergy, transport efficiency, storage behaviour, and boiler operation. Transport, intermediate storage, and pre-processing can therefore determine whether a regional chain remains viable (Sperandio et al. 2021; Stanula et al. 2023). Resilience also depends on how responsibilities, information, and risks are distributed among resource owners, contractors, and final users (Dashtpeyma, Ghodsi 2021).

Research on forest-biomass systems has extensively addressed cost optimisation and technical logistics, yet operationally capable actors may still fail to coordinate when their strategic incentives diverge. Forest owners seek stable outlets and acceptable prices for heterogeneous material; contractors require equipment utilisation and sufficient margins; district-heating plants prioritise continuous deliveries, certified origin, and predictable fuel quality. Short-horizon tendering can preserve price competition but may weaken joint inventory planning and shift risk among actors. Stakeholder research consequently emphasises the need for region-specific governance arrangements rather than uniform technical solutions (Pagot, Andrighetto 2024; Navrátilová et al. 2021; Szarka et al. 2023).

Slovakia combines a substantial forest resource with established district-heating infrastructure, yet previous studies identify fragmented coordination and high sensitivity to logistics costs (Palátová et al. 2022; Gejdoš, Hitka 2024). In 2024, Slovak forest land covered approximately 2.03 million ha, and forest cover reached 41.4%. Reported deliveries of fuelwood biomass from forestry confirm the continued relevance of forest biomass for regional heat and energy systems (MARD SR 2025). Evidence remains limited on how the strategic positions of consecutive actors differ within a single empirical chain and how that asymmetry shapes feasible coordination measures.

This study does not aim to estimate the prevalence of these coordination problems in the Slovak forest-biomass sector. Instead, it uses a strategically relevant regional chain to identify how actor-level capacities and external exposures may become misaligned even when the technical supply chain remains operational. The objective of this study was therefore to analyse actor roles, governance and strategic alignment within a regional forest-biomass chain in central Slovakia. The original research focus was preserved through two research questions: RQ_1: What type of strategy is applied by individual members of the forest-chip supplier-customer chain? RQ_2: What type of management is implemented in the forest-chip supplier-customer chain?

MATERIAL AND METHODS

Study design and case selection. A purposive single-case design was adopted because material flows, procurement practices, infrastructure, and organisational decisions had to be interpreted within their regional context (Yin 2003). The case comprises three consecutive functions: LESY Slovenskej republiky, s.p. (LESY SR), the primary supplier of energy wood and residues; WorldWood s.r.o., a mobile chipping and logistics contractor; and the Zvolen plant of MH Teplárenský holding, a.s. (MHTH Zvolen), the final energy user. The case was selected because the actors are linked by recurrent biomass transactions and represent public resource management, private processing and logistics, and public district heating. Their operational characteristics are summarised in Table 1. The case-study locations and the approximate aerial distances between the indicated nodes are shown in Figure 1; these distances are provided for contextual orientation rather than route optimisation.

Data collection. Four management-level informants participated: one LESY SR representative responsible for trade and logistics; the director of MHTH Zvolen; a biomass-procurement specialist from the same plant; and one WorldWood representative. Interviews were conducted between December and March 2025 and lasted approximately 35–60 minutes. Interview guides were pre-tested with managers and covered resource availability, product quality, machinery, storage, transport, labour, contracts, seasonality, regulation, certification, prices, market risk and innovation. Interviews were audio-recorded and transcribed verbatim. The first author manually coded the transcripts in a structured spreadsheet; no specialised qualitative coding software was used. A follow-up rating questionnaire quantified the factors identified in the interviews. Secondary evidence included company reports, public databases, procurement information and operating data provided by the actors.

Coding and evidence triangulation. Interview statements were coded into the four predefined SWOT domains and consolidated into organisa-

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Table 1. Characteristics of the actors in the analysed chain

Actor	Function and ownership	Operational evidence	Market and sustainability interface
LESY SR	primary supplier; state enterprise	energy wood and residues sold at forest roads, landings, and dispatch sites; reported forest-biomass volume 137 344 m^3 in calendar year 2024; no own chip production	FSC, PEFC, and SURE; material supplied to contractors and other customers
WorldWood	processor and logistics contractor; private company	three mobile chippers; own transport; approximately 2 000 t storage; approximately 8 000 t purchased annually from LESY SR as company-reported operating evidence	PEFC and SURE; diversified customer portfolio; approximately 5% of the LESY SR volume delivered to MHTH Zvolen
MHTH Zvolen	final energy user; state-owned district-heating plant	two 20 MW biomass boilers; approximately 40 000–45 000 t of forest chips per heating season; approximately 5 000-6 000 t storage; 23 suppliers	SURE-certified suppliers; recurring tenders; target moisture 30–45% for delivered chips; company-reported average net calorific value of the combusted forest biomass: approximately 3.1–3.2 $MWh \cdot t^{-1}$

LESY SR – LESY Slovenskej republiky, s.p.; WorldWood – WorldWood s.r.o.; MHTH Zvolen – Zvolen plant of MH Teplárenský holding, a.s.; FSC – Forest Stewardship Council; PEFC – Programme for the Endorsement of Forest Certification

tion-specific factor labels. Equivalent statements were merged, while factors with materially different operational meanings were retained separately. The final factor sets were checked against documentary and operational evidence. This triangulation was used to test consistency across reported practices, quantitative operating characteristics and strategic judgements; it did not convert the purposive sample into a statistically representative survey.

Weighted SWOT-TOWS procedure. Each identified factor was assigned two values: an im-

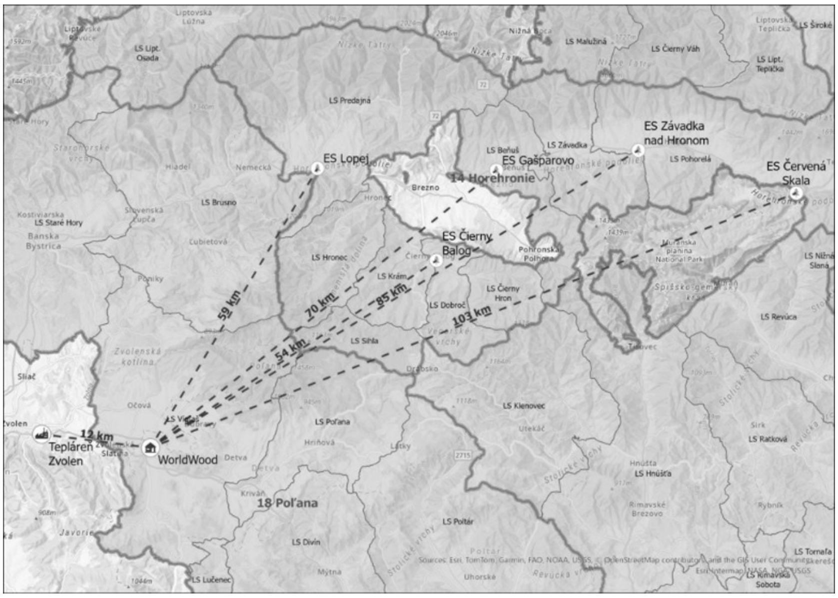

Figure 1. Location of the case study and indicative biomass-delivery distances in central Slovakia, focusing on Zvolen, Detva, Brezno and Revúca districts

Source: Authors' own elaboration based on the underlying map source (Esri, OpenStreetMap, LESY SR)

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pact score from 1 to 5, with 1 indicating the lowest and 5 the highest perceived influence, and an importance weight from 1 to 3, with 1 indicating low and 3 high importance. The weighted value of each factor was calculated as the product of the impact score and the importance weight. For each actor, the weighted values were summed separately for strengths, weaknesses, opportunities and threats. In the formulas, S denotes the total weighted score of strengths, W the total weighted score of weaknesses, O the total weighted score of opportunities and T the total weighted score of threats. The internal coordinate was calculated as $x = \Sigma S - \Sigma W$, and the external coordinate as $y = \Sigma O - \Sigma T$. Positive x indicates that strengths outweigh weaknesses, while negative x indicates that weaknesses prevail. Positive y indicates that opportunities outweigh threats, while negative y indicates that threats prevail. The final position of each actor in the SWOT-TOWS matrix was interpreted as follows: positive x and positive y indicate a strength-opportunity position; positive x and negative y indicate a strength-threat position; negative x and positive y indicate a weakness-opportunity position; and negative x and negative y indicate a weakness-threat position (Weihrich 1982). The scores should be interpreted as structured expert judgements derived from interviews and follow-up rating, not as statistically estimated parameters. The quadrant logic used for interpretation is shown in Figure 2.

Data-quality rule and sensitivity analysis. One WorldWood opportunity, an investment in energy-efficient technology, had an impact score of 3 and a recorded importance weight of 4, outside the declared 1–3 range. The primary analysis applied a transparent upper-bound rule and recoded the value to 3. Because this item influenced the sign of the external coordinate, a deterministic sensitivity analysis recalculated WorldWood's position at each permitted importance weight (1, 2 and 3). No inferential statistics were applied: the actor and inter-actor relationships were the unit of analysis, and the scores were treated as structured expert judgements rather than population estimates. The full actor-level factor matrices and the WorldWood sensitivity analysis are provided in Tables S1–S4 in the Electronic Supplementary Material (ESM).

Governance assessment. The chain was evaluated by assessing the allocation of ownership, processing, transport, procurement, quality control, and planning responsibilities. In this study, integrated governance means that consecutive actors jointly coordinate at least the main operational variables: planned delivery volumes, harvest and chipping schedules, pre-season inventories, target stock levels at the plant, quality parameters, responsibility for sampling and acceptance, and information transfer for certification and traceability. Weak integration was defined as a situation in which transactions are recurrent, but these variables are not jointly planned across the chain. Recurrent market transactions without joint planning for volume, inventory, or quality were

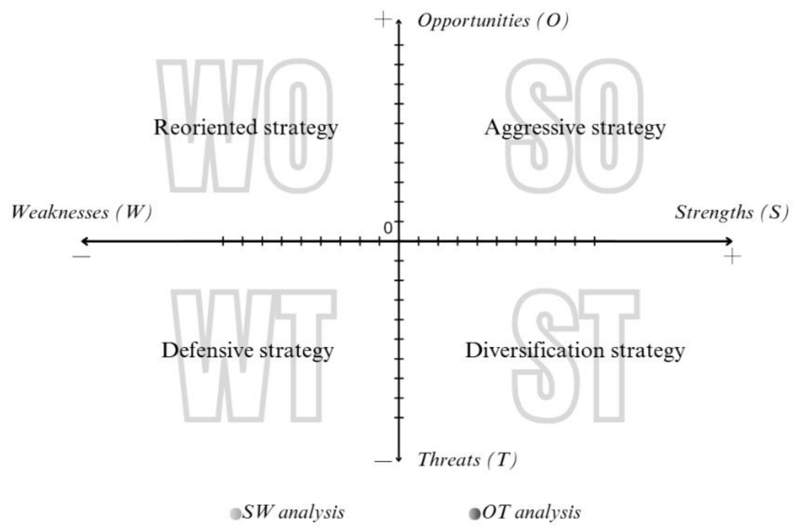

Figure 2. Quadrant interpretation of weighted SWOT-TOWS coordinates

Source: Authors' own elaboration based on Weihrich (1982)

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interpreted as weak integration. Recommendations were derived only where the same mechanism addressed an empirically identified factor and was supported by the supply-chain literature.

The methodological sequence is summarised in Figure 3. The diagrams in Figures 3 and 4 were prepared using Canva, a web-based graphic design platform.

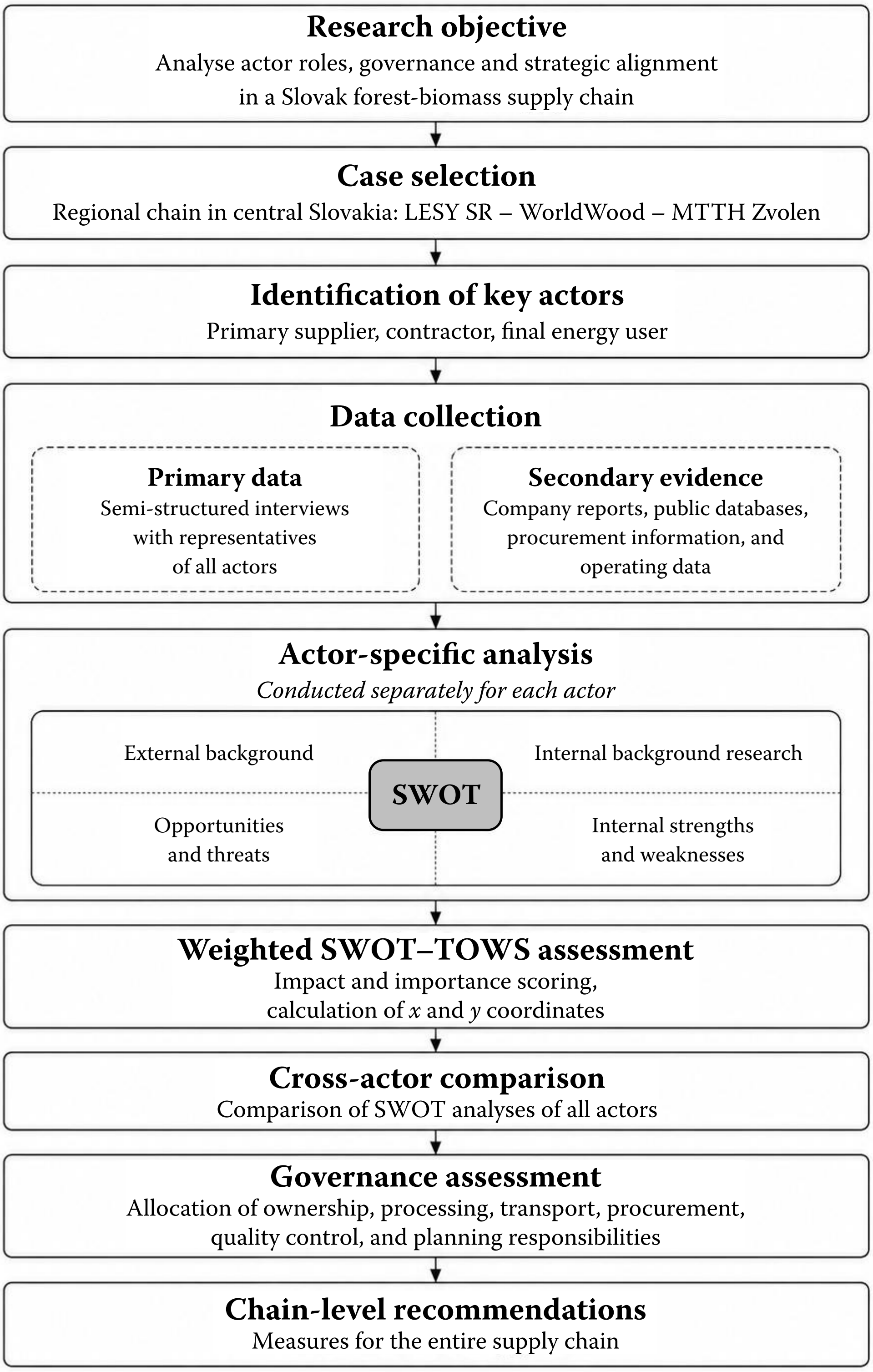

Figure 3. Methodological workflow of the case study

Source: Authors' own elaboration using Canva

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RESULTS AND DISCUSSION

Chain configuration and material flow. LESY SR sold energy wood, harvesting residues and processing residues at forest roads, landings and dispatch sites, but did not produce market-ready chips using its own chippers. WorldWood combined extraction, mobile chipping, transport and temporary storage. It reported purchasing approximately 8 000 t of biomass annually from LESY SR, of which only about 5% was delivered to MHTH Zvolen; the remainder was supplied to other customers. This diversified outlet structure reduced the contractor's dependence on a single plant. WorldWood considered approximately 50 km an operationally preferable delivery radius under local conditions, not a universal economic threshold. MHTH Zvolen operated two 20 MW biomass boilers, required approximately 40 000–45 000 t of chips during a heating season, and had storage capacity of approximately 5 000–6 000 t.

Procurement involved 23 suppliers, recurring competitive tenders, SURE-certified origin, and a target moisture range of 30–45% for delivered chips. The values expressed in cubic metres and tonnes are therefore not directly comparable, as the conversion from volume to mass depends on biomass assortment, wood density, degree of processing, and, especially, moisture content. Moisture is a key quality parameter for forest chips because it affects net calorific value, transport efficiency, and the actual amount of usable energy delivered to the plant. For this reason, the reported figures are interpreted as actor-specific operational indicators rather than directly convertible biomass quantities. LESY SR did not supply the plant directly; WorldWood and other intermediaries converted heterogeneous forest material into a tradable fuel and assumed responsibility for processing, transport, and delivery. The alternative operational variants identified in the case are summarised in Figure 4.

Actor-specific strategic positions. LESY SR recorded S = 62, W = 46, O = 35, and T = 96, yielding

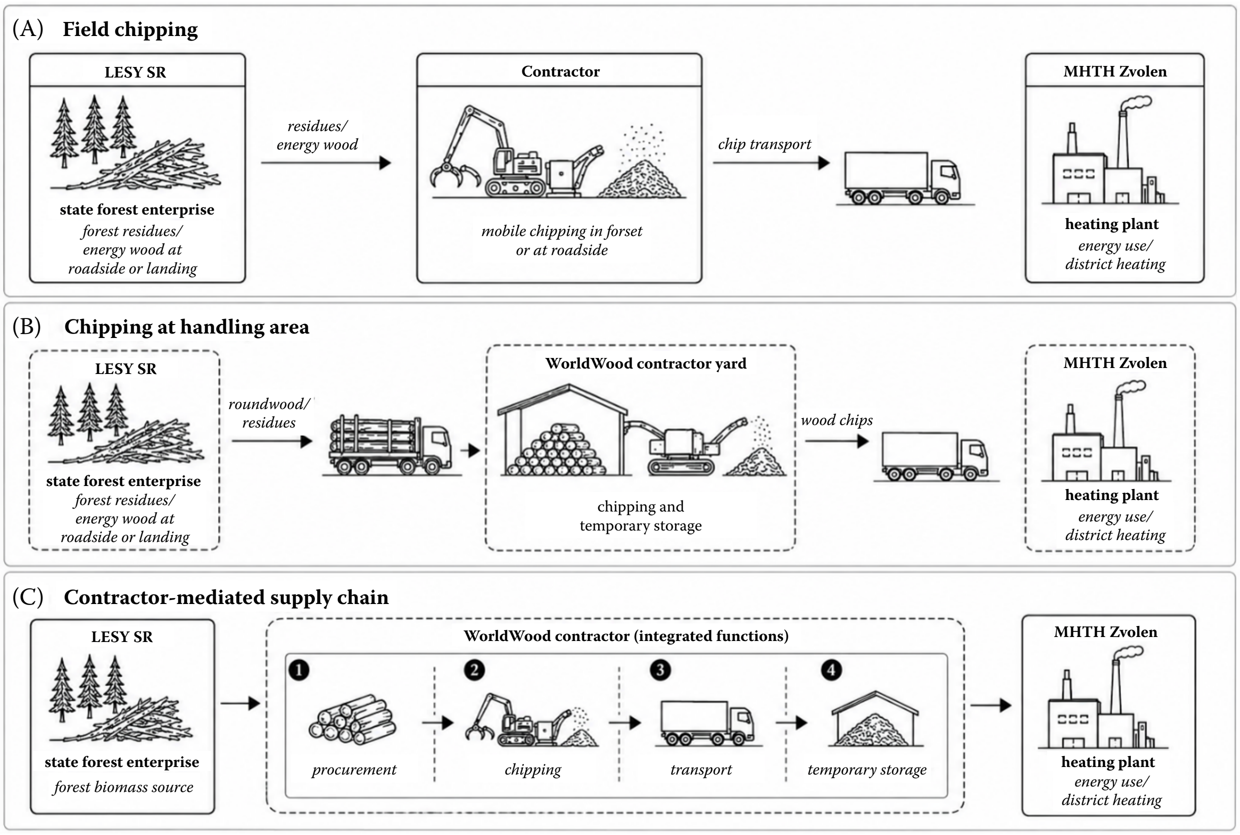

Figure 4. Operational variants of the analysed forest-biomass supply chain: (A) contractor-mediated delivery from LESY SR; (B) contractor-managed storage and outlet diversification; (C) multi-supplier procurement by the heating plant

Source: authors' own elaboration based on interviews and operational evidence using Canva

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x = 16 and y = –61 (Table 2). Biomass availability, reliable supply, infrastructure, and certification outweighed the lack of own chipping capacity and the mismatch between production and demand. The external position was substantially negative because off-season demand decline, storage and transport costs, seasonal inventory requirements, mild winters, and weather-related delays received high scores. Consequently, LESY SR occupied a clear strength-threat position. Its strategic priority is not resource expansion alone, but diversification of outlets, processing arrangements, and contract horizons.

MHTH Zvolen also occupied a clear strength-threat position (S = 101, W = 65, O = 20, T = 46; x = 36; y = –26). Diversified suppliers, extensive operating experience, certified procurement, emission-control technology, and technical readiness created a strong internal balance. However, raw-material availability, variable fuel quality, transport and processing costs, price instability, and regulatory change constrained the external environment. The result supports Proposition 1 for the plant and indicates that procurement resilience depends on supplier diversity, quality assurance, and pre-season inventory rather than on spot-price competition alone.

WorldWood had the strongest internal balance (S = 102, W = 45; x = 57), reflecting an integrated machinery chain, own transport, qualified personnel, repeat contracts, digitalised internal processes and certification. Under the upper-bound correction, O = 71 and T = 68 yielded y = 3, a strength-opportunity position. However, the sensitivity analysis produced y = –3, 0 and 3 at permitted importance weights of 1, 2 and 3, respectively. WorldWood must therefore be interpreted as lying on the opportunity-threat boundary rather than as a robust growth case. The strategic coordinates are visualised in Figure 5.

Actor-level strategic asymmetry as the central finding. The most important result is not the quadrant assigned to any single organisation, but the asymmetry between consecutive actors. The contractor can redirect material among customers and adjust operations, whereas LESY SR and MHTH Zvolen carry extensive fixed assets, public-sector obligations and greater exposure to seasonal demand. A chain-level intervention that maximises one actor's position may therefore increase another actor's risk. Coordination must share forecast, inventory, quality and price risks rather than transfer them to the intermediary. This interpretation aligns with stakeholder-based biomass studies showing that feasible strategies depend on local institutional conditions (Pagot, Andrighetto 2024; Szarka et al. 2023). It also strengthens the Slovak evidence reported by Gejdoš and Hitka (2024), who identify transport up to final consumption as a dominant cost component in forest-biomass logistics. The present case suggests that the same pressure is not only a cost problem but also a governance problem, because transport, storage and quality risks are allocated through contracts rather than managed jointly across the chain. Accordingly, the calculated coordinates constitute an indicative, time-specific diagnostic profile for this case rather than fixed or immutable empirical parameters.

Inventory, quality and logistics. Seasonal mismatch was the primary cross-actor constraint. Pre-season storage is necessary because heat demand peaks in winter, while harvest accessibility, chipping capacity and material availability fluctuate throughout the year. However, storage is costly and can reduce dry matter, particularly when moisture management is inadequate. Optimising drying and storage can lower supply-chain costs and greenhouse-gas emissions, but the net benefit depends on local access, terminal location, storage duration and demand timing (Acuña et al. 2022; Gautam et al. 2022).

Table 2. Weighted SWOT-TOWS scores and strategic positions

Actor	Internal scores	External scores	Coordinate and interpretation
LESY SR	S = 62; W = 46	O = 35; T = 96	x = 16; y = –61; clear ST position
WorldWood	S = 102; W = 45	O = 71*; T = 68	x = 57; y = 3; borderline SO position
MHTH Zvolen	S = 101; W = 65	O = 20; T = 46	x = 36; y = –26; clear ST position

*One recorded importance weight exceeded the 1–3 scale and was capped at 3 (the out-of-range value most likely resulted from a respondent's error in using the importance scale); across all permitted values for that item, WorldWood's y coordinate ranged from –3 to 3; S – strengths; W – weaknesses; O – opportunities; T – threats; SO – strength-opportunity; ST – strength-threat

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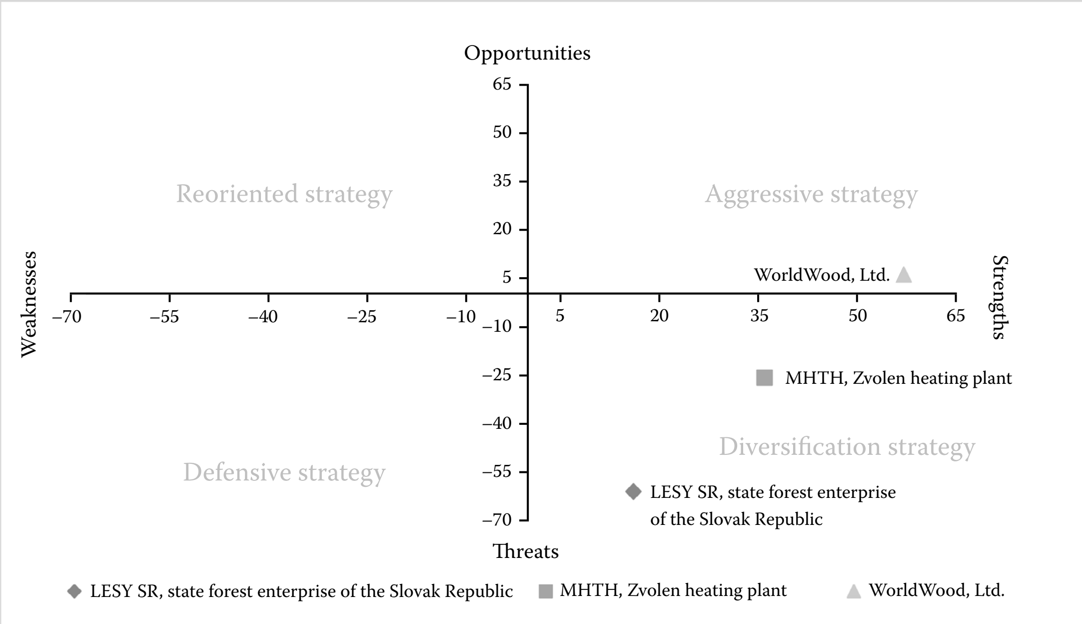

Figure 5. Strategic coordinates derived from the weighted SWOT-TOWS scores

WorldWood is shown at the corrected upper-bound; sensitivity analysis placed its external coordinate between −3 and 3

Quality-based procurement would better align incentives. Acceptance and payment should incorporate verified moisture or delivered-energy indicators, with responsibilities for sampling and rejection defined in the contract. The contractor's 50 km preference is consistent with evidence that biomass costs and emissions rise rapidly with distance, although the optimum depends on vehicle utilisation, road access, dry-matter losses and local supply density (Sperandio et al. 2021; Acuña et al. 2022). Regional sourcing and consolidated loads should be evaluated using actual cost and emissions data rather than adopted as an untested universal radius.

Certification and digital coordination. Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) support sustainable forest management at the resource stage, while SURE certification is required to access the heating-plant market. Their operational value depends on the consistent transfer of origin and delivery information between actors (Kożuch et al. 2024). A shared delivery record containing source, quantity, moisture, time of chipping, storage duration, vehicle and acceptance result would improve traceability and provide the data needed for forecasting, route optimisation and inventory control. Machine-learning tools should therefore be presented only as a future decision-support layer, after data standardisation, data ownership rules and routine quality records are in place. They should not replace managerial responsibility for procurement and logistics decisions (Zhao et al. 2024).

Coordination architecture. Table 3 links each empirical vulnerability to a specific governance response. Framework contracts should preserve competitive procurement while extending the planning horizon and setting volume corridors, indexation rules and quality-based adjustments. Monthly operational coordination should then translate the framework into rolling forecasts and stock targets. The proposed architecture is deliberately modular: it improves information and risk allocation without requiring vertical ownership integration. Implementation may nevertheless be constrained by public-procurement rules applicable to state-owned actors, which can limit the flexibility of multi-period or indexed contracts. Standardised moisture-based payment also creates administrative and transactional burdens related to sampling protocols, calibrated measurement, record-keeping and dispute resolution.

Governance and research-question assessment. RQ_1 explores the strategies employed by individual members within the forest-chip supply chain. LESY SR and MHTH Zvolen adopt strength-threat or diversification strategies, leveraging

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Table 3. Coordination architecture derived from the empirical findings

Empirical vulnerability	Evidence in the case	Coordination mechanism	Primary expected effect
Seasonal mismatch	Harvesting and processing are not jointly linked to winter demand.	rolling 3–6 month forecasts, pre-season stock targets, and delivery corridors	supply continuity and equipment utilisation
Price and tender exposure	Short-horizon tenders and input-cost volatility affect all actors differently.	multi-period framework contracts with indexation, floors/ceilings, and review clauses	more balanced risk allocation
Fuel-quality variability	Moisture and heterogeneous material affect transport, storage, and boilers.	standardised sampling and payment linked to verified moisture or delivered energy	higher procurement transparency and conversion efficiency
Transport and storage cost	Contractor prefers local deliveries; producer and plant face inventory costs.	regional sourcing, consolidated loads, and evidence-based terminal selection	lower cost and potentially lower emissions
Fragmented traceability data	Certification exists, but operational information is transferred separately.	shared digital delivery record for source, quantity, quality, time, storage, and acceptance	traceability, forecasting, and auditability

strong internal resources while facing high external risks. Meanwhile, WorldWood employs a flexible contractor strategy, balancing between growth and threat management. RQ_2 examines the management style in the chain, revealing a contractor-mediated, loosely integrated model. The actors are functionally linked, but coordination relies primarily on tenders, contracts, and bilateral deliveries, rather than joint planning of volumes, stock levels, quality, and delivery schedules.

Limitations. This study examined one regional chain and four purposively selected management informants. The scores reflect organisation-level expert judgements and are not statistical estimates of the Slovak sector. Individual-level repeated ratings were unavailable for reliability testing, and the WorldWood external coordinate was sensitive to a single corrected weight. Some operating data were company-reported and could not be independently audited. The study also did not quantify the financial or environmental effects of the proposed measures. The findings support analytical generalisation about coordination mechanisms, not prevalence estimates. Multi-case research should combine interviews with longitudinal data on volume, moisture, cost, distance, energy content and emissions. The mechanisms may be analytically transferable to neighbouring Central European settings, such as Czechia and Poland (Palátová et al. 2022; Wieruszewski et al. 2022), where comparable ownership, contracting and district-heating structures are present; they should not be assumed to apply to chains dominated by small private owners or vertically integrated enterprises.

CONCLUSION

The analysed chain had strong technical capabilities but weak strategic alignment. LESY SR and MHTH Zvolen occupied clear strength-threat positions, while WorldWood had a strong internal balance but lay on the boundary between strength-threat and strength-opportunity positions. The chain was mediated by contractors and recurring tenders, with no shared mechanism to synchronise harvesting, processing, storage and winter consumption. Based on first-round expert and documentary evidence, the chain indicates a coordination problem that warrants quantitative modelling. The study's contribution is to show that actor-level strength does not automatically produce chain-level resilience. Strategic asymmetry determines who can absorb seasonal, price, quality and logistics risk. A more resilient arrangement requires rolling forecasts, pre-season inventory planning, multi-period contracts with explicit risk-sharing rules, quality-based payment, regional logistics assessment and interoperable traceability records. These measures can be implemented without eliminating competition, but their effectiveness should be tested using longitudinal operational and environmental data across several Slovak biomass

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chains. These conclusions constitute an analytical generalisation from a single case, not a universal model for bioenergy chains. Their relevance beyond Slovakia depends on comparable ownership, contracting and district-heating structures.

REFERENCES

Acuña M., Sánchez-García S., Canga E. (2022): An optimization approach to assess the impact of drying and dry matter losses of Eucalyptus globulus roundwood and biomass on supply chain costs and GHG emissions. Forests, 13: 701.

Dashtpeyma M., Ghodsi R. (2021): Forest biomass and bioenergy supply chain resilience: A systematic literature review on the barriers and enablers. Sustainability, 13: 6964.

Gautam S., LeBel L., Rijal B. (2022): Integrating analytical hierarchical process and network optimization model to support decision-making on biomass terminal selection. Forests, 13: 1898.

Gejdoš M., Hitka M. (2024): Logistics analysis of the supply chain for forest biomass in Slovakia. LOGI – Scientific Journal on Transport and Logistics, 15: 20240015.

Kożuch A., Cywicka D., Górna A. (2024): Forest biomass in bioenergy production in the changing geopolitical environment of the EU. Energies, 17: 554.

Manrique S.M., Subelza C.R., Toro M.A., Quintero Bertel Q.R., Tauro R.J. (2023): Forest supply chain for bioenergy: An approach for biomass study in the framework of a circular bioeconomy. Energies, 16: 7140.

MARD SR (2025): Správa o lesnom hospodárstve v Slovenskej republike za rok 2024. Zelená správa. Bratislava, Ministry of Agriculture and Rural Development of the Slovak Republic: 74. (in Slovak)

Navrátilová L., Výbošťok J., Šálka J. (2021): Stakeholders and their view on forest-based bioeconomy in Slovakia. Central European Forestry Journal, 67: 240–247.

Pagot G., Andrighetto N. (2024): Fuel for collective action: A SWOT analysis to identify social barriers and drivers for a local woody biomass supply chain in an Italian alpine valley. Heliyon, 10: e38170.

Palátová P., Purwestri R.C., Marcineková L. (2022): Forest bioeconomy in three European countries: Finland, the Czech Republic and the Slovak Republic. International Forestry Review, 24: 594–606.

Pandey S., Erbaugh J.T. (2024): Driving sustainable uptake: A systematic review of global literature on policies governing woody biomass for energy. Discover Sustainability, 5: 28.

Sperandio G., Acampora A., Civitarese V., Bajocco S., Bascietto M. (2021): Transport cost estimation model of the agroforestry biomass in a small-scale energy chain. Forests, 12: 158.

Stanula Z., Wieruszewski M., Zydroń A., Adamowicz K. (2023): Optimizing forest-biomass-distribution logistics from a multi-level perspective – Review. Energies, 16: 7997.

Szarka N., García Laverde L., Thrän D., Kiyko O., Ilkiv M., Moravčíková D., Cudlínová E., Lapka M., Hatvani N., Koós Á., Luks A., Martín Jimenez I. (2023): Stakeholder engagement in the co-design of regional bioeconomy strategies. Sustainability, 15: 6967.

Weihrich H. (1982): The TOWS matrix – A tool for situational analysis. Long Range Planning, 15: 54–66.

Wieruszewski M., Górna A., Stanula Z., Adamowicz K. (2022): Energy use of woody biomass in Poland: Its resources and harvesting form. Energies, 15: 6812.

Yin R.K. (2003): Case Study Research: Design and Methods. 3rd Ed. Thousand Oaks, Sage Publications: 181.

Zhao J., Wang J., Anderson N. (2024): Machine learning applications in forest and biomass supply chain management: A review. International Journal of Forest Engineering, 35: 371–380.

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