Bois et Forêts des Tropiques – ISSN : L-0006-579X
Volume 362 – 2025 – p. 1-21
CHAÎNES D'APPROVISIONNEMENT EN BIOMASSE / RECHERCHE

Biomass supply chains for invasive alien trees in South Africa

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Photo 1.
Tree stems are bucked and piled up on the harvesting site.
Photo D. K. Ngwenya.

Doi : 10.19182/bft2025.362.a37616 – Droit d'auteur © 2025, Bois et Forêts des Tropiques – © Cirad – Date de soumission : 6 décembre 2024 ; date d'acceptation : 3 mai 2025 ; date de publication : 1er juin 2025.

Citer l'article / To cite the article
Pirard R., Ngwenya D. K., 2025. Biomass supply chains for invasive alien trees in South Africa. Bois et Forêts des Tropiques, 362 : 1-21. Doi : https://doi.org/10.19182/bft2025.362.a37616

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RÉSUMÉ

Chaînes d'approvisionnement en biomasse pour les essences forestières exotiques envahissantes en Afrique du Sud

Le défrichage et la restauration des terres envahies par des essences exotiques en Afrique du Sud sont stratégiques pour s'adapter au changement climatique. Les financements devenant insuffisants et les opérations de défrichage des essences exotiques ayant une efficacité limitée, les arbres étant laissés ou brulés généralement sur place, il y a lieu de privilégier les chaînes de valeur basées sur la biomasse. Cependant, la faisabilité financière des principaux produits d'intérêt (bioénergie et biochar) est contestée en raison d'une sous-optimisation des chaînes d'approvisionnement. Elles doivent être adaptées à une ressource dispersée, hétérogène et mal cartographiée. À cette fin, nous avons interrogé les principales catégories de parties prenantes sur la base d'un cadre analytique dérivé de la littérature. Nous avons validé nos résultats lors d'un atelier avec les parties prenantes. Il s'agit d'une première tentative d'étude et d'amélioration des chaînes d'approvisionnement basées sur les arbres envahissants, avec des résultats transposables à d'autres contextes. Nous constatons une gouvernance complexe des chaînes d'approvisionnement, sans coordination avec les programmes de défrichage des espèces exotiques, une diversité de modèles et des rapports mitigés sur la fluidité des interactions avec les propriétaires fonciers. Nous concluons par six recommandations : (i) création d'une association d'utilisateurs de biomasse (diffusion d'information et liens avec les acteurs publics) ; (ii) soutien aux grands utilisateurs de biomasse (potentiel d'innovation, certification de durabilité) ; (iii) financement centralisé (planification cohérente du défrichage des espèces exotiques) ; (iv) généralisation des plateformes collaboratives de paysage (amélioration de l'accès aux sites, soutien ciblé aux chaînes de valeur) ; (v) renforcement de l'application de la loi (réduction des coûts de transaction et renforcement du pouvoir de négociation des fournisseurs de biomasse) ; (vi) amélioration de la coordination entre les parties prenantes (articulation avec le défrichage des espèces exotiques, intégration accrue).

Mots-clés : bioénergie, biomasse, espèces exotiques envahissantes, logistique, chaîne d'approvisionnement, Afrique du Sud.

ABSTRACT

Biomass supply chains for invasive alien trees in South Africa

Clearing and restoring land invaded by alien trees in South Africa is strategic to adapt to climate change. As funding falls short of needs and alien clearing operations exhibit limited effectiveness while usually leaving or burning trees on site, there is a case for biomass-based value chains. However, financial feasibility for the main products of interest (bioenergy and biochar) is disputed due to sub-optimal supply chains. These must be improved to cope with a scattered, heterogeneous, and poorly mapped resource. To this aim, we surveyed key stakeholder categories based on an analytical framework derived from the literature and validated our results with a stakeholder workshop. This represents a first attempt to study and improve invasive tree-based supply chains with relevant results for other contexts. We find a complex governance of supply chains, without coordination with alien clearing programmes, a diversity of models, and mixed reports about the fluidity of interactions with landowners. We conclude with six recommendations: (i) establishment of a biomass users association (information dissemination and connections with public actors); (ii) support to large-scale biomass users (innovation potential, sustainability certification); (iii) centralised funding (consistent planning of alien clearing); (iv) generalisation of collaborative landscape platforms (improved access to sites, targeted support to value chains); (v) enhanced law enforcement (lower transaction costs and greater bargaining power for biomass suppliers); (vi) improved coordination between stakeholders (articulation with alien clearing, higher integration).

Keywords: bioenergy, biomass, invasive alien species, logistics, supply chain, South Africa.

RESUMEN

Cadenas de suministro de biomasa para árboles exóticos invasores en Sudáfrica

El desbroce y la restauración de tierras invadidas por especies exóticas en Sudáfrica son estratégicos para adaptarse al cambio climático. La financiación es insuficiente y las operaciones de desbroce de especies exóticas tienen una eficacia limitada, ya que los árboles suelen dejarse o quemarse in situ, es necesario dar prioridad a las cadenas de valor basadas en la biomasa. Sin embargo, la viabilidad financiera de los principales productos de interés (bioenergía y biocarbón) es cuestionable debido a la suboptimización de las cadenas de suministro. Estas deben adaptarse a un recurso disperso, heterogéneo y mal cartografiado. Con este fin, hemos encuestado a las principales categorías de partes interesadas basándonos en un marco analítico derivado de la bibliografía. Hemos validado nuestros resultados en un taller con las partes interesadas. Se trata de un primer intento de estudiar y mejorar las cadenas de suministro basadas en árboles invasores, con resultados transferibles a otros contextos. Observamos una gobernanza compleja de las cadenas de suministro, sin coordinación con los programas de desbroce de especies exóticas, una diversidad de modelos y resultados dispares sobre la fluidez de las interacciones con los propietarios de las tierras. Concluimos con seis recomendaciones: (i) creación de una asociación de usuarios de biomasa (difusión de información y vínculos con los actores públicos); (ii) apoyo a los grandes usuarios de biomasa (potencial de innovación, certificación de sostenibilidad); (iii) financiación centralizada (planificación coherente de la eliminación de especies exóticas); (iv) generalización de las plataformas colaborativas de paisaje (mejora del acceso a los sitios, apoyo específico a las cadenas de valor); (v) refuerzo de la aplicación de la ley (reducción de los costes de transacción y refuerzo del poder de negociación de los proveedores de biomasa); (vi) mejora de la coordinación entre las partes interesadas (articulación con la eliminación de especies exóticas, mayor integración).

Palabras clave: bioenergía, biomasa, especies exóticas invasoras, logística, cadena de suministro, Sudáfrica.

Introduction

Efforts to clear and restore land invaded by alien trees are strategic in South Africa due to adverse impacts on biodiversity, water supplies, fire hazards, and land productivity (O'Connor and van Wilgen 2020; SER 2020; Everson et al. 2014; Ndhlovu et al. 2011; Le Maitre et al. 2002). The negative impacts generated by invasions are assumed to be rapidly increasing in the context of climate change (IPCC 2022). In turn their eradication has been assessed as an effective strategy to adapt to climate change, mostly due to their pressure on the availability of water for productive uses and consumption (Holden et al. 2022). Indeed, the reduction in water availability due to tree invasions is significant according to measurements (Rebelo et al. 2022). For these reasons, they feature in the National Climate Change Adaptation Strategy of South Africa (DFFE 2019).

Despite such a consensual view, governmental programmes targeting tree invasions lack effectiveness, and funding falls short of needs (Potgieter et al. 2019; van Wilgen et al. 2016; van Wilgen et al. 2022). One avenue to expand clearing activities and restoration is the involvement of the private sector to develop value chains that process the biomass generated from clearing operations.

The fact that bioenergy and biochar could be produced at scale using invasive alien trees points to the potential win-win situation for climate change mitigation and economic development. Indeed, biochar enables long-term carbon storage, and bioenergy reduces emissions by substituting fossil fuels, which in turn opens the door for the distribution of incentives through carbon pricing mechanisms (Pirard et al. 2025).

However, while the idea of developing such value chains is not novel and has been an objective of the Working for Water programme (WfW – the main funder of alien clearing operations), it never took off due to the lack of competitiveness of the value chains, as the substantial supply costs for biomass jeopardise their feasibility (Ward et al. 2017). Arguably there is a lack of reliable information on supply costs, as published studies often overlook the cost issue with undocumented average values (Vera et al. 2022). Yet a report based on comparative field research concludes: "*there is a significant cost range for the preparation and harvesting* [. . .] *alternative sites will need to be studied to capture a range of tree sizes, stem counts, canopy densities, species and potential products*" (Shuttleworth and Ackerman 2009: 36-37).

Overall, these costs are assumed to be significant because of the characteristics of the source of feedstock, which is scattered, poorly mapped, uncertain over time, heterogeneous, of various densities, among other factors (Pirard 2023). Invasive species in unmanaged land (natural propagation) are a very specific source of feedstock, which differs from commercial plantation forestry because land ownership is split across a diversity of actors of varied nature (public, private, community). Long-term management plans and permits are non-existent, and there is a lack of contiguous plots at scale for biomass of relatively low value. It also differs from the use of biomass residues because alien clearing is expected to be a one-off operation so that the suppliers cannot rely on transport infrastructure networks and pre-processed material, as would be the case for residues from forestry operations or agriculture.

Suppliers could lower the overall costs by improving the supply chain model, which depends on the types of actors involved and their coordination, the logistics including transport and storage, the articulation with alien clearing-focused programmes, and other elements that shape the organisation of biomass supplies. Research is underway on important aspects such as the mapping of available biomass, e.g., the ongoing Mapping Woody Invasive Alien Plant Species (MAPWAS) project (Rebelo et al. 2023).

To our knowledge, no study has ever been published on such supply chains in any country, including how they operate, their levels of efficiency and margins for improvement. What might appear closest to the characteristics of biomass collection from unmanaged invasive alien trees is the case of forestry residues from salvage/sanitary harvests (and maybe thinning operations to a lesser extent). Indeed, the latter operations are opportunistic and unplanned, partially random (with no control over location), relatively costly, variable in quality and volumes, subject to seasonality and storage issues, and may involve a wide range of producers if one aims at significant volumes over time (Mansuy et al. 2018).

In this article, we aim at (i) describing the various supply chain models in South Africa for the use of biomass from unmanaged invasive alien trees by value-added industries, and (ii) determining how to achieve significant efficiency gains and associated cost reductions.

Methods

Our approach is presented in figure 1. A literature review underpins the design of an analytical framework and questionnaires for key stakeholder categories. In turn, results from the field survey are validated with a stakeholder workshop before generating a series of recommendations.

Literature review

For the literature review, which addresses specifically the supply chain models and other related issues in the framework of invasive alien species, we made the following searches with a selection based on abstract screening:

- on Google Scholar on the 29th of May 2023:
  - o "invasive" AND "supply" in title, 94 hits;

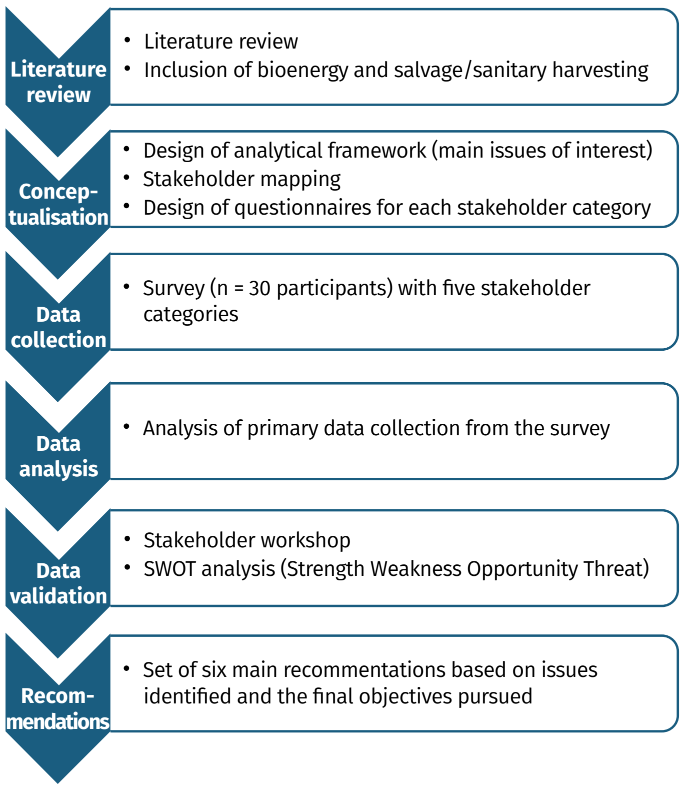

Figure 1.
Methodological workflow.

- o "supply chain model" AND "invasive species" AND "forestry" AND "costs" in text, 889 hits;
- on Web of Science (WoS) on the 1st of June 2023:
  - o "invasive" AND "species" AND "supply chain" AND "costs", 2 hits;
  - o "invasive" AND "species" AND "supply chain", 45 hits;
  - o "invasive" AND "forest" AND "supply", 226 hits.

Our inclusion criteria are: supply chain models are addressed AND deals with invasive tree species. Our exclusion criteria are: does not address supply chain models specifically OR deals with marine species or animals.

The abovementioned searches on Google Scholar and WoS did not provide a single reference meeting all our inclusion and exclusion criteria, so we had to extend our search in two ways: firstly, by being more flexible and keeping useful yet more general references (not specific to invasive species) on issues associated with optimal supply chain models and bioenergy; secondly, by extending the search to the case of salvage harvests (e.g., after fires) that shares characteristics with unmanaged invasive species.

The extended scope was addressed with the following search on the 1st of June 2023 using the Web of Science: "salvage harvest" and "supply chain", 15 hits, and 5 relevant references. Eventually, and considering the above, we based our literature review and design of the analytical framework on 6 references about logistics in bioenergy supply chains, 5 references about salvage harvesting models and 3 references on other specific cases.

Insights from the literature and analytical framework guiding the survey design

The literature review, combined with our own experience in South Africa, leads to the identification of problems and solutions associated with supply chains (appendix 1-table 1I). In turn, it provides insights for the analytical framework that underpins the questionnaire design (appendix 1-table 2). It is suggested that optimal supply chain models can address three complementary sets of problems: (i) optimal location and transport logistics (e.g., with additional storage facilities); (ii) the ability to manage uncertainties regarding biomass availability and characteristics (e.g., with rapid information dissemination systems); and (iii) effective governance in the access to biomass (e.g., with fluid networks and deals).

Data collection

All interviews (45 minutes – 2 hours each) were conducted either in-person or on the telephone with individuals involved in different stages of the alien biomass in South Africa. The open-ended questionnaires are presented in appendix 2 and were administered to 30 respondents from five stakeholder categories (table I). The research participants were individuals we identified as knowledgeable about alien biomass supply chains, selected through our network using a snowball sampling process, and involved in clearing invasive alien plants as well as collecting and processing the resulting biomass. Note also that all interviews were anonymous and a consent form was signed by all respondents.

We presented preliminary results during a workshop on the 27th of March 2024 with 12 participants representing all categories of stakeholders. A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was performed, then followed by a Threats, Opportunities, Weakness, and Strengths (TOWS) analysis that goes one step further and looks to match up the strengths with opportunities and weaknesses with threats. This allowed us to test and refine our preliminary analysis of results and identify strategic options for the discussion section. Both SWOT and TOWS sessions were conducted by workshop participants as two separate groups representing either private-orientated interests or public/civil society-orientated interests.

Table I.
Stakeholder categories, definitions and sample size.

Stakeholder category	Definition	Mode of Data collection and sample size
Landowners (and land managers)	It includes landowners and institutions with a mandate to manage the land (e.g. nature reserves and protected areas). Their role varies from passive when providing access to biomass suppliers upon request, to pro-active when involved in biomass processing and/or its use.	In person interviews (n = 2) Online interviews (n = 4)
Biomass suppliers	Entities that collect and supply the biomass to users. They come in many sizes and with varying levels of formality. When supply operations are internalised by biomass users then they fall into the latter category.	In-person interviews (n = 3) Online interviews (n = 4)
Biomass users	It includes processors of the biomass as an intermediate input for further marketing or own use, hence it excludes end-users because we are interested in supply chain models logistics and not value chains. We define "processing" as a significant operation required for the use of biomass in an industrial process or for its marketing, e.g. packaging for firewood sales but not debarking. Chipping is an ambiguous case because chips are prevalent in value chains and are both an intermediate (e.g. before making pellets) and consumption good (e.g. mulch). We classify chip producers either as biomass suppliers or users (internalised) because to our knowledge no company buys biomass to sell chips.	In person interviews (n = 3) Online interviews (n = 3)
Collaborative landscape platforms	It includes associations of landowners that coordinate land management activities. We can mention irrigation boards, water users associations and conservancies as the main examples.	In person interviews (n = 2) Online interviews (n = 2)
Mandators / funders	It includes actors that fund land clearing operations but do not have a direct financial stake in the supply chain. Landowners are not included because they only operate on their own land and are interviewed in their landowners capacity.	In-person interviews (n = 5) Online interviews (n = 2)

Photo 2.
Tree stems are gathered before bucking.
Photo D. K. Ngwenya.

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Results from the survey

Governance of supply chains is complex and unstable

While the structure of supply chains shows variations between cases and depends particularly on the level of maturity and volumes involved, we can provide a framework inclusive of all reported cases (figure 2). One striking feature lies with their complexity, which in turn is assumed to lead to inefficiencies with associated transaction costs. This complexity is not only due to the many actors involved but also to their changing nature: e.g., an NGO could change roles from funder to supplier depending on cases, and landowners can be users of the processing biomass collected on their property.

The core of the supply chain architecture is made of landowners that provide access to biomass suppliers. Other actors may also contribute – for example, through collaborative landscape platforms (typically associations of landowners) to coordinate actions, or via public agencies and programmes that provide funding and mandate alien clearing operations. Other actors at the national level (mainly NGOs) also contribute by participating in alien clearing and, less frequently, by supplying biomass. They could engage with collaborative landscape platforms (or other local actors such as Biosphere Reserves) hence adding another level of coordination among stakeholders at the landscape level, and connect to foreign bodies for funding (e.g., Overseas Development Assistance).

In terms of stickiness, i.e., the level of stability of relationships between actors along the chain, our limited number of respondents may not provide sufficient information to conclude. But they suggest that stickiness is low because suppliers frequently change locations and tend to serve different users; small companies come and go, with only a few well-established firms remaining; public programmes that fund alien clearing face financial uncertainties, administrative hurdles, and rarely operate at full scale; and local and international support sources typically function on a project basis.

Associations of landowners – defined as « collaborative landscape platforms » – are assumed to increase the efficiency of operations significantly. This is mainly due to their ability to organise operations across a broader landscape compared to working with individual landowners, but also because they serve as a much more effective interlocutor – and, for some funders, a required one – when negotiating access to the resource. Besides, their pro-activity supports the integration of their landowners into supply chains.

In theory, biomass users face two contrasted options: outsourcing (external operators are paid for the deliveries

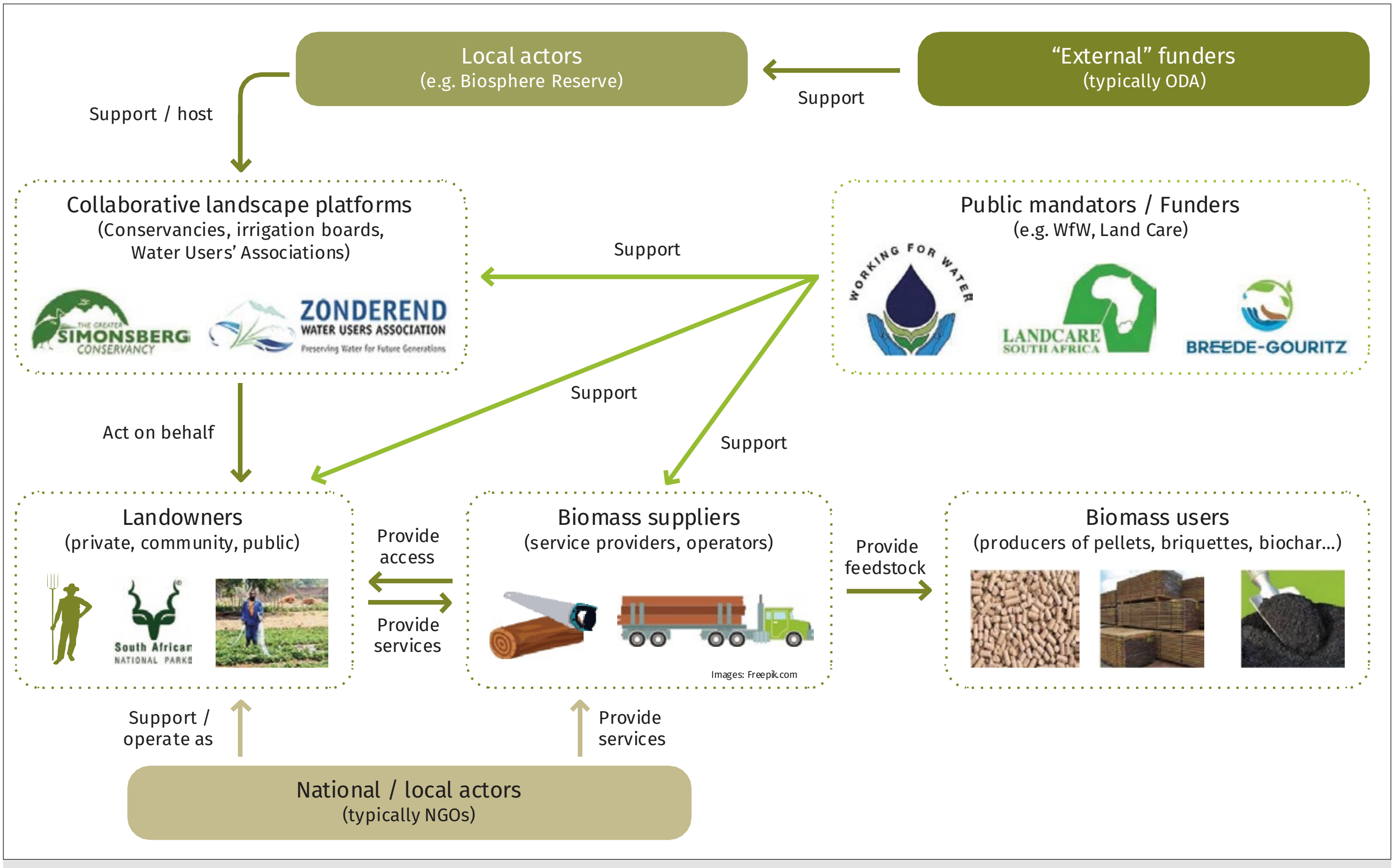

Figure 2.
Architecture and governance of supply chains.

to the factory) or internalising the supply process. In practice, we observe a clear trend towards outsourcing. The main reason is the associated convenience, as biomass users prefer to focus on their main activity, and being responsible for supplies is perceived as a liability and time-consuming. Yet an important observation is that a middle ground is favoured by key actors who co-design the supply strategy with an external company and follow operations very closely. This allows them to secure continued access to the feedstock under specific conditions related to operational quality and sustainability, without bearing the burden of directly managing supply operations.

The density of small, medium, and micro enterprises (SMMEs) active in harvesting and selling biomass varies among locations, while the informal actors involved in biomass collection, but without legal registration, are prevalent. The latter are mostly involved in the dynamic firewood sector to meet heating and cooking needs. Micro enterprises may be formally established but often fail to meet all the requirements set by funders and biomass users – such as quality of work and labour conditions – resulting in a perceived lack of reliability. The low degree of formalisation in the sector may partly explain the absence of a clear market price for biomass, which is reportedly based on case-by-case negotiations and only loosely refers to a standard price.

All respondents stated that only formal labour is used both for alien clearing programmes and industry-based value chains. This is probably due to a bias resulting from the inclusion of formal actors and programmes only in our survey. We acknowledge the presence of cases with varying levels of compliance with the law, including entities that tend to fly under the radar because these were always reported on the side of interviews. In this respect, we must also note that state-issued permits are not required on private land and communal land for operations to take place, which suggests a lack of monitoring by public authorities.

Coordination with alien clearing programmes and information management are poor

Although the availability of information on biomass resources such as standing trees (invaded areas) and logged trees (alien clearing areas) is key to value chain establishment, we find that this information is either non-existent or embryonic. While national maps have been created (e.g., Kotzé et al. 2010) and updated for further dissemination in open access mode, and specific projects past and present provide local maps using various methods (e.g., Holden et al. 2020), these efforts remain partially unsuitable for decision-making because of their scope and/or insufficient level of detail. A more useful approach would be to select large enough and highly relevant areas to produce maps that include estimations of biomass volumes and the species involved.

Currently, biomass suppliers report using existing national maps or an online tool with aerial imagery and cadastral information to have a first, superficial, and often outdated view of the resources. But the real means to generate useful information are the boots on the ground, driving and exploring the landscape and using networks of farmers mostly. This is costly and largely unreliable to have a comprehensive and accurate enough assessment of the situation to make informed decisions on investment and the planning of clearing operations. Sometimes, suppliers adopt a strategy to operate in visible areas, for instance, along main roads, to gain visibility and reputation credentials.

Although a key condition for affordable and successful supply chains would be to combine land clearing for restoration purposes and biomass collection and supplies, their respective environmental and economic criteria for site selection show limited overlaps. The economic aspects prevail for suppliers: distance to markets, high density of trees, topography and access, type of species, and tree characteristics (age, shape) relative to buyers' requirements. Environmental considerations prevail for control-orientated programmes such as the low density of invasions and, most importantly, the expected returns on key services such as water management, biodiversity conservation and fire risks. For instance, high densities are favoured by economic actors, while low densities are more valuable for invasion control. This might explain partly the lack of coordination.

Yet a reason for hope is that site selection is done with information at various scales, which provides flexibility. A meaningful example is with water management: targeting quaternary catchments provides coarse indicators as to where to operate, while finer analysis points to specific plots within such catchment areas or riparian invasions. The scale of the indicators that translate criteria into areas is thus hugely influential in the decisions made for the plots where operations take place. Therefore, coarser indicators would provide the means to align the objectives of suppliers and funders by defining broad areas of interventions further refined to meet both objectives, for instance, operating in plots near road infrastructures and with high enough tree densities within a priority catchment.

Our survey documented that alien clearing for invasion control leads to diverse types of biomass handling after logging. The biomass can be burnt on-site, pre-processed into chips or into small logs before being dumped away, stockpiled, and left on-site and available for informal firewood collection, or trees left on the ground. While it is difficult to identify a rule of thumb, biomass handling is a financial burden, and the lack of available budget may determine many decisions. In turn, this situation reinforces the need for better coordination; indeed, biomass removal serves the double purpose of completing alien clearing operations and supplying market actors.

This is all the more critical to address, as the survey demonstrates inadequate articulation and coordination between all actors. Some connections exist with alien clearing programmes in an *ad-hoc* manner (e.g., personal connections); however, there is no systematic approach to share information. It would be beneficial for large-scale operations if alien clearing programmes partnered with well-established companies involved in biomass value chains.

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It was reported that contractual challenges impede the replication of collaborations, e.g., when biomass is classified as an "asset" that cannot be exploited without specific contracts or when conservation area managers require a formal Memorandum of Understanding. Generally speaking, there is a lack of interest by investors in the invasion control programmes because the paperwork involved is burdensome; proactiveness is also lacking. However, recent experiments took place to design contracts with biomass suppliers that could overcome regulatory barriers and to reduce the financial burden for biomass removal.

The views of suppliers on the availability of biomass are contrasted: the more flexible the end product in terms of biomass quality and type, the less the concern about biomass availability. The views of biomass users are also contrasted: while the type of product plays a similar role as for suppliers, the supply model and strategy (e.g., dealing with a few large landowners with exclusive access to large resources) also determine perceptions. There is an interesting paradox that the larger the scale of the operations, the less concern there is about biomass availability. Indeed, larger-scale operations provide the financial and technical means to have better assessments of existing resources, greater efficiencies with higher acceptable access costs, and better bargaining power with landowners and suppliers.

Integration of value chains, and logistics, can be improved

Transportation has lots of potential for increased efficiencies with greater integration with other value chains. Transportation costs could be halved if trucks were to be used both ways. It was also reported that bigger trucks are another option with a walking floor enabling up to 100 m^3 compared to the biggest ones in operation with about two-thirds of that capacity. But this is certainly only the most visible inefficient part of the whole logistical system.

The harvesting stage offers a contrasted picture according to respondents who expressed doubts that breakthroughs could ever take place for techniques and equipment. Training is essential to making a difference, alongside wages. It is common for wages to be so low that worker turnover is high, as many leave for better opportunities, often on farms. Planning and budget allocation are also instrumental in ensuring that operations unfold smoothly and bottlenecks are avoided. Last, biomass handling offers significant opportunities, e.g., at the wood preparation stage, once trees are logged and the wood is cut into logs, then stockpiled not only near the road access but also in such a way that loading on the trucks is efficient.

Logistics also includes storage facilities. Respondents usually consider that the current situation is satisfactory

Photo 3.
Trees are sometimes chipped on the harvesting site.
Photo D. K. Ngwenya.

and that either harvesting sites or factories can be used as temporary log yards and storage facilities for chips. However, they also say this might change when capacities expand; the alignment of constant flows of feedstock for processing with biomass collection and supply might require a better storage strategy. This component will certainly have to be addressed more actively when biomass use increases significantly with more players and less certainty to access new sites.

We also report risks and challenges caused by increased efficiency goals. It may be tempting for suppliers and buyers to cut costs with sub-optimal practices related to follow-up treatments such as herbicide application and repeated clearing of seedlings over several years (soil compaction might also be an issue at the harvesting stage). Moreover, priority sites for invasion control are not the same as for affordable biomass supplies. These aspects illustrate that more trade-offs may be expected than win-win situations.

Overall, supply chains are a mix of professional and well-established companies on one side and relatively informal actors with limited capacities and human resources on the other side. Biomass users investing in large-scale capacities do rely on the former, but other emerging and lower-scale businesses have some connections with the latter to make up for supply shortages.

All cases are different due to access, species, ownership and other factors

The three main industries driving the biomass markets are agriculture (mulch, biochar, animal beddings/wood shavings, non-chemical fertilisers), construction (furniture, poles, flooring), and bioenergy (pellets, briquettes, charcoal, firewood). However, which biomass is valuable in each of these industries depends on its properties (e.g., species, shape, age) with varying degrees of requirements and complementarities: by-products of one industry can be used by another, and one site can provide biomass for several value chains (figure 3). In theory, in a site with big trees, the trunks and bigger straight logs are used as poles for construction, while small branches are chipped to produce briquettes, animal bedding or mulch, and small logs are packaged as firewood. Unfortunately, it seems these industries are operating in isolation, with a general lack of coordination leading to cherry-picking and wasted biomass. This has cost implications because harvesting operations generate lower volumes of marketable biomass, yet fixed costs (e.g., heavy machinery) and even some operational costs (e.g., logging) remain the same.

Our survey confirms that supply chains include a wide variety of situations with few conclusions that apply across the board. Starting with the sites, their characteristics are

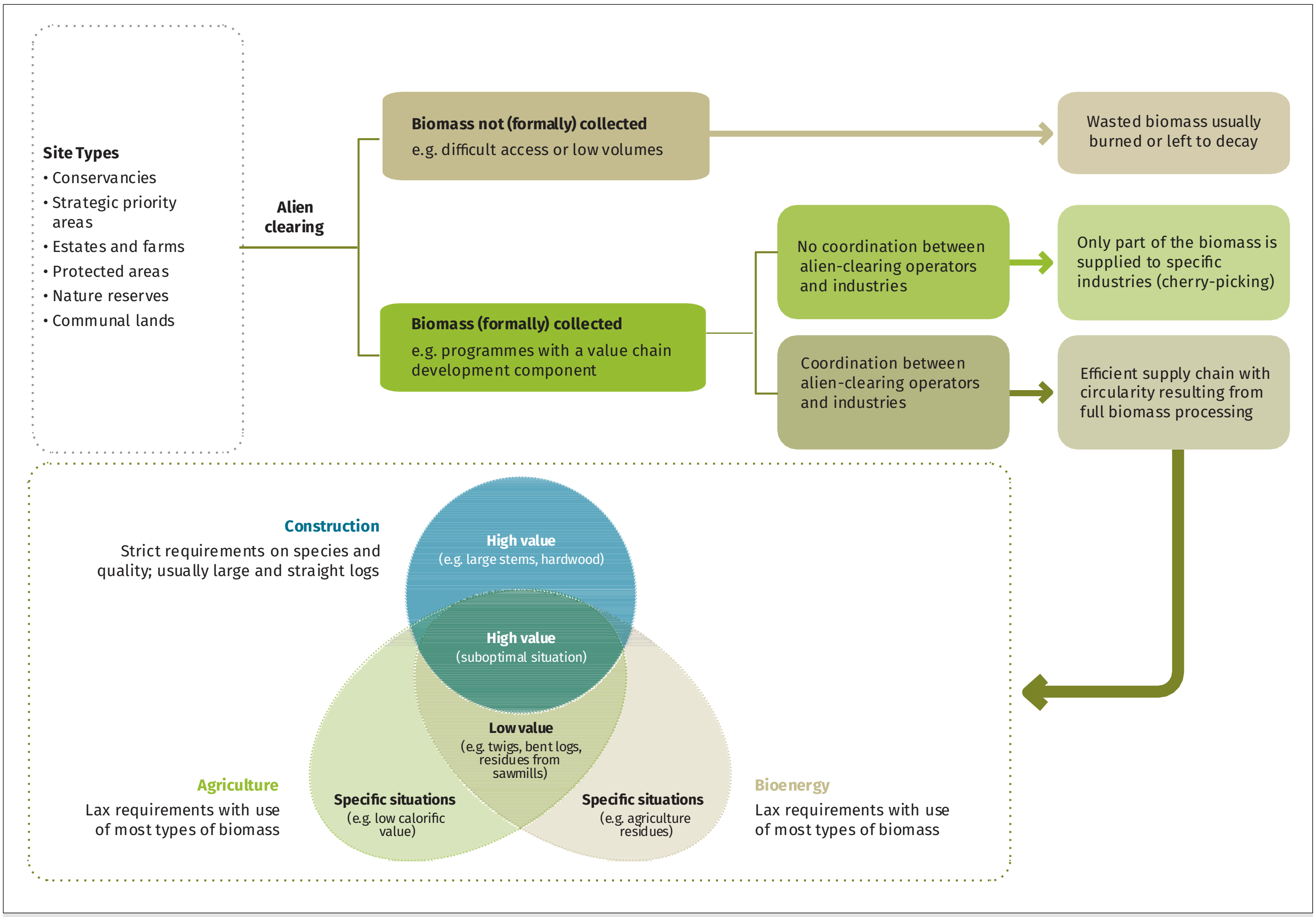

Figure 3.
Factors of efficient and consistent supply chains for biomass from unmanaged invaded areas.

multi-dimensional, and each of these dimensions might explain the diversity of practices (table II).

While these characteristics determine the cost of biomass, it remains unclear whether the maximum or average supply cost is considered by investors and practitioners for their decisions. Users' and suppliers' perspectives differ to some extent. Some supplier SMMEs make their decisions based on several parameters, of which not all correspond to profit maximisation, as exemplified by the quote "*keeping the guys busy*" (for social and employment reasons). This approach tends to favour average costs and continuous activity at full capacity, which is also the case when suppliers negotiate access to a location and must clear the whole area despite the contrasted costs involved depending on the plots. It is also not always possible or even desirable to be picky and to restrict activities to only part of a land property. It also makes little sense to assume that supply costs are strongly correlated to distance, as specific site characteristics may have a much bigger influence; consequently, the claim that only sites within a given radius would make economic sense is not robust. Overall, the concept of a maximum cost came across as more founded for biomass users who can theoretically choose between several suppliers.

Ownership and landowner characteristics are critical aspects. While landowners are compelled by law to remove invasive alien trees from their land, in effect law enforcement is weak, and *de facto* they decide whether to grant access. Our respondents agree on a rate of 10% failures in their negotiations with landowners due to several reasons, of which suspicion and reluctance to have strangers operating on their property in a country where crime is widespread, mistrust in the government and fears of being expropriated, or their own interest in keeping invasive trees for the services they provide (e.g., tourism and shade) are usually cited. Besides, their expectations in terms of payments for removing trees are sometimes hard to justify and misaligned with the capacity of suppliers to comply. Yet it is also reported that the situation tends to improve with changing mindsets and greater attention to environmental issues but also the negative role of these trees for water management and irrigation.

Our sample lacks diversity in terms of small versus large landholdings to conclude on their impacts on the easiness for suppliers to access the resource. But anecdotal evidence suggests that communal land poses challenges of its own (e.g., employment conditions imposed by communities and negotiation process) as well as public land (e.g., specific permit requirements).

The role of flexibility in biomass supplies from the users' perspective

In a context where supplies rely on unmanaged sites with heterogeneous biomass quality, flexibility for suppliers and users is key to the feasibility of value chains. End products have different requirements and levels of flexibility; specific requirements may also change over time. For instance, one respondent continues to test new species to determine which ones are suitable and under what conditions.

In general, low-value products (e.g., mulch, charcoal, and compost) show much greater flexibility than higher-value products (e.g., sawn wood and planks) in terms of species and quality of the biomass, with bioenergy being an intermediate case (e.g., one briquette producer mentioned the need for a blend of soft and hardwood, the importance of the ash content, calorific values matter, and firewood requires specific shapes and sizes). Yet they may be less flexible in terms of eligible sites due to their lower margins. Therefore, lower-value products can use more biomass per site, but fewer sites are eligible with sufficiently low supply costs; conversely, higher-value products can only use part of the biomass on any given site but can be supplied from sites associated with higher costs.

Flexibility in supplies is also dependent on the capacity to store biomass and flatten discontinuous flows according to the pace of harvesting operations. So far storage facilities are under-developed but this may change with more demand and competition due to an incentive to harvest as much as possible (especially in low-cost sites) and then store before supplying the market. Note also that the quality of biomass seems to be a lot about "purity" and the absence of pollutants such as dust or plastic during the chipping process, and it remains to be fully understood to what extent such requirements would impact the storage requirements and costs if such quality had to be maintained until the final processing stage.

Regarding biomass availability, the consensual view is that higher quality wood from specific species (e.g., Eucalyptus) and with a large diameter is much more a source of concern than lower quality wood (e.g., firewood and chips sources are perceived as unlimited) for which suppliers have identified plots with very high densities of wood (above 100 tonnes/ha).

Table II.
Distinguishing features among land clearing sites.

Site characteristic	Examples of consequences for supply chain logistics and costs
Topography	Steep slopes make it costly and even unsafe to harvest
Location	Distance to the market correlates with transport costs
Access	Existence of roads of good quality for trucks to get loaded at the proximity of the sites lowers supply costs
Water streams	Riparian trees involve safety measures to prevent logs from falling in the river
Density of invasions	Sparsely invaded areas make it uneconomical to use heavy equipment
Diversity of tree species	Mixed tree species stands induce specific costs at harvesting stage
Age and quality of the trees	Impacts on supply costs depend on the sensibility of end products to the type of biomass

Source: primary data from survey.

Besides, invasions are perceived to be on the rise. Contrasted views are likely due largely to the different markets being supplied with their own levels of requirements.

Our interpretation is that economies of scale will play an important role, with more established actors with a good track record and experience in making deals and harvesting efficiently (e.g., with their own heavy machinery and trucks) likely to dominate the market and secure their sources of biomass, as higher efficiencies enable sourcing from more sites.

Interactions and contracts with landowners

Interactions with landowners, whether public, private or communities, are a critical component to analyse the supply challenges of value chains. In economic terms this refers to the concept of transaction costs, or hidden costs, that are often neglected yet can be instrumental in determining the feasibility of a business model. Deals are reported to fail in about 10% of cases – probably much more if one considers that suppliers make their first selection of sites with greater chances to succeed – and having collaborative landscape platforms helps to smoothen such interactions.

Deals or contracts with landowners are not standardised, which leads to a variety of situations. Negotiations lead to contrasted outcomes with either the landowner or the biomass supplier financially compensating the other. In-kind contributions can also be provided when the landowner commits to follow up with the clearing of young seedlings in subsequent years. Other special cases also abound, e.g., the case of landowners supplying chips to the processor at a very low cost but benefitting from large discounts to buy and apply the end product in the form of biochar and chemical-free fertilisers.

Apart from such very special deals, contracts are verbal for most of the time, and trust is key. Yet respondents acknowledged that such deals are not always enforced, and follow-up activities with clearing in subsequent years are particularly uncertain once the biomass has been removed with the initial clearing.

In this context, we argue that the outcomes of such negotiations are determined by a combination of farmers' mindsets, knowledge, and objectives and site characteristics. But law enforcement may have an impact if landowners are forced to clear their lands and see suppliers as an opportunity to comply. Such a course of action is taking place in the municipality of Knysna, where bioenergy facilities were developed to increase energy self-sufficiency, and access to the biomass was supported by pressure on landowners to provide access.

Overall, the fluidity of deal-makings with landowners is key to the suppliers' business, which pleads for operations that involve large estates with sizeable biomass stocks and operations over a longer period. Besides, reputation and trust are fundamental to keep operating in the same region, because a good track record attracts more opportunities to collaborate efficiently with landowners with the highest potential.

Discussion and recommendations

Outputs of the SWOT analysis from the stakeholders' workshop (appendix 1-figure 1) were combined with the results presented above to support our six recommendations. The relationships between survey results, recommendations and expected gains and objectives are further presented in figure 4.

An important question remains: how can we increase the likelihood that recommendations are acted upon and implemented? The stakeholders workshop is a starting point for a community of practice that can help with dissemination and implementation; it then must be completed with other actions that depend on the nature of recommendations. These are of different natures and imply action by different actors, either governmental (e.g., law enforcement), civil society (e.g., collaborative platforms) or the private sector (e.g., association of biomass users). Apart from the support from the community of practice, specific communication means must thus be designed. Besides, we are using such findings in the development of proposals for projects that could take recommendations on board either at the national level (centralised funding) or in specific sites (e.g. stakeholders coordination).

Establishing an association of biomass users for information management and value chain integration

An urgent task is to generate suitable information on the availability of biomass resources. The updated maps at the national level are not enough, they must be developed at a scale and definition that suit the needs of biomass suppliers and users. Volumes, species, age and shape must be mentioned as these characteristics matter for many end products. Besides, logistical challenges and the costs involved plead for a deeper integration of value chains. Indeed, a given user can get supplies from various sites and a given site can provide biomass to various users depending on end products. Also, innovations must improve processing efficiencies, broaden the scope of acceptable species and biomass qualities for any given product, and increase the efficiency of logistics.

These three objectives would be supported by the establishment of a biomass users association to (i) use collective resources (e.g. collected through membership fees) to produce such information and disseminate it efficiently among its networks, and (ii) enhance coordination among actors along the value chains.

Coordinating stakeholders to align invasion control and sustainable supply objectives

We found that most of the biomass generated by alien clearing operations for invasion control purposes is unused and can be classified as "waste biomass". Besides, biomass suppliers and users face uncertainties that are usually greater for higher value products, with difficult access to such

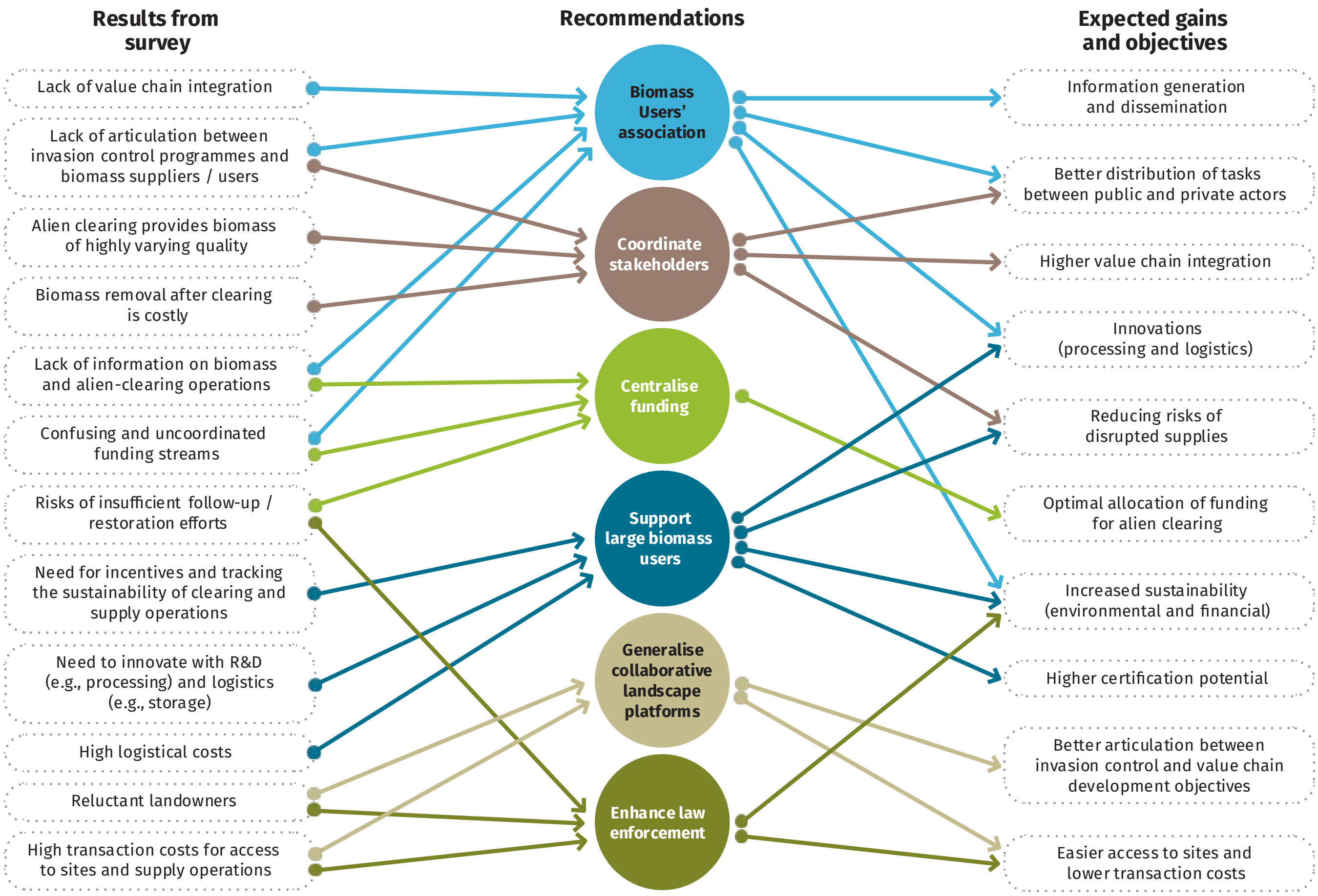

Figure 4.
From survey results to recommendations and expected gains: A simplified view.

waste biomass because of a lack of information. Also, biomass removal costs are significant and impede both the expansion of alien clearing into more areas and more effective follow-up over the years to secure restoration gains. In this context, prioritising a high level of coordination between invasion control programmes and supply chains to emerging industries is fundamental. The mutual gains are not only obvious with a better distribution of the financial burden with alien clearing operations funded by public (including international actors) or NGO-led programmes and biomass handling and removal by value chain (private) actors; they are also necessary to make such value chains financially feasible at scale.

The sustainability of value chains would also be enhanced by a clearer and more broadly endorsed alignment of objectives. While eradication and restoration are priorities in areas where the threats created by invasions and the benefits enjoyed from restoration or rehabilitation are highest, other areas could be used for a renewed production of biomass over the years. The latter would be in areas where the degradation of ecosystem services is limited, the costs of restoration are unaffordable, and markets for the biomass are significant (ideally the three conditions are met). This situation could help promote the sustainability of supplies in two ways: strategic areas for restoration are fully addressed, and supplies are guaranteed over the long term at affordable costs.

Supporting large biomass users to reduce risks and increase sustainability

Our research suggests that large entities might be in a better position to be sustainable both economically and environmentally. This might look counterintuitive if one assumes that the greater the needs the more challenging to secure renewed access to an unmanaged resource and the more pressure to cut on costs and investments into restoration. But inputs collected in the survey convey another narrative whereby large actors would have more capacity to generate their information about available resources, gather more experience in dealing with landowners, invest in heavy machinery and vehicles to lower the costs of biomass collection and operating at longer distances, and undertake research and development operations.

Furthermore, larger businesses are more likely to process a diversity of products, which in turn broadens the basket of eligible biomass and lowers the supply costs overall.

Large entities also hold promise for the environmental sustainability of operations. First, they are visible and easily targeted by those who criticise the risks associated with the development of value chains using invasive species. The reality is that the many informal actors likely represent the bulk of the exploitation for firewood and charcoal principally. These have no interest, or even capacity, in sustainable operations and they fly under the radar outside of the legal framework. The situation is different for large, incorporated actors that need to manage their reputation, even more as exporters.

Second, certification is used for sustainable forest management and ecosystem services in the case of alien clearing (at least one pellet exporter in South Africa is certified by the Forest Stewardship Council (FSC) and two group schemes have received respectively water and conservation credits by FSC – e.g. SGS 2020), which involves sustainability indicators and the monitoring and verification by external auditors. Certification is an easier objective for large actors who can afford substantial costs involved and administrative requirements. Furthermore, certification requires the traceability of operations and thus enables to keep track of the sites where biomass is sourced and land supposedly rehabilitated. Last, large actors may be the only ones with the capacity to put in place the appropriate processes for better bookkeeping and data collection.

Centralising funding for alien clearing

The WfW programme has led efforts to control invasions in South Africa for 25 years providing the lion's share of funding in this space. It was followed by an increasing number of complementary initiatives both at the national level (e.g. Land Care), local level (e.g. Greater Cape Town Water Fund) and even international level (Overseas Development Assistance and NGOs). While the emergence of new initiatives is a positive trend that inflates available funding for alien clearing, sometimes with their specificities such as targeting strategic water areas, it is disputable that uncoordinated programmes lead to the best outcomes.

The multiplication of standalone initiatives is confusing and calls for more coordination in a context where the lack of information remains a barrier to investments, e.g. regarding biomass resources and on-going land clearing operations. This would enable to put resources in common and serve the general interest objective of combining invasion control with economic development. Ideally, funders would share their objectives and financial commitments as well as conditions associated with their spending, and a body in charge would ensure coordination (e.g. the biomass users association, see above). Such an approach would not only nudge funders to clarify their criteria for site identification and objectives but also to achieve economies of scale. The efficiency of spending would also be enhanced if this approach helps to achieve a critical mass of biomass production and support private investments in value chains to contribute to biomass removal, which was identified as a significant cost of alien clearing and restoration efforts.

Generalising the Collaborative Landscape Platforms model

Our survey provided evidence that collaborative landscape platforms play a key role in facilitating action across large areas that involve multiple landowners. This role is manyfold: smoother interactions, better vision at landscape level, and expanded area of interventions that facilitates planning of supplies over the longer term. Furthermore, being part of such a platform is expected to facilitate the alignment of mindsets among landowners who can share experience and are likely to participate more proactively. Indeed, only action at scale can have a significant impact on services such as water availability and this is illustrated by the creation of water users associations and irrigation boards.

The transaction costs involved in dealing with each landowner individually also plead for the generalisation of such platforms, as illustrated by alien clearing programmes that transact with platforms rather than individuals. South Africa has put in place biodiversity tax incentives, effective since 2023, to support conservation on private and communal lands. One avenue of reflection would be to tie such incentives to the establishment of collaborative landscape platforms. As the mechanism requires candidates to submit a Biodiversity Management Plan in a gazetted area, having such plans established at a greater landscape level would provide a good opportunity to coordinate with value chain actors.

Strengthening suppliers' bargaining power with greater law enforcement

The transaction costs involved in negotiations between suppliers and landowners can be addressed with the collaborative landscape platforms; they could also be reduced by action from the public authorities to enforce existing laws and regulations, especially the National Environmental Management Biodiversity Act 10 (NEMBA) that compels landowners to get rid of alien invasive trees on their property. In practical terms, enforcement is reported to be exceptional and landowners hardly conduct alien clearing to comply with legal requirements.

In this context landowners often consider invasive trees as a valuable resource that can be sold with a profit rather than a liability. It leads to difficult negotiations and a diversity of situations with payments and contributions going both ways. More law enforcement would provide biomass suppliers with greater bargaining power, with better deals and lower supply costs to users. This could be combined with an idea collected during the workshop, namely that insurance companies could put more pressure on landowners to comply if only due to fire risks and potential damages.

Conclusion

Essentially our analysis demonstrated that solutions exist at the supply chain level to support the emergence of new value chains that contribute to the control of invasive alien trees. Notwithstanding the controversies around the establishment of value chains using invasive species, we showed that financial challenges for the feasibility of value chains can be addressed with efficient supply chain models for which there has been no blueprint or analysis so far.

We proposed six main avenues for improvement that we argue to be realistic and achievable considering our methodology with the collection of inputs from the full range of stakeholders involved in this space and the discussion of early findings. We emphasise that our results and recommendations can certainly be applied beyond South Africa or at least serve as a source of inspiration to push relevant policies in other parts of the world. Indeed, not only invasive alien species are an understated problem that only becomes more acute and urgent over time, but supply chain challenges also frequently act as a barrier (IPBES, 2023).

The solutions must be built on the initial recognition that invasion control is a nature-based solution for adaptation to climate change, which justifies investments and public funding into land clearing. The next step is to acknowledge that using the resulting biomass would contribute to climate change mitigation. Indeed, producing bioenergy and biochar would contribute, respectively, to the replacement of fossil fuel energy and carbon storage in the soils, which in turn increases the resilience of agriculture. As such, we consider that our recommendations are highly relevant for the bioeconomy-related reflections. Besides, one of the identified barriers for dedicated value chains lies with biomass supply uncertainties, which in turn pleads for the establishment of a more ambitious biomass management strategy including agriculture or forestry residues. It is presumed that only a bioeconomy model at the national level would create the conditions to square the circle of developing economically sustainable value chains and controlling invasions at the same time.

Photo 4.
Chips are loaded on trucks and transported to the processing factory.
Photo D. K. Ngwenya.

Acknowledgements

We would like to thank all stakeholders who agreed to be interviewed as part of our survey and the participants in the stakeholder workshop used for validation purposes, as well as Konstantin Engelbrecht who played a key role in the organisation of the workshop and the two anonymous reviewers.

Funding

This work was funded in part by MarginUp! (Project 101082089 with the European Research Executive Agency). The French Ministry for Europe and Foreign Affairs supported the first author. However, the views and opinions expressed are those of the author only and do not necessarily reflect those of the European Union, the European Commission or the French Ministry for Europe and Foreign Affairs. Neither the European Union, the granting authority nor the French Ministry for Europe and Foreign Affairs can be held responsible for them.

Appendix 1

Table 1.
Analytical framework used to design survey questionnaires and analyse primary data.

Component	Sub-component	Example from questionnaire
Logistics for biomass collection and transport	Pooling of transport vehicles	Do trucks run empty before/after your deliveries? (B)
	Integration of value chains	Are trucks that deliver biomass also used for other products / value chains? (D)
	Use of storage facilities	Do you use storage facilities? Please describe if at processing site, what products are stored, what are the expected benefits. (C)
	Harvesting techniques	Are there land clearing costs differences between sites and what is their magnitude? (E)
	Coordination with land clearing operations under other programmes	Do you collect biomass from sites where land clearing operations are done for other reasons than biomass production? Please elaborate on reasons and type of coordination. (C)
Management of uncertainties with biomass availability	Flexibility to deal with mixed species and heterogenous quality	Do you use only a selected group of species? (D)
	Flexibility to deal with uncertainties (e.g. diversification of suppliers)	Can you collect biomass with stable quantities according to plan, and if not does it create significant additional costs and how do you deal with this? (C)
	Capacity to mix sources of feedstock (e.g. including forest and agricultural residues)	How do you cope with uncertainties in biomass availability and their implications (e.g. mixing sources of feedstock such as residues) (D)
	Means and capacity to access biomass at affordable costs on average	Do you have more difficulties getting land clearing done in some plots compared to others? (A)
	Access to up-to-date information on resource availability and quality	What information and criteria are used to decide on sites for alien clearing and what are the avenues for more relevant site selection? (E)
Governance of supply chain	Structure of supply chain (e.g. intermediaries)	Which actors are involved from site selection to tree logging all the way down to delivery at mill gate? (All categories of stakeholders)
	Density of SMME's network for biomass supplies	Is there a large diversity of SMMEs to do the land clearing? (E)
	Sub-contracting or vertical integration for biomass supplies	Why did you decide to internalise / outsource biomass supplies? (D)
	Fluidity of negotiations with landowners (including private, public, and community)	How would you describe negotiations with landowners in terms of easiness and fluidity? What is the rate of success? (C)
	Type of contracts with landowners	Please describe the type of contracts with biomass collectors. (A)
	Degree of formalisation in labour	Is labour formal or informal for harvesting operations? (B)
Others	N/A	What happens after harvesting operations, is there any post-removal treatment? (C)

Note: The framework is based on the literature review. (A): questionnaire to landowners, (B): questionnaire to collective land managers, (C): questionnaire to biomass suppliers, (D): questionnaire to biomass users, (E): questionnaire to land clearing mandators/funders.

Table 2.
Main conclusions from the literature review with lessons for unmanaged invasive alien trees.

Case/context	Problem	Solution	Reference
General	Buyers (demand side) must deal with uncertainties in terms of volumes and quality	Achieving a sufficient level of flexibility; three strategies stand out: (i) diversification of suppliers, (ii) tolerance to varying quality and species, (iii) storage capacity to level ups and downs of supply volumes	N/A
General	The supply side is not addressed in the literature (only the demand side) yet the observed heterogeneity of suppliers (e.g. formal/informal) and the rarity of reliable and performing SMMEs might become a problem for value chains to develop	Vertical integration is an option, otherwise rationalising and regulating the landscape of SMMEs that undertake alien clearing and supply producers may be considered	N/A
Woody biomass for bioenergy	Biomass characteristics such as their low density and unpredictable quality imply difficulties to have a final product that can compete with more conventional sources of energy. These characteristics are mainly about the heterogenous nature of material (e.g. moisture)	Sensitivity analysis, stochastic or robust optimisation	Shabani et al. (2013)
Woody biomass for bioenergy	Uncertainty in terms of availability is a major aspect and the authors list the specific characteristics of forest biomass in this regard: new markets and production technologies that impact availability due to highly uncertain longer-term availability and prices, cascading effects with residues and by-products (e.g. economic downturn)	Scenario-based approaches	Shabani et al. (2013)
Bioenergy	Biomass as feedstock with low calorific value, high moisture content, and low density	Storage capacities (different options), optimal size of supply chain, optimal scheduling of operations based on modelling	Nunes et al. (2020)
Biofuel in the USA (Tennessee) using switchgrass	Variability in biomass quality (random nature of ash content and moisture)	The role of technologies and end products is critical due to their differing sensitivities to biomass quality variations. But the need for quality control measures along the chain carries significant costs	Castillo-Villar et al. (2017)
Agroforestry residues in Portugal	Residues should be removed due to their role as fuel for natural fires but the economic feasibility is questionable	Better coordination between site managers and biomass suppliers and users; creation of a Web Platform that would centralise and disseminate all relevant information in near real time	Casau et al. (2022)
Pulp and paper industry	Supply and demand uncertainties calls for optimised flows between all stages	Merchandizing yard that helps in managing risks in the supply chain, but modelling suggests that savings are accompanied by increased costs in handling and transportation tasks because suppliers must all bring their material to a central location first	Shahi et al. (2018)
Solid biomass fuel	Insufficient guaranteed supplies of raw materials	Contracts that involve a subsidy and protection price by the manufacturer to the farmer, and a buyback and revenue sharing mechanism between the manufacturer and the middleman	Fan et al. (2019)
Salvage logging after natural disturbances for bioenergy in Canada	Uncertainties around estimates of available feedstock and its suitability for bioenergy, constraints in developing an integrated supply chain and cost-effective mobilization of the biomass	Integration of a terminal in the supply chain to allow constant and uniform feedstock delivery throughout the year; real-time operational data on biomass stocks for improved logistics; flexible supply chains that rely on multiple sources of feedstock	Mansuy et al. (2018)
Use of biomass from fire-killed trees and harvest residues to supply the pellet industry in Canada	Uncertainty of supplies	Reliance on multiple feedstock sources (traditional forest products and waste streams) increases the flexibility of supply chains	Mansuy et al. (2015)
Salvage harvesting in Canada for wood industry	Uncertainties due to a lack of updated information in a rapidly changing environment	N/A	Mushakhian et al. (2020)
Bioenergy in USA	Technical and economic feasibility of feedstock logistics are usual barriers because of their limitations compared to silvicultural treatments and harvesting methods	Integration of timber and bioenergy value chains holds promises	She et al. (2019)

Source: Inter 3, 2024. SWOT analysis of a workshop on supply chain models for biomass generated from clearing alien invasive species. Germany, Institute for Resource Management GmbH.

Figure 1.
SWOT analysis based on the workshop with some research participants held at Stellenbosch University.

Appendix 2

Questionnaires for surveys

Different questionnaires were designed for each of the five categories of stakeholders. These questionnaires shared a common set of questions. The questionnaires are based on the analytical framework and are copied below.

a. Biomass users

- **Basic information**

Duration of interview:

Date & venue (also in-person/remote):

Name & affiliation of respondent:

Contact details of respondent:

Location:

How was the respondent identified (e.g. who gave contact):

Observations and general description of the respondent case (introduction):

Range of activities of the respondent, type of biomass processing, and starting date of biomass use activities:

Annual use/processing of biomass per type/species (specific to invasive alien trees outside of plantations):

Markets for the processed biomass (end-products, e.g. energy):

Are the biomass and/or the end products certified?

Do you outsource biomass supplies? <u>If yes then also ask questions underlined</u>, **if not then also ask questions in bold**.

- **Component 1: Logistics for biomass collection and transport**

Are trucks that deliver biomass (in what form?) also used for other products/value chains?

Do the trucks run empty before/after deliveries?

Are there margins for increased efficiency if trucks were managed collectively for more than one value chain?

What are the possible avenues for reduced transportation costs?

Do you use storage facilities? Please describe if at processing site, what products are stored (e.g. various types of feedstock), if it makes a difference, what are the benefits, etc.

Is there a margin for increased efficiency with harvesting operations? Please describe which ones, and what decides on their application (e.g. barriers).

What is the magnitude of harvesting cost differences between sites? Please elaborate on sources of differences, if any significant ones.

Does it make any difference to operate in monospecies or mixed species stands?

Do you collect biomass from sites where land clearing operations are done for restoration purposes (e.g. WfW)? Please explain which ones and describe how the coordination is done (e.g. access to information).

- **Component 2. Management of uncertainties with biomass availability**

Do you use only a selected group of species? What would it take to enlarge the scope?

How flexible are you in terms of wood quality? Please elaborate on the options and costs to increase flexibility.

<u>Would you welcome an increased number of suppliers as a diversification strategy to limit supply uncertainties?</u>

Are uncertainties in biomass availability and supply a source of concern? Please elaborate (e.g. sources of uncertainties).

How do you cope with these uncertainties and their implications (e.g. mixing sources of feedstock with residues or others)?

Is there a maximum cost you can afford for biomass supplies, and to what extent do you account for the average cost over all supplies (e.g. lower costs compensate for higher costs)?

Do you always need formal permits to collect biomass (e.g. for harvesting, transport)?

Can you always access biomass on the sites you've identified? If not, what is the percentage of failures (e.g. no deal with landowner) and reasons for failure?

Do you have access to constant supplies of biomass, If not, does it create significant additional costs and how do you deal with this?

How satisfactory is access to up-to-date information on resource availability and quality and what are the avenues for improvement?

What are your sources of information on the resource availability, and do you generate your own?

How do you decide on the sites for land clearing, what are the criteria based on available information?

- **Component 3. Governance of supply chain**

Which actors are involved from site selection to tree logging down to delivery at the mill gate? (sketch the supply chain structure with the respondent)

Any observations about this supply chain structure and avenues for improvement?

Why did you decide to internalise biomass supplies (vertical integration)? <u>Why did you decide to outsource biomass supplies?</u>

What is the density of SMEs' network for biomass supplies (for instance: there are plenty of SMEs that compete with one another, or there is a lack of SMEs to deal with the demand for biomass)? Please elaborate on the reasons if possible.

How would you describe the negotiations with landowners to access biomass in terms of easiness and fluidity?

Are these negotiations different depending on the type of landowner (private, public, community)? Please elaborate.

How would you describe the type of contracts with landowners, and does it depend on the type of landowner (private, public, community)? Please elaborate (e.g. payments involved).

Is labour formal or informal for harvesting operations?

- **Component 4. Others**

What happens after harvesting operations, is there any post-removal treatment (e.g. applying arboricides, or cutting seedlings due to natural regrowth)? Explain the reasons for the treatment (or its absence).

b. Biomass suppliers

- **Basic information**

See the Questionnaire for Biomass Users above.

- **Component 1: Logistics for biomass collection and transport**

Are trucks that deliver biomass also used for other products/value chains?

Do the trucks run empty before/after your deliveries?

Are there margins for increased efficiency if trucks were managed collectively for more than one value chain/product? Please elaborate.

What are the possible avenues for reduced transportation costs?

Who pays for transportation?

Do you use storage facilities? Please describe if at the processing site, what products are stored (e.g. various types of feedstock), what are the benefits of using such storage facilities.

Is there a potential for increased efficiency with harvesting operations? Please describe the magnitude of this potential, the sources of increased efficiency, and the barriers.

Are there harvesting cost differences between sites and what is their magnitude? Please elaborate on the reasons for the differences.

Does it make any difference to operate in monospecies or mixed species stands?

Do you collect biomass from sites where land-clearing operations are done for other reasons than biomass production (e.g. WfW, farming)? Please elaborate on the reasons and the type of coordination (e.g. access to information).

- **Component 2. Management of uncertainties with biomass availability**

Do you have to make sure about a market/demand for the biomass before collection/harvest, how do you align biomass collection volumes with demand?

Do you use only a selected group of species? Please elaborate.

How flexible are your clients in terms of wood quality? Please elaborate.

Are uncertainties in biomass availability a source of concern? If yes, how do you cope with these uncertainties and their implications (e.g. mixing sources of feedstock with residues or others)?

Is there a maximum cost you can afford for biomass collection, and to what extent do you account for the average cost over all sites in case of significant cost differences (e.g. lower costs compensate for higher costs)?

Do you always need formal permits to collect the biomass (harvesting and/or transport)?

Can you always access biomass on the sites you have identified? What is the percentage of failures (e.g. no deal with the landowner or delays due to permit requirements) and the reasons?

Can you collect and supply biomass with stable quantities and as desired (e.g. according to your capacities)? If not, does it create significant additional costs and how do you deal with this?

How satisfactory is access to up-to-date information on resource availability and quality and what are the avenues for improvement?

What are the sources of information you use and do you generate your own information?

What are your criteria to decide on the sites for land clearing, and do you have options to choose from?

- **Component 3. Governance of supply chain**

Which actors are involved from site selection to tree logging down to delivery at the mill gate? (sketch the supply chain structure with respondent)

What is the density of SMEs' network for biomass supplies? Please elaborate.

How is the price of the biomass decided?

How would you describe the negotiations with landowners to access biomass in terms of easiness and fluidity?

Are these negotiations different depending on the type of landowner (private, public, community)?

How would you describe the type of contracts with landowners, and does it depend on the type of landowner (private, public, community)? Please elaborate (e.g. payments involved).

Is labour formal or informal for harvesting operations?

- **Component 4. Others**

What happens after harvesting operations, is there any post-removal treatment? Explain the reasons for the treatment (or its absence).

c. Landowners

- **Basic information**

See the Questionnaire for Biomass Users above.

- **Component 1: Logistics for biomass collection and transport**

Do you proactively search for operators to clear your land? Please elaborate.

Do you have competing requests by different operators to clear your land (e.g. WfW versus private companies involved in biomass marketing)? If yes, how do you choose?

Do you allow access to all invaded sites on your property? Please elaborate.

- **Component 2. Management of uncertainties with biomass availability**

Do you have more difficulties getting land clearing done in some plots compared to others? Please explain the reasons. (e.g. no operator willing to clear some plots on landowner's terms)

- **Component 3. Governance of supply chain**

How is the process of getting in touch with land clearing operators on your land (e.g. who has information about invaded areas)?

Which actors are involved from site selection to tree logging down to delivery at the mill gate? (sketch the supply chain structure with the respondent)

Please describe the type of contracts with biomass collectors (e.g. payments involved, duration of contract, risk management).

Is labour formal or informal for harvesting operations?

- **Component 4. Others**

Did you decide to have your land cleared because (can be multiple choices):

  - o It is mandatory
  - o It was ordered by the authorities
  - o It is beneficial for land productivity (what uses? e.g. farming, grazing…)
  - o It is important for environmental reasons
  - o Others:

Do you (or the operators) need a permit to have your land cleared?

What happens after harvesting operations, is there any post-removal treatment (e.g. applying arboricides, or cutting seedlings due to natural regrowth)? Explain the reasons for the treatment and to what extent it suits your preferences.

Do you use the biomass for your own needs?

d. Mandators / Funders

- **Basic information**

See the Questionnaire for Biomass Users above.

- **Component 1: Logistics for biomass collection and transport**

Is there some coordination with biomass suppliers/users (or other land-clearing programmes) to spread the information about biomass availability? Please elaborate.

How is biomass handled once trees are logged, w/wo coordination with biomass suppliers?

Is there a potential for increased efficiency with land-clearing operations? Please describe the magnitude of this potential, the sources of increased efficiency, and the barriers.

Are there land clearing cost differences between sites and what is their magnitude? Please elaborate on the reasons for the differences.

Does it make any difference to operate in monospecies or mixed species stands?

- **Component 2. Management of uncertainties with biomass availability**

Can you always access the sites you have identified? What is the percentage of failures (e.g. no deal with landowner) and the reasons?

What information and criteria are used to decide on sites for land clearing and what are the avenues for more relevant site selection?

- **Component 3. Governance of the supply chain**

Which actors are involved from site selection to tree logging down to delivery at the mill gate? (sketch the supply chain structure with the respondent).

Are land-clearing activities outsourced? If yes, is there a large diversity of SMEs to do the land clearing?

How do you approach landowners, is there a negotiation, and does it depend on the type of landowner (private, public, community)?

How would you describe the type of contracts with landowners, and does it depend on the type of landowner (private, public, community – e.g. payments involved)?

- **Component 4. Others**

What happens after harvesting operations, is there any post-removal treatment? Explain the reasons for the treatment (or its absence).

e. Collaborative Landscape Platforms

This applies only to organisations such as conservancies, irrigation boards or water users' associations that have had experience with land clearing operations. The respondent answers in their capacity as collective land manager (e.g. head of Conservancy **when the question is in bold**) but also on behalf of all landowners whenever relevant (e.g. "range of land-based activities" concerns all landowners, not the conservancy objectives <u>when the question is underlined</u>). When neither underlined nor in bold it means the question covers all cases; the enumerator needs to specify whenever relevant when noting down the response.

- **Basic information**

See the Questionnaire for Biomass Users above.

- **Component 1: Logistics for biomass collection and transport**

Do you proactively search for operators to clear your land? Please elaborate.

Do you have competing requests by different operators to clear your land (e.g. WfW versus private companies involved in biomass marketing)? If yes, how do you choose?

<u>Do you allow access to all invaded sites on your property? Please elaborate.</u>

- **Component 2. Management of uncertainties with biomass availability**

<u>Do you have more difficulties getting land clearing done in some plots compared to others? Please explain the reasons. (e.g. no operator willing to clear some plots on the landowner's terms)</u>

- **Component 3. Governance of supply chain**

What are the respective roles of the institution (e.g. Conservancy) and landowners in the decisions regarding land clearing?

Are there competing/differing interests and objectives among landowners?

To make a plan for biomass supplies and processing, does it help to have many landowners involved due, e.g., to greater scale and easier coordination?

How is the process of getting in touch with land clearing operators on your land (e.g. who has information about invaded areas)?

Which actors are involved from site selection to tree logging down to delivery at the mill gate? (sketch the supply chain structure with the respondent)

Please describe the type of contracts with biomass collectors (e.g. payments involved, duration of contract, risk management).

Is labour formal or informal for harvesting operations?

- **Component 4. Others**

Did you decide to have your land cleared because (can be multiple choices):

  - It is mandatory
  - It was ordered by the authorities
  - It is beneficial for land productivity (what uses? e.g. farming, grazing...)
  - It is important for environmental reasons
  - Others:

Do you (or the operators) need a permit to have your land cleared?

What happens after harvesting operations, is there any post-removal treatment (e.g. applying arboricides, or cutting seedlings due to natural regrowth)? Explain the reasons for the treatment and to what extent it suits your preferences.

<u>Do you use the biomass for your own needs?</u>

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