Linking Forest Restoration to Sustainable Value Chains with se.plan

By

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Executive Summary

Stumpage prices for timber can be low due to lack of demand for wood products, which threatens the sustainability of tree-growing projects. Prices can increase with more investment in local wood processing facilities and related infrastructure – the links in the value chain that would increase timber demand. se.plan, a geospatial tool built by the UN Food and Agriculture Organization (FAO) Forestry Division, helps investors find suitable locations for reforestation projects in emerging markets, but it does not have the capability to help find locations for wood processing facilities. Using Uganda as a case study, we augment the capabilities of se.plan and provide geospatial data to build a wood processing facility siting capability into the tool. To determine decision-making factors relevant to investments in reforestation and wood processing, we conducted a literature review and focus groups, and then we found and modified geospatial datasets relevant to those factors. We made recommendations on how FAO can incorporate the datasets into se.plan.

We subdivided investment decision-making factors into four broad categories: government regulation and policy environment factors, infrastructure and economic factors affecting the supply of wood products, wood product demand factors, and supply and demand for one wood product, mass timber.

Evaluating the governmental and policy conditions, we identified 17 factors that fell into five overarching categories that improve value chain development:

- More institutional support from government agencies, NGOs, and civil society organizations that can help provide land rights, technical training, financial resources, and other assistance.
- Greater land security based on the availability of land, clear and simple property registration procedures, and strong enforcement of property rights by local governments.
- Stronger land rights that result from the formalization of multiple land tenure systems, gender equity in land matters, and recognition of timber rights.
- Lower country risk that reduces likelihood of land grabs and conflict due to civil unrest or political corruption.
- A friendly environment for legal timber, created through strong government enforcement of timber certification standards and taxation, straightforward regulations, and streamlined processes of compliance.

Many datasets that represent a country's performance in the above factors exist at the national level and are indices or rankings formulated by international development groups, government agencies, and global data catalogs.

From a wood product supply perspective, a geographic area's commercial species stumpage volume, wood product prices, distance to major roads, size of the nearby domestic market for wood products, and distance to major seaports proved most important for locating a new wood processing facility. In total, we identified 21 factors relating to infrastructure and the downstream supply of wood products, and we created geospatial data layers for se.plan related to the following factors:

- Distance to Major Roads
- Distance to Seaports (export market access)
- Distance to Existing Plantations
- Electricity Prices
- Commercial Species Stumpage Volume
- Labor Force Participation
- Electricity Access

Regarding the demand trends for wood products, the prices of wood products, the types of products, and overall consumption were the most significant factors. Due to a lack of easily accessible geospatial data, our focus shifted to developing a wood products consumption layer. To do so, we utilized national data on the production, import, and export quantities of two focal wood products (industrial roundwood and sawnwood), as well as GDP per capita and population density. We generated several linear models using R and, assuming that national level effects were comparable to those at the subnational level, we employed the best equations to forecast consumption for different districts in Uganda to 2030 in GIS to create usable geospatial layers.

An innovative product that offers an opportunity to increase stumpage price is mass timber, which involves the use of wood to construct high rise buildings. We conducted a case study that describes what mass timber is and how the product provides opportunities to create value through reforestation via sustainable forestry management, generation of climate-smart housing to assist with housing demand due to urban expansion and population growth in emerging markets, and reducing carbon emissions from the construction industry. The case study highlights factors that are important for forestland investors and concludes with recommendations for data layers to be incorporated into se.plan.

We recommend the following process to incorporate data layers created in the project into se.plan:

- **Create a new tool within se.plan:** Keep the original afforestation-reforestation (AR) tool as is and add a variant for the downstream value chain that can help make mill location siting recommendations.
    - **Incorporate new data layers into the original AR tool when appropriate:** Many of the data layers, especially relating to environmental, land use, and government policy factors, can be folded into the existing se.plan questionnaire. We envision that these layers would go into the Constraints tab, where the user could threshold their tolerance for each constraint. For example, the Ease of Doing Business layer could be added to the "Socio-economic" tab.
- **For the wood processing facility location tool, use supply and demand scores:** The layers we found do not necessarily relate easily to a cost/benefit ratio like the one the se.plan AR tool uses. Instead, since three of the four categories have to do with supply (cost) or demand (revenue) attributes of a mill, it would be better to have a questionnaire dealing with supply constraints and demand constraints, and then adding a tab for the government policy constraints.
    - For both supply and demand factors, if eligible, the user could threshold the constraint and also choose the weight of the constraint through the five-point no importance/very important scale se.plan uses for the AR tool.
- **Provide a heatmap output:** The wood processing facility location tool will have an output of a heatmap similar to the AR tool, where areas are ranked based on suitability for investment. These ranks will be based on a weighted sum of how many supply, demand, and policy/legal constraints an area meets.

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Introduction

The Client and Task

The Food and Agriculture Organization (FAO) is a part of the United Nations and works in over 130 countries ("Forests" 2022). FAO's Forestry Division aims to enable the sustainable management and conservation of our world's forests and create economic, social, and environmental benefits. Particularly relevant to this project, the program prioritizes promoting global forest restoration, conserving and sustainably using forests to improve forest-based livelihoods, and strengthening forest-related data and monitoring. The Forestry Division is specifically responsible for building geospatial tools that support programmatic decision-making about forestland investment worldwide ("Forests" 2022).

In partnership with the Spatial Informatics Group, the US Government's SilvaCarbon program, and researchers at Duke University and Peking University, the Forestry Division has developed se.plan, a geospatial tool in Google Earth Engine that is part of the SEPAL (System for Earth Observation Data Access, Processing and Analysis for Land Monitoring) toolkit in FAO's free, open-source software suite Open Foris. se.plan helps inform forest restoration planning at a high level (e.g., national) by providing spatial data at ~1 km resolution on sites where benefits from restoration are relatively high and the costs of restoration are relatively low. Benefits, or restoration indicators, include improving biodiversity conservation, carbon sequestration, local livelihoods, and wood production. Costs include the opportunity cost of the land use and the implementation expenses of regenerating forest. Users can rate the importance of the benefit indicators in their focal geographical area and add various biophysical and socioeconomic conditions that are needed for a site to match their suitability criteria. From this information, se.plan calculates a restoration value index (a ratio of benefits to costs), generates a map of the index in the given area, and produces a dashboard with detailed numbers (Sepal Development Team 2022).

Using Uganda as a case study, we aimed to identify additional factors that influence forest restoration suitability, especially factors that link economic incentives for tree-growing to wood products businesses along the wood products value chain. We identified these factors through a literature review and interviews with investors inside and outside Uganda. We created geospatial data layers related to those factors that can be incorporated into se.plan, allowing governmental and institutional investment decision-makers to identify geographic areas ripe for investment in forest restoration and/or wood processing.

Problem Statement

Uganda has promoted tree growing for smallholders (Jacovelli 2009). Some smallholders have now completed their first rotations and have begun harvests. However, the stumpage prices for those harvests have been low, which threatens the sustainability of tree-growing projects, and reforestation projects more generally. For these plantations to sustain themselves or even expand, prices must increase and become less variable.

Prices can increase with increased demand for Ugandan timber. When demand for forest products like timber or fuelwood or pulpwood increases, prices will also increase (Prestemon and Apt, 2002). Landowners have incentives, through higher prices, to devote more land to growing trees through afforestation or reforestation projects (Favero et al. 2020, Daigneault et al. 2022).

Uganda's government (and other stakeholders) now needs to know which factors influence investment in wood processing facilities and associated infrastructure – the links in the wood products value chain that would increase timber demand. The government and other interested investors need to know how these factors relate geospatially in order to find the most suitable geographic locations for new processing facilities.

Adding value-chain investment decision factors into a spatial tool that distills investment factors into geographic locations would aid the government and other stakeholders in value-chain investment decision-making.

Research Questions and Objectives

Our objective was to identify factors influencing investment in forest restoration, wood processing facilities and sustainable timber production, and then put those factors into se.plan as new spatial data layers in the tool. This will help investors find land areas in emerging markets that are suitable for forest restoration and sustainable product value chains, as well as help governments with beneficial decisions and with infrastructure investments. Adding more layers will augment se.plan to better illustrate and transmit this information to local stakeholders and potential investors, making data related to investment decisions more accessible. As a case study, we focused on Uganda as an emerging market country of interest.

We identified an overarching research question: What factors influence foreign and domestic investment in emerging market wood product value chains, including reforestation projects and wood processing facilities? What datasets are available to represent those factors? For any country? For Uganda?

Each member of our team focused on specific, related subquestions:

1. What are the governmental, land use, and policy factors that encourage/hinder forestry investment in Uganda? (Meixin Wang)
2. What transportation and downstream value-chain factors (mills, roads, ports, rail, existing plantations) affect processing facility investment decisions in Uganda? (Micah Ezekiel)
3. What demand trends for forest products direct the interest of local and foreign producers or stakeholders in investment in Uganda? What are the sources of demand for forest products? (Gabriel Piacsek)
4. What are the factors that encourage/hinder mass timber developments for housing to accommodate urban expansion in Uganda? (Reed Caradine)

All team members worked on a fifth subquestion:

5. What datasets related to the foregoing questions can be integrated into se.plan to help government planners, domestic and foreign investors, and other stakeholders visualize the feasibility of forest restoration projects and wood industry development projects in spatially explicit areas? How should they be integrated: should they simply be added to the existing layers in se.plan as additional constraints that users can apply when defining suitable areas, or should they be structured as a discrete module within se.plan?

The subquestions were formulated after initial discussions with FAO, the se.plan team, and our advisor, as well as an initial review of the literature. The first subquestion concerns the regulatory environment in which investors make decisions. From there, investors must consider supply considerations and demand considerations when creating a new business venture. The second and third subquestions relate to supply and demand, respectively. The fourth subquestion deals with a case study whereby a country's regulatory framework, supply considerations, and demand considerations can be brought together when considering a specific wood product, mass timber.

Methods

To answer the subquestions, we performed a review of available literature, which we then processed in the qualitative data analysis program NVivo. We also conducted and recorded three focus groups with experts on forestland and wood processing facilities investment, transcribed the recordings, and analyzed them in NVivo. Based on the investment factors the literature and focus groups revealed, we searched for data layers from reliable sources. We relied on the focus groups to help inform our recommendations for how the data layers can be incorporated into se.plan.

Literature Review

We conducted a literature review through expert suggestions and self-research. At the beginning of the project, our client FAO and our advisor provided us with many academic articles, white papers, and "gray" literature that could possibly point to factors influencing investment decisions for forestland and/or wood processing facilities.

After reviewing these documents, we used a combination of Google Scholar and Google Search to search for additional literature on forestry investment decision-making factors. We chose search terms based on themes and factors found in the initial expert-delivered documents, as well as terms based on our problem statement and individual subquestions (Table 1).

We then decided which of the documents we found were relevant and should be included in the literature review. If we were given literature by FAO or our advisor, we believed that source to be credible, useful, and of good quality. We included literature given to us and literature we found through our search in the review only if a document directly related to our overarching research question. That is, we included a document in the review if it explicitly or implicitly revealed factors investors consider when making an investment in tree plantations or wood processing facilities.

Subquestion	Search Term
1	Uganda Tree Growers Association, timber grading for export, land tenure Uganda, land titling in Uganda, Uganda land registered coverage, Uganda Sawlog Production Grant Scheme, land tenure reform in Ugandan districts
2	Lumber mill investment, wood processing facility investment, lumber mill investment factor analysis, transportation cost lumber mills, sawmill location investment, exchange rate risk
3	Uganda wood markets, wood products Uganda, Uganda export/import markets, Uganda wood consumption, Uganda fuelwood, wood production in Uganda, wood demand in Uganda.
4	Mass timber in emerging markets, mass timber housing, mass timber building codes, Uganda population growth/degree of urbanization, housing

	demand in Uganda, domestic market demand

Table 1: Search terms used in literature review

We ended the literature review after we finished the focus groups and determined that we did not have any more factors to find that the literature review or focus groups hadn't already revealed.

Focus Groups

We conducted three focus groups with various stakeholders representing landowners, investors, and different industries with interest in the wood products supply chain (Appendix 1 and 2) We divided our stakeholders into groups based on domestic or international presence and investor type (on-the-ground operator vs private equity investor).

We conducted our focus groups based on the following method (George, 2022):

1. Choose the topic of interest
    a. Data collection revolved around factors that encourage or hinder forestry investments regarding topics in infrastructure, government and policy interests, and international markets.
2. Define research scope and hypotheses
3. Develop the interview format and a strategic list of questions, including individual responses and encouraging group discussion.
    a. Questions for the forestland investors were developed from our literature review and focus on general investment interests. We developed industry specific questions and prepared follow-on questions to stimulate further discussion.
    b. Questions for the tree planters and wood processors were also developed from the literature review, but focused on the Ugandan supply chain. This focus provided perspective on what is important in emerging markets regarding forestland investments.
4. Select a moderator or co-moderator
    a. All team members cycled through this role. Team members who were not moderating supported the focus group by taking notes or asking clarifying questions.
5. Recruit participants
    a. Target participants were suggested by our advisor and client. The MP team discussed which participants could provide valuable input from their range of experiences in forestland investments and wood processing facilities. The diverse backgrounds even in the same industries allowed for great discussion between participants and moderators.

6. Set up the focus group
    a. Three focus groups were executed on the following dates:
        i. 9 January 2023 - Ugandan Tree Planters and Wood Processors
        ii. 26 January 2023 - Forestland Investors 1
        iii. 31 January 2023 - Forestland Investors 2
7. Host the focus group
8. Analyze data and report results
    a. The focus groups were recorded and transcribed which allowed the team to process the data in Nvivo to understand more details and nuances about the proposed factors.
    b. The focus groups also allowed the team to research and integrate new information or factors that arose from the interviews to ultimately tailor our factors and datasets to the feedback.

We asked the following main questions to focus group participants:

- 9 JAN 23 Ugandan Tree Planters and Wood Processors
    a. Uganda has a well-known program for tree planting, SPGS. What, in your view, will it take for private companies to continue commercially viable forestry operations, or to expand existing operations? Our research indicates successful forestland investors need high stumpage prices relative to costs to continue to operate, as well as easy access to a nearby processing facility. Do you see stumpage prices and/or the availability of processing facilities as obstacles to continued success? Or are there more pressing obstacles?
    b. In your view, what factors undermine the Ugandan wood processing industry? Our research indicates that wood processing sectors struggle when lumber prices are low, raw material prices are high, government policies and rules prevent commerce, unreliable transit systems, high and/or unavailable electricity and fuel, and more.
    c. What do you think is the one thing Uganda needs to grow the wood processing industry in your country? Put another way, what major area could improve to induce new mills to begin operating in Uganda?
    d. Imagine you have the capital and permits to build a new permanent wood processing facility in Uganda. Where would you build such a facility? Near the raw material source, or near end-consumers? Close to competing processing facilities, or further away?
    e. If there's time: Are there any types of customers in Uganda that you expect to demand more wood products of in the coming years? Are there products that

aren't currently produced in Uganda that you'd like Ugandan companies to produce?

- 26 and 31 JAN 23 Forestland Investors 1 and 2
    a. Our research indicates that viable forestland investments require stumpage prices and timber growth rates to be high relative to costs, along with ready access to processing facilities. Are these factors the most important ones affecting investors' willingness to make new investments in forestland in emerging markets and expand existing ones? Or are other obstacles more pressing, such as secure access to land?
    b. Our research also indicates that wood-processing sectors struggle when lumber prices are low, raw material prices are high, electricity, fuel, and transport are costly or unreliable, and government policies and rules do not actively encourage commerce. Are these factors the most important ones affecting investors' willingness to make new investments in wood-processing facilities in emerging markets and expand existing ones? Or are there more pressing obstacles?
    c. Imagine you have the capital and permits to build a new wood-processing facility in an emerging market where you already invest in forestland. Where would you build such a facility? Near the raw material source, or near product markets (or ports)? Close to competing processing facilities, or further away?
    d. Are there wood products that either are not currently produced in emerging markets or are undersupplied in them that have the potential to earn or attract returns for investors? For example, mass timber, CLT, wood pellets, etc.

Analyzing Literature Review and Focus Groups

While reviewing documents, whether academic literature, white papers, or gray literature, we analyzed and noted when a document directly addressed a sub research question or directly pointed to a factor influencing investment. Each of us reviewed documents through close reading, highlighting key terms, and note-taking. We met regularly to inform each other of progress toward developing, to the extent possible, comparable sources of information related to our research subquestions. Coordination between group members consisted of discussing potential factors we found that related to our subquestion, and ensuring that we were not overlapping factors. If a factor applied to multiple subquestions, we decided which group member would be responsible for finding data layers related to that factor. We did not mind if the same literature revealed factors related to multiple subquestions.

Similarly, we transcribed each focus group, de-identifying the transcripts to remove names and personal information. We then analyzed the transcriptions and summaries by highlighting and noting any statements from participants that directly addressed a research subquestion or directly pointed to a factor influencing investment.

After reading through documents and focus group transcriptions, we uploaded all documents and transcriptions into NVivo 12, a widely-used software package for qualitative data analysis. For each of our specific research subquestions, we individually coded investment factors mentioned in the literature or by focus group participants. Then, we analyzed the quantity of mentions and documents under each code. Since each code (node) in NVivo stands for an investment factor, we understood that the more times a document references a code, and the more documents in a code, the more important the investment factor.

Choosing Sources for Data Layers

For most of the factors we identified, there was an obvious type of spatial, or at the very least, tabular dataset to find. If there wasn't a direct relationship between a factor and a dataset, then we needed to find data representative, or analogous to, that factor. Once we identified the type of data we needed, we chose our dataset based on its date and source. We identified datasets from well-known organizations with long histories of reliable data collection. Secondarily, we aimed to gather the most recent and up-to-date data from organizations that have the most on-the-ground knowledge, or collected information from knowledgeable local sources.

Results

Research Subquestion One: *What are the governmental, land use, and policy factors that encourage/hinder forestry investment in Uganda?*

Literature Review and Focus Groups

Inductive coding in NVivo of the relevant literature, an expert interview, and input from focus groups resulted in the identification of 17 factors that affect forestland investment. The factors fell into five overarching categories of Institutional Support, Land Security, Strength of Various Land Rights, Country Risk, and Legal Timber (Table 1).

The literature review began with a search using the terms in Table 1. In addition, the client recommended an expert on land tenure at FAO, Safia Aggarwal, to consult for both her interpretation of the factors and to refer the team to further resources on the topic. Based on her guidance, we reviewed two additional sources:

- "The State of the World's Forests," for information on forest ownership and forest reserve leases (FAO 2022)

- "Status of community-based forestry and forest tenure in Uganda," an FAO policy brief that also contains more details on the Sawlog Production Grant Scheme (FAO 2019)

The focus group interviews with Ugandan tree growers, wood processing facility owners, and global forestland investors reinforced the existing themes and specifically emphasized the Legal Timber category. They cited frustration with the weakness or lack of government enforcement of timber certification, taxation, and streamlined management and harvest procedures. Their input also strengthened the importance of the Country Risk category, referring to uncertain land tenure and civil unrest as an important factor in their decision-making.

Factors in this subquestion are extremely interrelated such that it is difficult to isolate one factor from another. For example, sustainable forest management and forest-dependent livelihoods can be improved through support from the national government via land tenure reform, which includes forest tenure reform (Nsita et. al. 2020); however, security will be stronger with the recognition of the customary tenure system that accounts for approximately 80% of Uganda's land and these unregistered land parcels' boundaries (Musinguzi et. al. 2021). The following sections describe each category of factors at a high level and the rationale for their grouping.

Institutional Support Factors

Institutional support can occur in many different forms. Government agencies such as Uganda's National Forest Authority can help in leasing land to investors for forest operations, provide tax advantages, implement land tenure reform and arbitrate conflicts, and facilitate forest product export and trade (Ofoegbu and Babalola 2015, Binkley et. al. 2020, Nsita et. al. 2020, FAO 2020). Non-governmental organizations (NGOs) and development organizations can provide technical and financial support via incentive programs such as SPGS, as well as lend confidence to the program (SPGS 2023, Binkley et. al. 2020). Civil society organizations (CSOs) are critical in connecting both government agencies and NGOs to individuals and groups engaged in forestry to advocate their interests, provide technical and financial support, and build capacity and awareness of sustainable forestry practices (Nsita et. al. 2020, FAO 2019). Technical support includes information on plantation practices, management regimes, and basic forestry information for the area such as suitable species, growth rates, soils, and marketability - in fact, Binkley et. al. describes the lack of this information as a "classic market failure" (Binkley et. al. 2020). This information is helpful in assessing the appeal of investment as well as saving participants time and money in practice (Binkley et. al. 2020).

Land Security Factors

Land ownership and land tenure rights highly affect the likelihood of a long-term investment in forestland (Castrén et al. 2014). In countries where obtaining legal rights to land is clear, institutions are able to create a longstanding investment in forestland (Binkley et al. 2020). In many developing countries, public forestland can be leased to an enterprise or community by granting them forest concessions; this means that the enterprise or community has a contractual right to harvest and manage the forests and timber on that land for a specified period of time. Depending on its implementation, forest concessions can encourage or discourage investment. For instance, inconsistent or changeable regulations on forest concessions or lack of government enforcement may lead to financial uncertainty. On the other hand, if consistent and enforced, forest concessions can help regulate forest product prices, create monetary incentives, and provide land tenure security, as well as other socioeconomic benefits (FAO 2018). Government land leases to private investors were crucial to the success of Uganda's SPGS (Ofoegbu and Babalola 2015). The ease, accuracy, coverage of land registration can also help prevent future land conflict and promote sustainable forest management (Hurlbert and Krishnaswamy et. al. 2019). Finally, land security can be increased through local and district-level institutions who educate people on their rights and allow them to be defended in court (LEMU n.d.).

Strength of Various Land Rights Factors

Once land is acquired, it may be another matter to understand one's rights on the land and its resources, including the rights of others who have long been managing the land (FAO 2019, FAO 2022). Well-defined and straightforward land rights and land law have motivated institutional forestry investment in the past (Binkley et. al. 2020). This category addresses the strength of different types of land rights by tenure systems, groups, and natural resource usage (timber).

Local people may challenge government ownership of land in rural areas and therefore its land concessions to investors, leading to social, political, and environmental conflict that impact both the investment and investor's reputation (Binkley et. al. 2020). Instead, the legal recognition of the customary, Indigenous, or regional tenure systems can provide clarity on land use and rights for landowners. For instance, formalized community-based forestry programs can use customary tenure rights and their traditional authorities as a foundation to avoid and mediate clashes among forest users (FAO 2022, LEMU n.d.). The African customary tenure system has been shown to have widely agreed upon rules and creates the security for long-term investments such as tree growing (LEMU n.d., Hurlbert and Krishnaswamy et. al. 2019).

Additionally, greater security of land rights for women boosts their contributions to sustainable land management, increasing their engagement in tree planting, soil management, and monetary income (Hurlbert and Krishnaswamy et. al. 2019).

One of the forestland investor focus groups mentioned that "social mapping" must be performed to identify the local communities, their expectations, and potential land rights conflicts to then negotiate an acceptable agreement for all (Focus Group 2). As Binkley et. al. states, governments can simultaneously create land tenure conditions that encourage forestry investments, such as those from pension plans, and protect locals' rights (Binkley et. al. 2020).

Country Risk Factors

As established above, maintaining land ownership and avoiding conflicts that can hinder operations is essential. Country risk refers to conflicts that arise from wider-ranging factors such as civil unrest and political corruption. Globally, politicians, government officials, and land agencies have coordinated land grabs despite local usage (Hurlbert and Krishnaswamy et. al. 2019). This is due to corrupt government land agencies, illegal land usage, and the absence of enforcement of resource extraction regulations (Hurlbert and Krishnaswamy et. al. 2019). Rule of law and governmental integrity has also been important in protecting land rights from being arbitrarily removed or reduced, which disincentivizes sustainable forest management (FAO 2022).

In a survey of national and district-level government officials in Uganda on forest tenure reform, nearly a third of participants described that politicians "interfered more than they supported the process of reform implementation" and have pressured technical staff to participate in or protect illegal forest activities (Nsita et. al. 2020).

Legal Timber Factors

The government must set clear regulations, efficient processes for compliance, and enforce the rules on legal and sustainable timber evenly among international and domestic investors (Binkley et. al. 2020). Regulations may range from protecting natural resources, standards for grading and harvesting timber, or obtaining a timber export license, but all should be "transparent, efficient, and obviously necessary" to encourage financial investment (Binkley et. al. 2020, FAO 2020). Simplified regulations that remove needless hurdles and streamlined processes can promote sustainable resource usage, wood processing, and value-added product creation (FAO 2022).

This category was raised by all focus groups as essential, additionally referring to keeping illegal timber off the market and equal taxation. New Generation Plantations has raised concerns about "informal timber" in Uganda, which is often sold on the roadside and at a cheaper price because of tax evasion (New Generation Plantations 2019). This presents additional burdens to tree growers and wood processing facility owners to continue sustainable practices when they can be easily undercut by those who do not abide by the same rules.

Factor	Investor Preference	Sources	% of Documents Mentioning Factor	Total References of Factor Across All Documents
Institutional Support Factors				
Support from government agencies	Higher	Binkley et. al. 2020, Musinguzi et. al. 2021, Focus Groups 1-2, Nsita et. al. 2020, LEMU n.d., Ofoegbu and Babalola 2015, Hurlbert and Krishnaswamy et. al. 2019, FAO 2019, FAO 2020	59%	45
Support from NGO incentive programs	Higher	SPGS 2023, Binkley et. al. 2020, Focus Group 3, Nsita et. al. 2020, Ofoegbu and Babalola 2015, Jacovelli 2010	35%	8
Support from CSOs	Higher	Nsita et. al. 2020, FAO 2019, FAO 2022	18%	6
Ease of doing business and exporting	Higher	FAO 2020, Focus Group 1	12%	7
Land Security Factors				
Ease and feasibility of land titling and registration	Higher	Binkley et. al. 2020, Musinguzi et. al. 2021, Nsita et. al. 2020, Hurlbert and Krishnaswamy et. al. 2019, Aggarwal 2022, FAO 2019, Gochberg 2020, FAO 2022	47%	20

Strength of general land tenure	Higher	Binkley et. al. 2020, Focus Groups 2-3, Nsita et. al. 2020, Hurlbert and Krishnaswamy et. al. 2019, FAO 2022, Qasim 2022	47%	16
Land availability via government concessions	Higher	Binkley et. al. 2020, Ofoegbu and Babalola 2015, FAO 2022, Focus Groups 2-3	29%	87
Government enforcement of land tenure	Higher	Binkley et. al. 2020, Focus Group 2, Hurlbert and Krishnaswamy et. al. 2019, FAO 2022	24%	5
Use of technology in land administration	Higher	Qasim 2022	6%	1
Strength of Various Land Rights Factors				
Recognition or formalization of customary and Indigenous rights	Higher	Binkley et. al. 2020, Musinguzi et. al. 2021, Focus Group 2, Nsita et. al. 2020, Hurlbert and Krishnaswamy et. al. 2019, Aggarwal 2022, FAO 2019, Gochberg 2020, FAO 2022	53%	27
Recognition or formalization of gender equity in land rights	Higher	Hurlbert and Krishnaswamy et. al. 2019, FAO 2019, FAO 2022	18%	5
Recognition or formalization of timber rights	Higher	Binkley et. al. 2020, Focus Group 3, FAO 2019	18%	4
Country Risk Factors				

Risk of land grabs	Lower	Binkley et. al. 2020, Musinguzi et. al. 2021, Focus Groups 2-3, Nsita et. al. 2020, LEMU n.d., Ofoegbu and Babalola 2015, Hurlbert and Krishnaswamy et. al. 2019, FAO 2022	53%	18
Government stability	Higher	Nsita et. al. 2020, Hurlbert and Krishnaswamy et. al. 2019, FAO 2022, Aggarwal 2022, Focus Groups 2-3	35%	16
Legal Timber Factors				
Government enforcement of timber certification	Higher	Binkley et. al. 2020, Nsita et. al. 2020, New Generation Plantations 2019, FAO 2020, Focus Groups 1-3	41%	18
Government enforcement of timber taxes	Higher	Binkley et. al. 2020, Focus Groups 1-3	24%	5
Streamlined procedures and government enforcement for management and harvest levels	Higher	Binkley et. al. 2020, Focus Group 3, FAO 2022	18%	4

Table 1: Governmental, land use, and policy factors that affect sustainable forest product value chain development, grouped by high-level categories.

Most Important Factors

The top factors (Table 2) were chosen based on the percentage of documents that mentioned each factor.

Factor	Investor Preference	% of Documents Mentioning Factor
Support from government agencies	Higher	59%
Recognition or formalization of customary and Indigenous land rights	Higher	53%
Risk of land grabs	Lower	53%
Ease and feasibility of land titling and registration	Higher	47%
Strength of general land tenure	Higher	47%

Table 2: The top 5 governmental, land use, and policy factors taken out of Table 1.

Choosing Sources for Data Layers

Many datasets that represent a country's performance in the above factors exist at the national level. The most relevant ones (Table 3) are in tabular form and are sourced from international development agencies, global data collections, and government sources such as the World Bank Group, Our World in Data, the Land Portal Foundation, Prindex, and Uganda's Ministry of Lands, Housing and Urban Development (MLHUD).

For many of the factors, data can be drawn from two long-term assessments conducted by the World Bank Group's International Development Agency (IDA): the Land Governance Assessment Framework (LGAF), which rates countries' practices around land governance; and the Country Policy and Institutional Assessment (CPIA), which rates the effectiveness of countries' policies and institutions in bolstering sustainable growth and economic activity (World Bank Group 2023, World Bank Group 2021).

The Ugandan MLHUD is able to supply finer-grained data at a subnational level, such as the number of digitized land titles per Ministry Zonal Office and ratings of land use compliance in urban local governments. While the former would be more helpful if contextualized as a proportion of total land parcels and the latter if for rural local governments, they are listed here as sources that can potentially be included in se.plan if paired with other data.

The World Bank's 2020 Worldwide Governance Indicators which is already in se.plan and therefore not included in Table 3.

Factor	Dataset	Purpose	Level of Detail	Format
Support from government agencies *and* Government enforcement of land titles and registered land *and* Government enforcement of land tenure	CPIA property rights and rule-based governance rating [World Bank Group, 2021]	Assess the ability of the government to promote economic activity through enforcement of property and contract rights	National	Tabular
Strength of general land tenure *and* Recognition or formalization of customary and Indigenous rights	Perceived property security index [Prindex, 2020]	Measure individual perception of their land security and level of documentation	National	Tabular
Recognition or formalization of customary and Indigenous rights	Customary tenure rights are (i) recognized and (ii) protected in practice [World Bank Group, 2016]	Assess the practices that recognize and protect lands held under Indigenous tenure (ranked A-D)	National	Tabular
Recognition or formalization of customary and Indigenous rights	Indigenous rights to land & forest are (i) recognized and (ii) protected in practice [World Bank Group, 2016]	Assess the practices that recognize and protect lands held under customary tenure (ranked A-D)	National	Tabular
Recognition or formalization of customary and Indigenous rights	Boundary demarcation of communal land [World Bank Group, 2016]	Assess the practices that delimit land boundaries (ranked A-D)	National	Tabular
Risk of land grabs	Land disputes are a small share of formal legal cases [World Bank Group, 2016]	Contextualize the proportion of formal legal cases that are land conflicts (ranked A-D)	National	Tabular
Ease and feasibility of land titling and registration	Time required to register property [World Bank Group, 2017]	Understand the time (days) needed to title and register land	National	Tabular
Ease and feasibility of land titling and registration *and* Use of technology in land administration	Digitized Land Title Records per Ministry Zonal Office [Uganda's MLHUD, 2015]	Proxy to characterize the accuracy and ease of land titling in different areas of Uganda	Subnational	Tabular

Factor	Dataset	Purpose	Level of Detail	Format
Strength of general land tenure *and* Government enforcement of land tenure	Registries information is up-to-date and reflect ground reality [World Bank Group, 2016]	Characterize the accuracy of the land registry (ranked A-D)	National	Tabular
Strength of general land tenure *and* Government enforcement of land tenure	Land Use Compliance for Urban Local Governments [Uganda's MLHUD, 2016]		Subnational	Tabular
Government stability	Political stability and absence of violence/terrorism (index) [World Bank Group, 2017]	Quantifies the "perceptions of likelihood that the government will be destabilized or overthrown" (World Bank Group 2017)	National	Tabular
Government enforcement of land tenure *and* Government enforcement of land rights for legal timber	Rural land tenure rights (i) recognized and (ii) protected in practice [World Bank Group, 2016]	Assess the land practices that recognize and protect rural lands, which are where forestland is located (ranked A-D)	National	Tabular
Support from CSOs	Civil Society Participation index [Our World in Data, 2021]	Understand how much citizens participate in organizations that influence policy	National	Tabular
Ease of doing business and exporting	Ease of doing business score [World Bank Group, 2017]	Understand how conducive the regulatory environment is to conducting business	National	Tabular
Ease of doing business and exporting	Cost to export (border compliance) [World Bank Group, 2017]	Quantify the cost (USD) of compliance with customs, inspections, handling, and other processes for export	National	Tabular
Ease of doing business and exporting	Cost to export (documentary compliance) [World Bank Group, 2017]	Quantify the cost (USD) to provide the documents necessary for export, as required by the origin, destination, and transit governments	National	Tabular

Table 3: Datasets for governmental, land use, and policy factors, with factors in descending importance as defined by the number of sources that mention it.

Data Manipulation and Final Layers

The following datasets are recommended for addition to se.plan, based on the ranking and number of factors that each dataset addresses as well as covering a spread of factors.

The CPIA rating has 16 dimensions that contribute to a country's overall score, but there are 4 dimensions that are especially relevant for sustainable forestland investment factors. These are described in the framework's 2021 criteria:

- **Criteria #6, "Business Regulatory Environment"**: how much the law, regulations, and policy support or impede private business, including those related to labor and land markets, export and trade, and business operations (World Bank Group 2021).
- **Criteria #11, "Policies and Institutions for Environmental Sustainability"**: how much the policies and institutions protect and promote sustainable use of natural resources, such as access to information, public participation, and coordination between sectors (World Bank Group 2021).
- **Criteria #12, "Property Rights and Rule-based Governance"**: how much the legal system and rule-based governance framework protect and enforce property and contract rights, thereby facilitating economic development. This criteria factors in the negative effect of crime and violence (World Bank Group 2021).
- **Criteria #16, "Transparency, Accountability, and Corruption in the Public Sector"**: how much government officials and politicians are answerable for their behavior, including the transparency of finances and decision-making processes (World Bank Group 2021).

Two metrics were chosen from the LGAF:

- **"Customary tenure rights are (i) recognized and (ii) protected in practice"**: This is the most relevant to add since 80% of Uganda is under customary tenure although the assessment has metrics for various tenure systems (Musinguzi et. al. 2021, World Bank Group 2023).
- **"Land disputes are a small share of formal legal cases"**: This metric can give a limited view of the prevalence of land disputes, provided they are adjudicated through a formal legal system (World Bank Group 2023).

One metric was chosen from the World Bank Group's Doing Business report:

- **"Time required to register property"**: The days needed to register land and reflects the cost of time (World Bank Group 2019).

Two metrics were chosen from Prindex:

- **"Tenure security"**: The percentage of people who feel that they are either very unlikely or unlikely to lose their property rights in the next 5 years (Prindex 2020).
- **"Formal documents"**: The percentage of people who have formal, legal documents for living on and using their land (Prindex 2020).

All metrics were downloaded in a tabular format and joined to ESRI country polygons, matching on country name. This was done in ArcGIS Pro to create individual feature classes for each data source.

Data Limitations

Subnational data were hard to come by for Uganda. While Uganda's MLHUD has certain subnational data, the two listed in Table 3 (the number of digitized land titles per Ministry Zonal Office and ratings of land use compliance in urban local governments) need supplemental data. For instance, the number of digitized land titles would be more useful if calculated as a proportion of all formalized land titles, all land parcels (if known), or land area. Land use compliance for local governments would be more useful for rural areas, where forestland and wood processing facilities are located. Due to time, we were not able to provide this contextual data. However, MLHUD is a promising data source and could use more investigation.

Generally, the factors in this subquestion quantify "country risk," which is a measure of the political, economic, and social conditions and events that affect financial investment (OCC 2016). National metrics can help give a high-level view but miss the details of extremely nuanced and complex situations on the ground.

Evaluating Credibility of Data Layers

Datasets were chosen for their recency, authoritativeness of source, and availability of public metadata that documents systematic methodologies. All datasets come from reputable sources and studies, which in some cases have gone through multiple rounds of review and revision over years. The CPIA has been performed since the late 1970s with multiple reviews and revisions over the decades (World Bank Group 2021). Prindex captures more individual-level detail from those surveyed in each country and states that its methods "are more inclusive of the views of women, younger people, and people living in informal housing" (Prindex 2020) which is a good complement to the studies and metrics calculated by development agencies and academia.

Some of the indicators in Table 3 are from the World Bank Group's Doing Business report, which was discontinued in 2021. Internal reports of "data irregularities" and "ethical matters" resulted in a pause to review and ultimately terminate the reporting (The World Bank 2021). An in-depth external review found political influence from several countries and individuals, resulting in questionable last-minute changes to the methodology (Machen et. al. 2021). These events specifically affected scores for China in the 2018 report and scores for the United Arab Emirates, Saudi Arabia, and Azerbaijan in 2020 (Machen et. al. 2021). Assuming that the methodology changes affected other countries' scores as well, we recommend using data from the 2017 Doing Business report, not more recent reports.

Research Subquestion Two: *What transportation and downstream value-chain factors (mills, roads, ports, rail, existing plantations) affect processing facility investment decisions in Uganda?*

Literature Review and Focus Groups

A review of available relevant literature plus focus group participant feedback revealed many infrastructure factors related to investment in wood-processing facilities in emerging markets. NVivo coding analysis revealed 21 factors to be important to wood-processing facility location placement.

In his spatial econometric analysis of where to locate lumber mills in the U.S. South, Aguilar (2009) identified, through surveys and factor analysis, several factors necessary for a successful lumber mill investment, including many non-policy factors relevant to this research subquestion. Through a Bayesian spatial autoregressive probit model with 19 location factors, Aguilar identifies only six as statistically significant: "stumpage prices, availability of labor, presence of a highway, local availability of forest resources, energy costs, and land values" (Aguilar 2009). Many of these six factors, some of which we renamed (Table 4), proved to be the most-coded in our NVivo analysis for wood processing facility location factors.

The focus group participants corroborated Aguilar's model, particularly the international forestry investors. For example, participants routinely emphasized the need to have adequate transportation networks and reliably close roads from which to receive logs from the forest. They also emphasized that they would rather transport a board of lumber than a log of timber, as the former is less costly. Therefore, wood processing facility investors would rather locate a mill near, or even within, commercial forestry operations to minimize the distance logs have to travel to the mill.

The literature and focus group participants alike emphasize the need to locate mills nearby adequate stocks of commercial timber (Aguilar's "local availability of forest resources"). Not only does that mean locating the mill physically close to a forest, as mentioned above, but also in a forest that generally has a high volume, or with high projected growth and yield. A mill operator would not locate near a forest with a low supply of its main raw material input.

Mills use various inputs, and these proved especially important as location factors. Besides stumpage availability and transportation costs, our NVivo analysis revealed that costs and availability of labor and power (electricity) and stumpage prices (not only physically available timber stocks) all contributed to investment decisions, with locations with lower costs and better access to low-cost timber supply preferred. Ugandan wood processors and tree growers told us in the focus group that unreliable electricity, or indeed lack of access to any electricity in rural areas, makes locating mills impossible or prohibitively expensive even in areas with high commercial timber volume. Other sources, including at least one facility investor, lamented the lack of labor force availability and mentioned the need for competent local managers and workers. Similar to electricity prices, locations where workers earn relatively low wages are more favorable than those with relatively higher wages. And of course, a high level of supply in a competitive timber market will drive down stumpage prices, preferable for mill operations where wood often accounts for over 50% of variable costs (Fu 2021, Figure 4; Griffin et al. 2020).

Griffin et al. (2020) developed a linear programming model to locate mills in locations within the southeast United States that minimize variable costs. Like Aguilar and focus group participants, Griffin et al. considered costs of standing timber, electricity, labor, and transportation in their model for low-cost mill locations.

Some sources mentioned competition, i.e., existence of other local mills, as a negative factor in locating new mills, but no focus group or source mentioned the existence of nearby mills as an impediment for investing. If anything, the presence of other mills signals that factors for investment in new facilities are favorable (Griffin et al 2020).

Much discussion in the literature and the focus groups centered on the need for wood product markets in which to sell products produced in processing facilities. Focus group participants in Uganda lamented the lack of a robust domestic market for quality wood products (and the resulting low wood product prices), while international investors in focus groups identified the presence of a domestic wood products market as favorable, or even preferable to export markets. Exports markets become key, however, when products fetch better prices in the export market or a domestic market for quality wood products simply does not exist. Then, the need to cheaply transport lumber, or even logs, to the nearest international port becomes paramount, and the literature and focus groups identified a short distance between mills and ports as a key location factor. Related to export markets, exchange rate risk also occasionally came up in focus groups and the literature. Binkley et al. (2020) in particular point to exchange rate risk as an important factor for forestry investments in countries where most timber is exported. It is difficult to hedge against foreign exchange rate fluctuations, and even when domestic logs are effectively priced in USD, production costs are priced in local currency, so investors want to short the local currency (Binkley et. al 2020).

Many sources agreed that wood product prices – whether in the domestic or export market – are an important factor in locating a new processing facility. In a white paper on private equity investment in lumber mills, Fu (2021) emphasizes that high lumber prices relative to timber cost will help spur investment in new processing facilities. Dezember (2021), however, in a *Wall Street Journal* article on lumber mill investment amid record-high lumber prices in the United States, notes investors are hesitant to spend the billions in capital for a multi-year buildout of a new mill just because prices are high. Rather, they are more likely to invest in efficiency upgrades at existing mills. Experts that Dezember (2021) interviewed implied that the best time to invest in a new mill is when lumber prices are expected or projected to rise, not when they have already peaked.

Finally, the literature and focus groups revealed a number of other, related factors relevant to locating new processing facilities (Table 4).

Factor	Investor Preference	Sources	% of Documents Mentioning Factor	Total References of Factor Across All Documents
Distance Factors				
Distance to Major Roads	Shorter	Aguilar 2009, Binkley et al. 2020, Focus Group 1.9, Focus Group 1.31, Fu 2021, Griffin et al. 2020, Howard 2019	70%	12
Distance to Seaports (and general export market access)	Shorter	Aguilar 2009, Binkley et al. 2020, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31, Howard 2019	60%	18

Distance to Existing Plantations	Shorter	Aguilar 2009, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31, Fu 2021	50%	24
Distance to Processing Facilities	Neutral	Aguilar 2009, Fu 2021, Griffin et al. 2020	30%	4
Cost Factors				
Stumpage Prices	Lower	Aguilar 2009, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31, Fu 2021, Griffin et al. 2020	60%	19
Fuel (Diesel, Petrol, Woodchips, etc.) Prices	Lower	Aguilar 2009, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31, Griffin et al. 2020	50%	8
Electricity Prices	Lower	Aguilar 2009, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31	40%	8
Wages	Lower	Aguilar 2009, Focus Group 1.26, Fu 2021, Griffin et al. 2020	40%	6
Land Prices	Lower	Aguilar 2009, Binkley et al. 2020	20%	2
Mobile Sawmill Price	Lower	FAO 2021, Howard 2019	20%	2
Input Supply Factors				
Commercial Species Stumpage Volume	Higher	Aguilar 2009, Binkley et al. 2020, FAO 2021, Focus Group 1.9, Focus Group 1.31, Fu 2021, Griffin et al. 2020, Howard 2019	80%	16

Labor Force Participation	Higher	Aguilar 2009, Binkley et al. 2020, Dezember 2021, Focus Group 1.26, Focus Group 1.31	50%	15
Number of Forestry Operations Managers	Higher	Aguilar 2009, Binkley et al. 2020, Focus Group 1.31, Fu 2021	40%	4
Species Mix	N/A	Focus Group 1.31	10%	1
Demand Factors				
Wood Product Prices	Higher	Aguilar 2009, Dezember 2021, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31, Fu 2021, Howard 2019	70%	20
Domestic Market	Stronger	Binkley et al. 2020, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31, Fu 2021, Howard 2019	60%	22
Infrastructure Quality Factors				
Transportation Infrastructure Quality	Better	Aguilar 2009, Binkley et al. 2020, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31	50%	8
Electricity Access	More	Aguilar 2009, Focus Group 1.9, Focus Group 1.26, Focus Group 1.31	40%	11
Financial Risk Factors				
Risk-Adjusted Returns (including country risk premiums)	Lower	Binkley et al. 2020, Focus Group 1.26, Focus Group 1.31, Fu 2021	40%	16

Exchange Rate Risk	Lower	Binkley et al. 2020, Focus Group 1.26, Focus Group 1.31, Fu 2021	30%	8
Access to Patient Capital	More	Binkley et al. 2020, Focus Group 1.9	20%	6

Table 4: Infrastructure and economic factors considered when locating a wood processing facility.

Most Important Factors

We sorted the above factors for mill infrastructure by the share of documents that mentioned a factor, then by total references. We consider the first five of these factors (Table 5) to be the most important factors related to this subquestion. Distance to Seaports was tied with Stumpage Prices as the fifth-most important factor. We selected Seaports to be in the most important factor group because focus group participants in particular emphasized this factor, and because it is more geospatially relevant than prices.

Factor	Investor Preference	% of Documents Mentioning Factor
Commercial Species Stumpage Volume	Higher	80%
Wood Product Prices	Lower	70%
Distance to Major Roads	Shorter	70%
Domestic Market	Stronger	60%
Distance to Seaports	Shorter	60%

Table 5: Top-Five infrastructure and economic factors considered when locating a wood processing facility.

Choosing Sources for Data Layers

For this subquestion, we chose data layers for factors identified by the literature and NVivo as most important to wood processing facility investment decision making. We did not look for datasets for factors that were also important to other research subquestions, like product prices and availability of domestic demand (Tables 9-12).

We obtained our data layers for this subquestion from several sources. Praise Atwiine, an FAO employee in Uganda, provided us with a shapefile of current commercial tree plantations in

Uganda. Road and port layers were readily available in the World Bank's data repository, and we obtained a raster of land-based travel times from Weiss and Nelson (2018). se.plan already includes a layer for forestry employment, and to that we add the labor force participation rate of Uganda in general. For electricity data, access metrics come from a 2018 raster dataset of electricity grids in sub-Saharan Africa, while electricity prices come from announced tariffs in Uganda for 2023. The World Bank provides tabular data for Labor Force Participation, and FAO white papers provide projected commercial species harvest volumes in Uganda (Tables 6-7)

Factor	Dataset	Rationale
Commercial Species Stumpage Volume	FAO, *Unlocking Future Investments in Uganda's commercial forest sector* and Howard, *Assessment of the Ugandan Commercial Timber Plantation Resource and the Markets for Its Products*	Best available data on projected commercial species volume in Uganda
Wood Product Prices	3rd Research Question	N/A
Distance to Major Roads	World Bank, Africa Infrastructure Country Diagnostics (AICD) and Weiss and Nelson, Global Friction Surface 2019	The World Bank has reliable, trusted, regularly updated shapefiles. Weiss and Nelson have a reliable, tested, updated friction surface layer for land speeds.
Domestic Market	3rd and 4th Research Questions	N/A
Distance to Seaports	World Bank, International Ports and Weiss and Nelson, Global Friction Surface 2019	The World Bank has reliable, trusted, regularly updated shapefiles. Weiss and Nelson have a reliable, tested, updated friction surface layer for land speeds.

Table 6: Rationales for choosing the geospatial data layers for the top-five factors related to infrastructure and economic decision-making for locating a wood processing facility.

Factor	Dataset	Purpose	Level of Detail	Date	Format
Distance Factors					
Distance to Major Roads	World Bank, Africa Infrastructure Country Diagnostics (AICD)	Calculates Cost Distance to Uganda's major highways.	Subnational	2009, shapefile updated 2017	Shapefile

Distance to Major Roads	Weiss and Nelson, Global Friction Surface 2019	" "	Subnational	Updated 2020	Raster (30 arc-seconds)
Distance to Seaports (export market access)	World Bank, International Ports	Calculates Cost Distance to Uganda's nearest international seaports (Mombassa, Dar es Salaam).	Subnational	Updated 2020-2021	Shapefile
Distance to Seaports (export market access)	Weiss and Nelson, Global Friction Surface 2019	" "	Subnational	Updated 2020	Raster (30 arc-seconds)
Distance to Existing Plantations	FAO/Atwiine, Uganda Plantations Shapefile	Calculates Cost Distance to Uganda Commercial Tree Plantations	Subnational	2022?	Shapefile
Distance to Existing Plantations	Weiss and Nelson, Global Friction Surface 2019	" "	Subnational	Updated 2020	Raster (30 arc-seconds)
Cost Factors					
Stumpage Prices	See Third and Fourth Research Subquestion Results				
Electricity Prices	Uganda Electricity Regulatory Authority, Tariff Schedules	Assess country-wide commercial electricity prices	National	2023	Tabular
Land Prices	The opportunity cost layer in se.plan	The se.plan opportunity cost layer serves as a proxy for land prices in rural areas	Subnational	2020	Raster (30 arc-seconds)
Input Supply Factors					
Commercial Species Stumpage Volume	FAO, *Unlocking future investments in Uganda's commercial forest sector*, and Howard, *Assessment of the Ugandan Commercial Timber Plantation Resource and the*	National-level volume projections for Uganda.	National	2020, 2019	Tabular

	Markets for Its Products				
Labor Force Participation	Forest Employment Layer in se.plan	Country-wide estimate of forest employment.	National	2020	Tabular
Labor Force Participation	World Bank, Labor Force Participation rate (% of total population ages 15+)	General labor force available for any type of work	National	2021	Tabular
Demand Factors					
Wood Product Prices	See Third Research Subquestion Results				
Domestic Market	See Third and Fourth Research Subquestion Results				
Infrastructure Quality Factors					
Electricity Access	Falchetta et al., *A high-resolution gridded dataset to assess electrification in sub-Saharan Africa*,	Assess electrification in sub-Saharan Africa	Subnational	2019	Raster (30 arc-seconds)
Financial Risk Factors					
Risk-Adjusted Returns (including country risk premiums)	Country Risk Premiums is already a spatial layer in se.plan	Tabular			

Table 7: Shapefile, raster or tabular datasets related to infrastructure and economic factors considered when locating a wood processing facility.

Data Manipulation and Final Layers

For distance factors related to this subquestion, we created distance cost layers using Weiss and Nelson' 2019 Global Surface Friction layer as a cost, and feature layers for plantation polygons, port points, and road lines. The results show the cost (minutes per meter) associated with moving one kilometer in geographic space. To create these layers, we first downloaded Weiss and Nelson's publicly available surface friction from Google Earth Engine (defining a region of interest), and then used ArcGIS Pro's Cost Distance tool. We also provided the raw cost raster from Weiss and Nelson clipped to Uganda's borders in case FAO or se.plan users want general travel times in an area as a quick heuristic. se.plan users should be able to use this layer to threshold a maximum distance or travel time they'd want a processing facility to be from a road (Figure 1), plantation, or port. The final raster has WGS 1984 coordinates at approximately 1-km spatial resolution (30 arc-seconds)

For the cost distance to the ports layer, we provide the cost distance from seaports in Mombasa and Dar es Salaam in Kenya and Tanzania (Figure 2). Final rasters have WGS 1984 coordinates at approximately 1-km spatial resolution (30 arc-seconds). The final raster has WGS 1984 coordinates at approximately 1-km spatial resolution (30 arc-seconds).

For the electricity access layer, we downloaded Falchetta et al.'s publicly available electrification rate raster from Google Earth Engine, then clipped it to Uganda's political boundary. The resulting raster shows the percentage of an area (1-km) that has access to electricity. The final raster has WGS 1984 coordinates at approximately 1-km spatial resolution (30 arc-seconds).

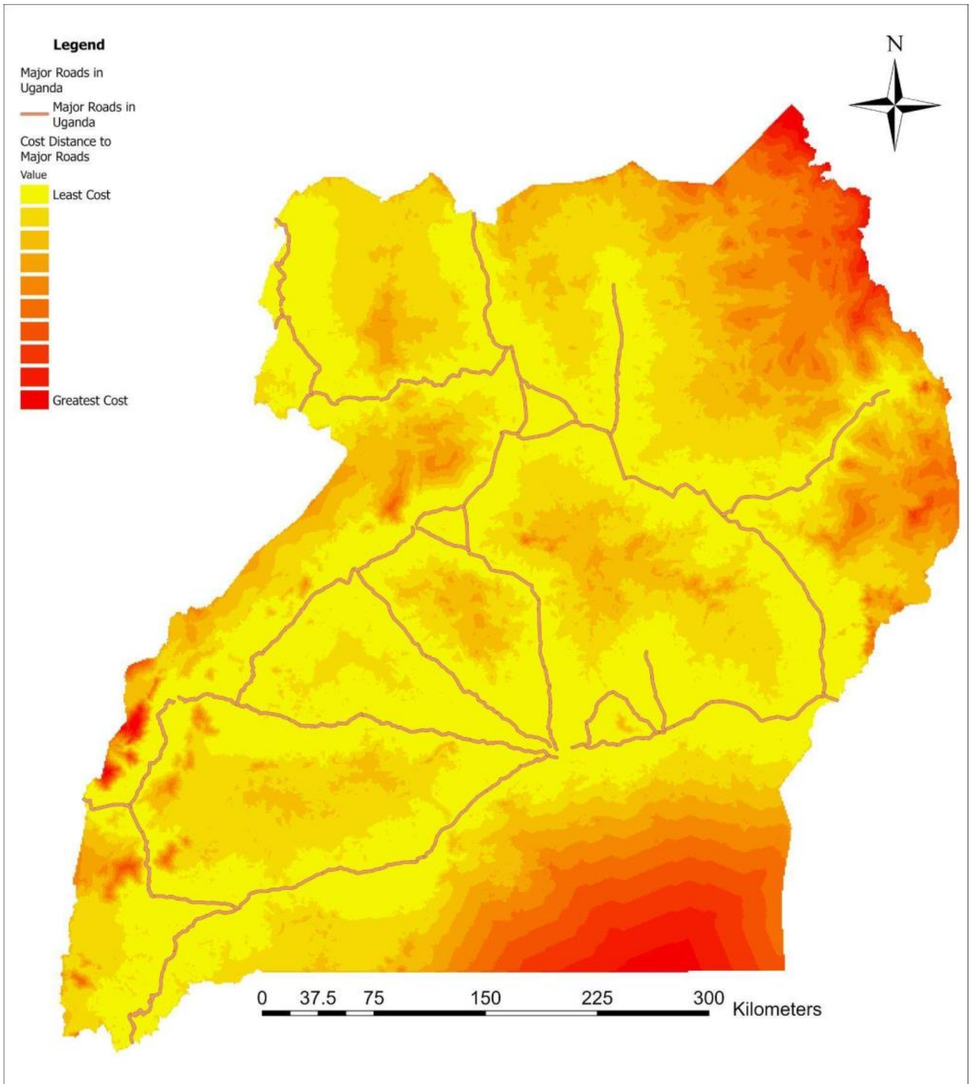


Figure 1: Least Cost Distance Raster to Major Roads in Uganda, using Weiss and Nelson's 2019 friction surface layer for land speeds in minutes per meter (1km-resolution). Lower costs in yellow, higher costs in red.

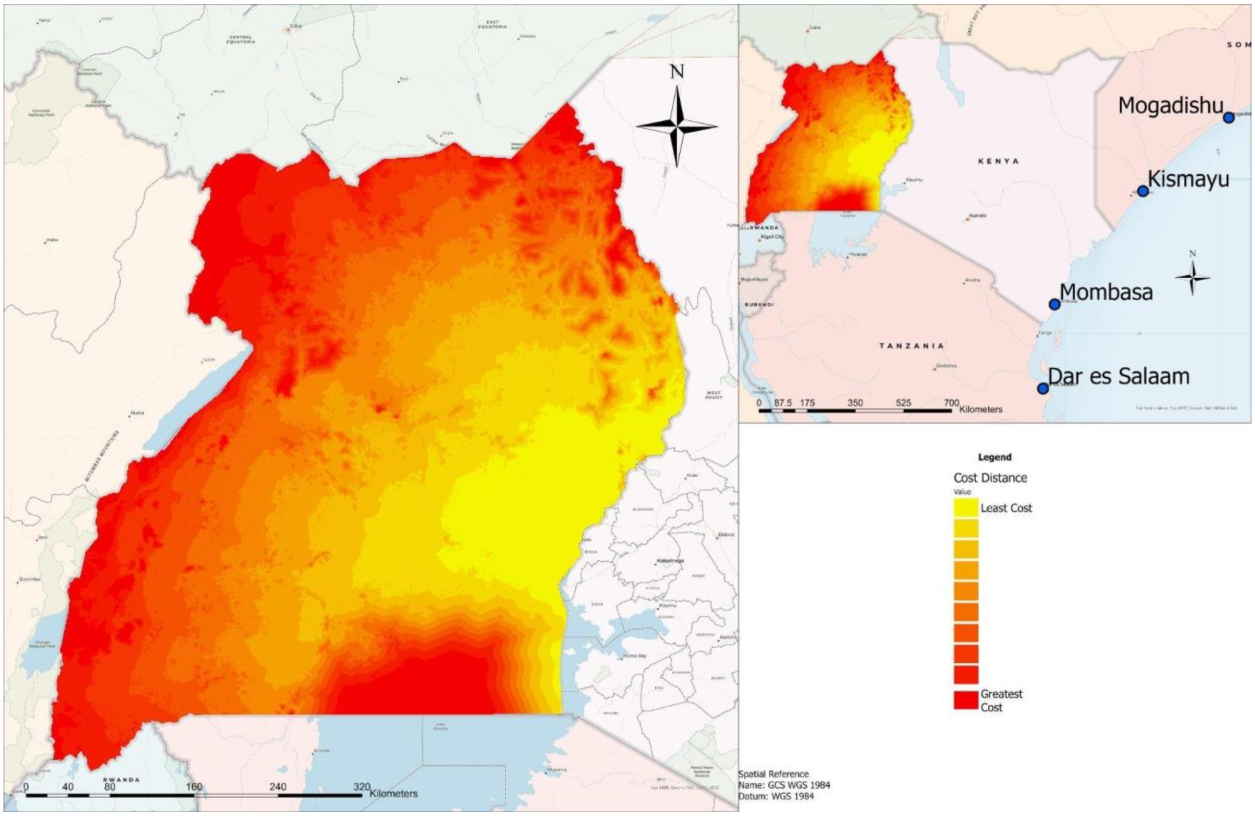


Figure 2: Least Cost Distance Raster to Mombasa and Dar es Salaam ports, using Weiss and Nelson's 2019 friction surface layer for land speeds in minutes per meter (1km-resolution).

All other factors for which we processed geospatial data for this subquestion only have data at the national level. As such, the rest of the layers created in for this subquestion (Table 7) were created using up-to-date polygon shapefiles of the political boundaries, whether Uganda or other countries in se.plan, and attaching tabular data to those polygons to create an attribute table in ArcGIS Pro.

We chose not to process certain layers, either because they were not geospatially relevant, we could not find reliable data, or we ran out of time in this project (Table 8).

Factors without Related Geospatial Data Layers	Reason the Factor Was Not Processed Geospatially
Access to Patient Capital	Not of Geospatial Concern (Each investor will have different access levels)
Distance to Processing Facilities	No Time
Exchange Rate Risk	No Time
Fuel (Diesel, Petrol, Woodchips, etc.) Prices	No Good Subnational Data

Mobile Sawmill Price	No Time
Number of Forestry Operations Managers	No Time
Species Mix	No Time
Transportation Infrastructure Quality	No Time

Table 8. Factors not processed geospatially for infrastructure and economic factors considered when locating a wood processing facility.

Data Limitations

We would have liked to have subnational tabular data for certain layers, particularly commercial species stumpage volume and stumpage prices, but also for many others. More granular data would allow se.plan users to have more accurate results.

For the exchange rate risk factor, we needed tabular data that showed more than just the exchange rate of international currencies to the U.S. dollar. If we had time, we might have used one of several available models that estimate exchange rate risk. One widely-used model for measuring exchange rate risk, recommended in an International Monetary Fund working paper, is the value-at-risk method (VaR; Papaioannou, 2006), which calculates the greatest potential loss over a specified currency holding period (usually one day) at a certain probability level (usually 95% or 99%). That is, a VaR measurement gives the maximum loss one could expect with 95% confidence from holding a position in a given currency over one day (Papaioannou, 2006). In theory, one could calculate the VaR for all se.plan country currencies and update the calculations regularly.

Evaluating Credibility of Data Layers

Gathering the data was a somewhat systematic process. For this subquestion, we only searched government and NGO geospatial data depositories. We also used data found in the literature review or found in literature given to us by the client or our advisor, as well as the ArcOnline layers depository. All of these sources have a paper trail and clear citations, as well as dates of publication. Sources include the World Bank, FAO, the Ugandan Government, open-source data created by academics, the U.S. Treasury, and U.S. Geological Survey. Once we found a layer, we made sure it was the most recent version of the layer.

Research Subquestion Three: *What demand trends for forest products direct the interest of local and foreign producers or stakeholders in investment in Uganda? What are the sources of demand for forest products?*

Literature Review and Focus Groups

A review of available and relevant literature, plus focus group participant feedback revealed the most pressing factors associated with the demand trends and market conditions in Uganda. In short, these were:

- Product types: Different products were mentioned in the literature review, many of which were later also mentioned during our focus groups. In addition to the expected sawnwood and plywood, there are products such as engineered wood products (CLT) (Walter 2021), woodfuels (Bamwesigye 2017), wood furniture (Kizito 2012), and wooden utility poles (Howard 2019).

- Wood products prices: Prices for wood and wood products are fairly low currently in Uganda (Howard 2019). Members of our first focus group expressed concern with this fact and blamed low quality products from less permanent sawmills. Thus, prices should be a factor to help guide decisions on which wood products are most valuable to consumers.

- Woodfuel consumption: Woodfuel is ubiquitous as a source of energy for cooking or heating in Uganda, as up to 90% of Ugandan households depend on it (Bamwesigye 2017). The focus groups also mentioned how important this product is but expressed concern about illegal trade of woodfuel. This overall importance made it a factor for our research.

- Wood product consumption: The overall consumption of wood products is imperative as a factor in estimating demand trends and market conditions. In our literature review and during the focus groups, the demand for particular products, such as sawnwood and plywood, was stated as an important factor for analyzing production viability. Some of the biggest concerns in forest value chains are, in fact, low prices causing low production from existing mills of all sizes (Howard 2019).

To estimate wood product consumption, its underlying components need to be analyzed. Firstly, there are hints in the literature that income growth affects demand for wood products, with past booms being linked to stimulated demand for wood products (Kizito 2012). The same also appears to be the case for lower quality goods such as firewood; as income increases, there seems to be no cessation to its demand (Bamwesigye 2020). The prevalence of the use of these products suggests that population growth similarly influences their demand, with some of the focus groups echoing this view.

Further NVivo coding analysis of the focus groups and literature highlighted the following factors:

Factor	Investor Preference	Sources	% of Documents Mentioning Factor	Total References of Factor Across All Documents
Wood products prices	Higher	Howard 2019, Walter 2021, Groups 1, 2, 3	70%	19
Wood Products	Higher	Howard 2019, Walter 2021, Kizito 2012, Groups 1, 2, 3	60%	36
Woodfuel Consumption	Same	Howard 2019, Bamwesigye 2017 and 2020, Groups 1, 3	70%	13
Consumption of Wood Products	Higher	Howard 2019, Walter 2021, Groups 1, 3	40%	11

Table 9: Top factors for subquestion three.

Choosing Sources for Data Layers

With the factors stipulated by the literature review and focus groups, corresponding data layers were selected as being important, but a few alterations had to be made. Firstly, we decided to exclude woodfuel consumption as it would be more productive to focus on further processed wood products for our analysis of the value chain. Additionally, se.plan already has a woodfuel harvest layer. Secondly, due to a lack of reliable data, the product prices factor was not able to be implemented, and a data layer on wood product consumption had to be created manually. This process generated intermediate datasets, "Quantity Exported / Imported", "Quantity Produced", "Population", and "GDP", which were used to generate a final "Wood Products Consumption" layer.

Overall, the intermediate and final datasets were as follows:

Factor	Dataset	Purpose	Level of Detail	Date	Format
Wood Products Consumption	Created Manually	Demonstrates the expected consumption of a particular product in a selected year. For our purposes, this was 2030.	Subnational	NA	Raster (30 arc seconds)
Quantities Exported / Imported	**Forestry Production and Trade (FAO 2023)** and **Biennial review statistics (ITTO 2022)**	Provides data to look at the exports/imports quantities of a product. Used for generating the consumption models with data from 1990-2021.	National	2023	Tabular
Quantities Produced	**Forestry Production and Trade (FAO 2023)** and **Biennial review statistics (ITTO 2022)**	Data on the quantities of products produced. Used for generating the consumption models with data from 1990-2021.	National	2023	Tabular
Population	**Uganda Population (World Bank 2023)**	Historical data for population in Uganda. Used for generating the consumption models with data from 1990-2021.	National	2023	Tabular
	Projecting 1 km-grid population (Wang, X 2022)	Estimated population density per grid-cell based on Worldpop.org that was based on the UN's population estimates. This data were used to calculate the consumption of wood products in 2030. Moreover, this source has data for all other countries and could be applied for similar purposes elsewhere.	Subnational	2022	Raster (30 arc seconds)
GDP	**Uganda GDP data (World Bank 2023)**	Historical data for GDP in Uganda. Used for generating the consumption models with data from 1990-2021.	National	2023	Tabular
	Global gridded GDP data (Wang, T 2022)	Gridded GDP data set based on SSPs. Likewise, to the above, the data were used to calculate the consumption of wood products in 2030. With data on future predictions also available.	Subnational	2022	Raster (30 arc seconds)

Table 10: Datasets related to wood product demand.

Data Manipulation and Final Layers

Methods

We defined consumption as apparent consumption, i.e., production + imports – exports. Most of the data for products' quantities had to be inputted manually into a geospatial format. The products analyzed were sawnwood (FAO item codes 1632 for coniferous and 1633 for nonconiferous) and industrial roundwood (codes 1623 for coniferous and 1626 for nonconiferous). We utilized a similar idea that FAO's se.plan utilized for calculating woodfuel harvest, which was based on population-driven demand, although we used a linear model approach while se.plan used a quadratic one (Sepal Development Team 2022).

Furthermore, using the concept of Engel Curves, we had some ideas on another important variable our model could include. This concept stipulates that as income increases, the share of income spent on a particular good or service changes (Chai 2010). Thus, we suspected that income growth (GDP growth) would also be relevant to consumption trends, perhaps more so than population growth. Consequently, an analysis had to be made to determine variables to include in our final model.

This analysis used the program R (R Core Team 2021) for a linear regression model to confirm if we should use GDP growth or population growth as the optimal predictor for changes in wood products' consumption. The wood consumption data were calculated with the total m^3 values for all products of interest from FAOSTAT (FAO 2023) and the International Tropical Timber Organization's Biennial review statistics database (ITTO 2022). For GDP and population, we used the World Development Indicators dataset as our source. For GDP we chose to utilize GDP per capita (created by dividing "GDP, PPP (constant 2017 international $)" by "Population, total"), and for population we had "Population density (people per sq. km of land area)" (World Bank 2023).

All data were downloaded for the time period 1990 to 2021. Unfortunately, for sawnwood, we had to exclude 2005 to 2010 data as it showed a sudden implausible drop followed by a sudden implausible recovery. We suspect that the discrepancy does not correspond to reality but is actually erroneous data. The drop might be related to legislation that went into effect in 2004 and required licenses to harvest sawlogs in Uganda; this new requirement possibly caused some of the wood to be illegally harvested and thus not reported, a known problem in the Ugandan wood products market (Turyahabwe 2015).

With the chosen data in hand and transformed into a .csv table (Appendix 2.1) for R, we first established response and explanatory variables. Our response variables were consumption of sawnwood (coniferous and non-coniferous) (FAO 2023) and industrial roundwood (coniferous and non-coniferous) (ITTO 2022). The explanatory variables were GDP per capita and population density (World Bank 2023). Using these variables, we estimated linear models and log-transformed linear models (for better fit) for each variable and for multi-variable models that included both GDP per capita and population density (full R code available in Appendix 2.2).

The models then had their fits tested by comparing all R-squared values and selecting the highest ones for each product, provided that the models also demonstrated significant p-values lower than 0.05 for all variables. Moreover, we favored log-transformed models as they are the standard for forestry-related analytical models (Kallio, Dykstra, and Binkley 1987). The resulting models that best represented their product's consumption according to these criteria were selected and used in the subsequent analysis.

We estimated the portion of the total national quantities each district in Uganda would consume based on each product's model, under the assumption that the effects of population density and/or GDP per capita on consumption per capita at the national level would be the same at subnational levels. The calculation was done using ArcGIS, and we projected district-level consumption of each product to 2030. This date was chosen as it is the end year of the UN Decade on Ecosystem Restoration (UN 2021). We first clipped existing raster datasets for gridded global population density (Wang X. 2022) and GDP (Wang T. 2022) for 2030 with a Uganda shape file from ESRI to focus on our region of interest. These datasets are, respectively, based on a study that used the WorldPop data and Shared Socioeconomic Pathways (SSPs) to make predictions extrapolating future population trends (Wang X. 2022) and one that used SSPs to predict future GDP values in a geospatial format (Wang T. 2022). It is also important to note that out of the SSP-based predictions, we used SSP2 (middle of the road), which is considered the most reliable and is based on the continuation of current trends into future decades (Riahi 2017).

After these steps, we used Zonal Statistics tools in ArcGIS to calculate mean or total values in each district, depending on the variable. Additionally, each district had its GDP per capita generated with the Raster Calculator tool by dividing the GDP by population. Then, using more Raster calculators, the linear models previously estimated were used to predict district level per capita consumption of the four products. The gridded GDP data were expressed in constant 2005 prices, which had to be divided by 1.015 (number obtained by comparing World Bank's "GDP, PPP (constant 2017 international $)" to "GDP, PPP (current international $)" values for 2005 (World Bank 2023)) to match the 2017 price year for the GDP per capita variable used in the regressions models. Lastly, with the Ugandan district-level m^3 per capita wood product consumption values in hand, we expanded them to the total consumption in each district for 2030 by multiplying the per capita values by the total populations in another Raster Calculator (full model of process in Appendix 2.3).

Results

Our estimation of the linear models generated the following tables comparing all model variants. The tables display the regression coefficients, their significance (significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.', and 0.1 ' '), and the R^2 values:

- Industrial Roundwood, Nonconiferous:

IRWnc	Consumption Models ~		
Values	GDP pc	Population density	Population density and GDP pc
Ln GDP pc	-0.06	-	0.48 *
Ln Pop. density	-	-0.08 .	-0.6
Intercept	-1.78 ***	-1.80 ***	-2.74 ***
R^2	0.03629	0.07621	0.1841
Selected	No	No	Yes

- Industrial Roundwood (Coniferous):

IRWc	Consumption Models ~		
Values	GDP pc	Population density	Population density and GDP pc
Ln GDP pc	1.46 ***	-	1.76 ***
Ln Pop. density	-	1.57 ***	-0.34
Intercept	-15.06 ***	-12.15 ***	-15.60 ***
R^2	0.9144	0.8759	0.9127
Sected	Yes	No	No

- Sawnwood, Nonconiferous:

SWnc	Consumption Models ~		
Values	GDP pc	Population density	Population density and GDP pc
Ln GDP pc	0.92 **	-	2.75
Ln Pop. density	-	0.94 **	-2.01
Intercept	-11.78 ***	-9.72 ***	-15.23 ***
R^2	0.298	0.2611	0.2994
Selected	Yes	No	No

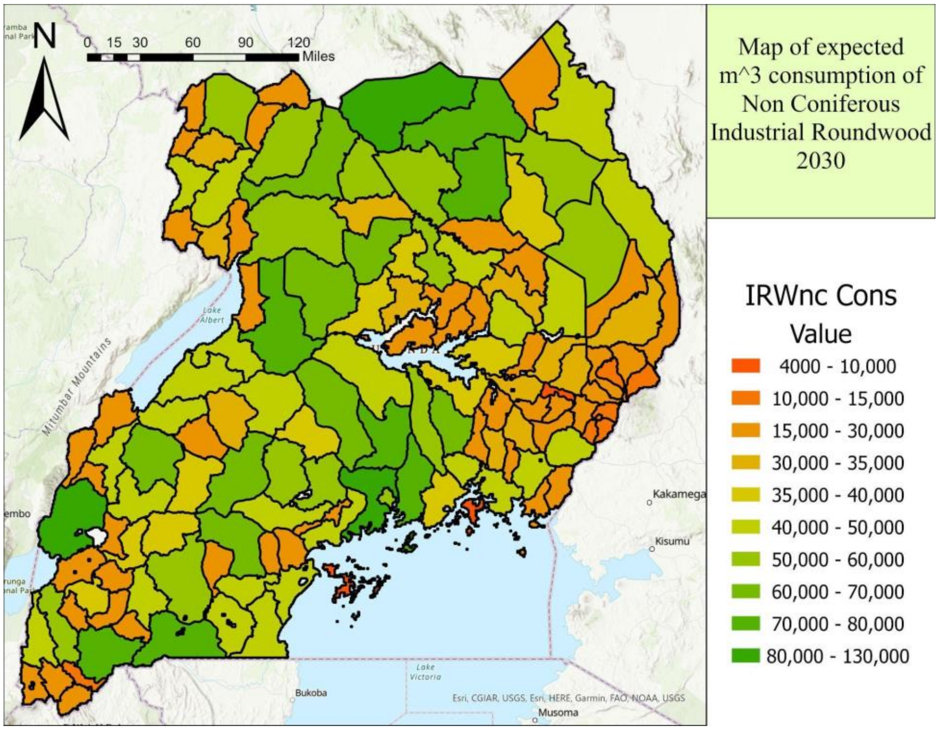
- Sawnwood (Coniferous):

SWc	Consumption Models ~		
Values	GDP pc	Population density	Population density and GDP pc
Ln GDP pc	0.97 ***	-	1.59
Ln Pop. density	-	1.02 ***	-0.68
Intercept	-13.15 ***	-11.13 ***	-14.32 ***
R^2	0.4225	0.4231	0.4019
Selected	Yes	No	No

The following 4 models were selected for projecting district-level 2030 total consumption according to the procedures described above:

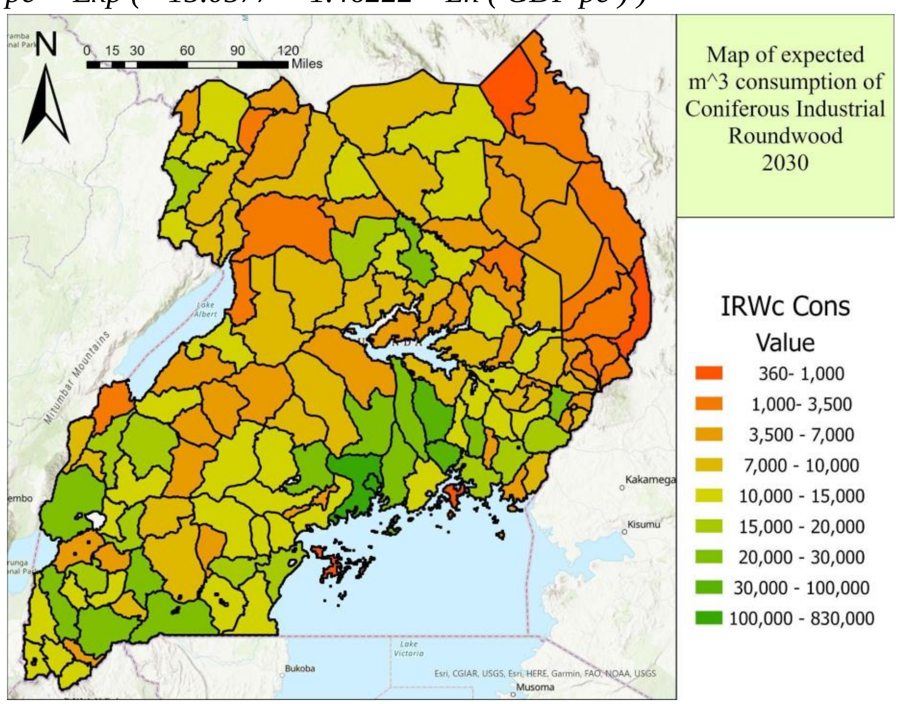
- Industrial Roundwood, Nonconiferous:

$Consumption\ pc = Exp\ (\ -\ 2.743\ -\ 0.601\ *\ Ln\ (\ Population/km^2\ )\ +\ 0.48\ *\ Ln\ (\ GDP\ pc\ )\ )$



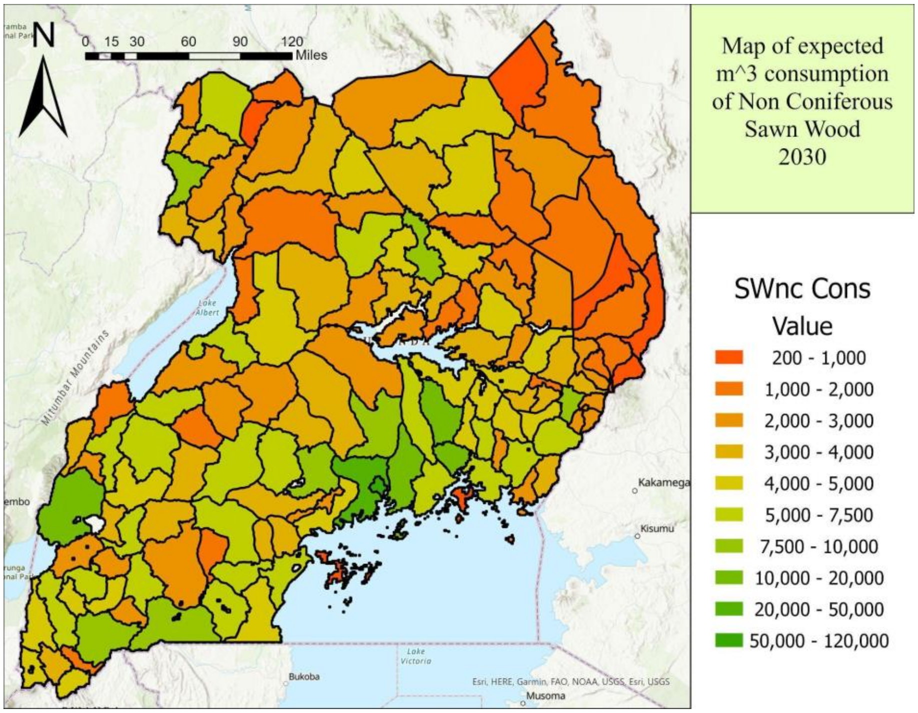
- Industrial Roundwood, Coniferous:

*Consumption pc = Exp (- 15.0577 + 1.46222 * Ln (GDP pc))*



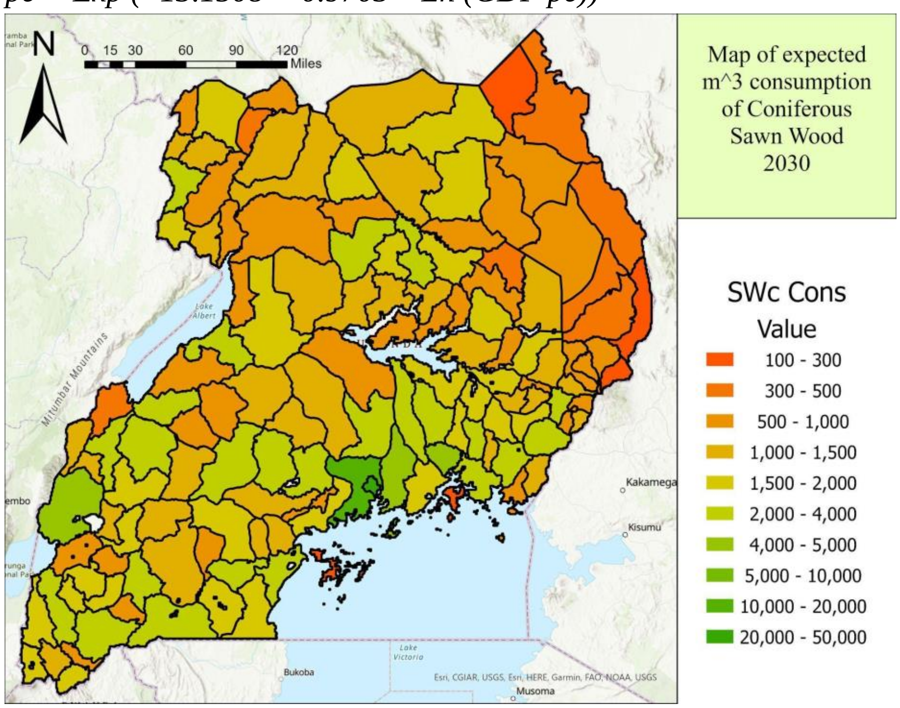
- Sawnwood, Nonconiferous:

*Consumption pc = Exp (- 11.7854 + 0.9204 * Ln (GDP pc))*



- Sawnwood, Coniferous:

*Consumption pc = Exp (- 13.1508 + 0.9703 * Ln (GDP pc))*



Evaluating Credibility of Data Layers

Regarding the model for the consumption layers, there is ample reason to believe that the data sources were credible. Much of the data was sourced from FAOSTAT (FAO 2023), and what was found elsewhere came from either ITTO (ITTO 2022) or The World Bank (World Bank 2023). Both are trustworthy international organizations that provide high-quality data. The gridded Population and GDP datasets are likely to be reliable too. The gridded GDP data (Wang T. 2022) are based on SSP datasets, which are widely used by researchers, policymakers, and other stakeholders for generalized predictions such as ours. Similarly, the population data were also based on SSPs and use data from Worldpop.org for its predictions (Wang X. 2022). Worldpop.org is operated by the University of Southampton and is based on peer-reviewed academic research to ensure its accuracy and reliability (WorldPop 2020). Finally, for the maps, the district layer was trustworthy as it came directly from ESRI and was dated 2021.

While the data sources for our consumption models are trustworthy, the models are subject to error. This is indicated by the varying values observed for the R^2, which indicate some models have good fits and others do not. This variation could be due to a variety of reasons. As previously mentioned, the production data could be misleading due to underreporting as a consequence of illegal operations (Turyahabwe 2015). The models could be underfitted, as they might omit important variables for which we lacked data, such as wood product prices. Lastly, we must also exercise caution when interpreting future predictions. SSP data, while good for generalized models, contain many uncertainties (Riahi 2017, Wang T. 2022), and both the GDP and population datasets used the SSP data in their predictions (Wang T. 2022, Wang X. 2022).

Research Subquestion Four: *What are the factors that encourage/hinder mass timber developments for housing to accommodate urban expansion in Uganda?*

Literature Review and Focus Groups

Introduction

To increase the stumpage price of timber, there must be an increase in demand for wood products. Promoting the use of wood products in innovative ways can help stimulate demand for wood, thus increasing stumpage prices. A product that offers this opportunity is mass timber, which involves the use of engineered wood to construct buildings. The following is a case study that describes what mass timber is and how the product provides opportunities to create value through reforestation via sustainable forestry management, generation of climate smart housing to assist with housing demand due to urban expansion and population growth in emerging markets, and reduce carbon emissions from the construction industry. The case study highlights factors that are of importance for forestland investors and conclude swith recommendations for data layers to be incorporated into the United Nations Food and Agriculture Organization's geospatial tool se.plan, which helps investors make decisions on forestland investments. A discussion of the timber stock, the human population, a brief overview of mass timber, and investment motivations follow before focusing on Uganda as a country of focus and providing a deeper understanding of mass timber to demonstrate how it can provide value to forestland investors and the human population at large.

A Lot of Timber

The surplus of timber is a reason why stumpage prices have been stagnant even though timber products are used in many ways throughout the world. North American and European countries have seen an increase of timber growth in managed forests where harvest rates average around 60 to 65 percent of forest growth leading to timber growth exceeding removals over the last several decades and inventory increasing (Dangel 2016). Only 1.3 percent of all forest land in the United States is affected by annual harvest (Dangel 2016). Africa and Latin America are nearly in balance with the supply and demand for timber while Asia is in a timber deficit (Binkley et al 2020).

The main global use of harvested wood today is for bioenergy. Wood harvested for bioenergy is utilized for heating and cooking and accounts for 50 percent of the world's total wood harvest where many developing countries use wood as the only domestically available and affordable source of energy (Dangel 2016). Using wood for bioenergy has spread to the industrialized world as well with companies such as Enviva creating value from timber in the United States to sell to European countries in an effort to provide green energy through wood pellets.

The bioenergy demand placed on forests has helped keep forests as forests by providing landowners with more options to sell their products, but more value could be derived through the creation of innovative uses such as mass timber. Keeping forests as forests is an important part of mitigating climate change through sustainable forest management. In both industrialized and emerging markets, forest restoration can see benefits if the timber industry is able to derive more value for timber products and non-timber forest products. A pressure point with maintaining and restoring forests is an increasing human population. Population growth and urban expansion could result in loss of forestland through development, but population growth, economic development, and increasing urbanization continue to drive demand for wood products (Binkley et al 2020). The growth of the population and reliance on wood products should result in upward price pressure (Binkley et al 2020) and hopefully provide more incentives for landowners to maintain and restore forestland instead of selling for development.

A Lot of People

Yet there is an issue with the increasing population, where will people live? The world population reached 8 billion in late 2022 and is expected to reach 9.7 billion in 2050 and 10.4 billion in 2100 with Africa as the fastest growing continent (United Nation 2022). Currently over 50 percent of the world's population lives in urban areas, with a projected increase to 70 percent by 2050 (Dangel 2016) and 80 percent by 2100 according to Shared Socioeconomic Pathway (SSP) 2 (Mishra et al 2022). The SSPs indicate a continued increase in urban areas with growth rates in emerging markets such as Africa and Asia remaining higher than industrialized regions such as North America and Europe (Li et al 2019).

In emerging markets, it is important to consider the number of people living in slum households. Slum housing is considered a lack of adequate housing or informal settlements according to the United Nations Sustainable Development Goal 11.1.1. The number of people living in slums increased to over 1 billion in 2018 and is estimated to be near 3 billion in 2030 (UN Statistics Division 2019). The majority of this growth is located in sub-Saharan Africa and Asia (UN Statistics Division 2019).

Whether in emerging or industrialized markets, population growth and urban expansion will continue to emphasize the demand for sustainable and affordable housing. New and sustainable housing will be needed to accommodate the growth of the population in urban areas, and timber construction has an established history of providing accommodation quickly (Mishra et al 2022, Dangel 2016).

Mass Timber as an Opportunity

The combination of a lot of wood and a lot of people globally sets the stage for mass timber as an opportunity to increase the value of timber while satisfying a need for housing in urban areas. Mass timber can help drive demand for wood products, aid in forest restoration, keep forests as forests, and provide long-term financial gains for forestland investments by creating a viable product in both emerging and industrialized markets. It is important to highlight the opportunity that mass timber presents for climate mitigation as well. Sustainable forestry management balances harvest of trees with reforestation to allow for sustained use of forest products throughout generations. As trees grow and mature, the rate of carbon sequestration slows, therefore it is vital to maintain forest management that removes older trees once their growth rates slow and replant with young trees which will sequester carbon at a higher rate. Trees take up carbon as they grow and once harvested and dried, half of the weight of the timber product is stored carbon; a single tree can contain a ton or more of carbon with each cubic foot of wood holding 11-20 pounds (Mayo 2015). Not only does mass timber utilize a product that stores carbon, but also emits less carbon dioxide when produced and utilized. Choosing to build with mass timber was found to emit 80 percent less carbon dioxide emissions when compared to using steel and concrete (Binkley et al. 2020). Utilizing wood for construction provides an opportunity for long-term storage of carbon in the form of commercial and residential buildings while creating an incentive to replant forests for further use for building materials.

The importance of building with wood is underscored when compared to conventional building materials of concrete and steel. The increase of urban populations and urban sprawl means new buildings will be needed. The growing demand for housing provides an opportunity to "demonstrate mass timber's equivalence to reinforced concrete or structural steel in construction and it's superiority as a sustainable, low carbon resource," according to University of Arkansas Fay Jones School of Architecture Dean Peter Mackeith (Mackeith, 2023). Out of all the comparable building materials, wood has been found to be the renewable resource with the lowest carbon footprint especially in comparison to steel and concrete which both require vast amount of energy for refinement and processing (Mishra et al 2022). Ulrich Dangel, author of *Turning Point in Timber Construction,* further explains that cement, the key ingredient in concrete, produces one ton of carbon dioxide for every ton of cement. Manufacturing and construction make up 13.8 percent of global carbon dioxide emissions. The use of wood in construction offers more than a 100 percent reduction in fossil fuel emissions compared to conventional building materials (Mayo 2015). The reduction in fossil fuels is emphasized by the forestry industry's capability to generate much of its own energy through the use of mill residues such as sawdust and tree bark (Dangel 2016).

Wood provides another advantage over steel and concrete due to its comparative light weight and ease of transportation. Wood weighs around 35 pounds per cubic foot while concrete and steel weigh 150 and 490 pounds per cubic foot respectfully (Mayo 2015). This advantage allows for the movement of wood products further distances for less cost than conventional building materials. Because of this, mass timber can provide potential cost savings and reduce construction time (Binkley et al 2020). These are important factors to consider when looking to construct buildings for an ever-increasing population attempting to mitigate climate change.

Uganda as Emerging Market Focus

Uganda was selected as the emerging market to focus on for investment opportunities and limitations. This section discusses how Uganda presents opportunities and challenges for mass timber investments.

Binkley et al. (2020) highlight that East and Sub-Saharan Africa provides a great opportunity for forest sector development due to the following advantages: considerable land not currently used for food production is available, there is a high productivity rate of the land, population and economic growth are driven by strong growth in domestic demand, much of the energy needs are met by wood, and many countries import considerable amounts of wood products. An opportunity is also present for reforestation due to a loss in natural forest cover from 24 percent in 1990 to 9 percent in 2015 (FAO 2020). During the decline of forest cover, the National Forest Authority in 2003 mandated the management of Uganda's Central Forest Reserves to increase the supply of sustainably produced forest products for the market (FAO 2020). Uganda has another unique feature with the creation of the Sawlog Production Grant Scheme (SPGS) created in 2004 (FAO 2020). The SPGS has laid the foundation for sustainable commercial forestry and attracted substantial investment into timber plantations (Jacovelli 2009). Since 2004, the SPGS has supported planting over 60,000 hectares of commercial forests, primarily of Caribbean pine (*Pinus caribaea var. hondurensis*), which has a standard rotation length of 18 years (FAO 2020). The Food and Agriculture Organization of the UN (FAO) believes that pine production will reach 800,000 cubic meters in 2023 and reach as high as 2 million cubic meters if incentives are in place for plantation owners. These figures demonstrate Uganda's capability to provide wood products for various uses throughout society.

Uganda presents the situation mentioned previously of a lot of wood and a lot of people. Both the trees and human population are seeing high growth rates with the annual population growth rate at 3.2 percent according to the World Bank's latest data. This combination is a large incentive to utilize mass timber to meet housing demand of the growing urban population. Li et al. (2019) mention that the urbanization rate is higher in developing regions such as Africa where many people are migrating from rural to urban environments, which is putting a strain on sustainable development. For context, the growth rate of urban areas in developed regions of North America and Europe is less than half of the rate in developing regions (Li et al. 2019). Urbanization in Kampala, the capital city of Uganda, has led to increased housing demand, rising land prices, and growing urban poverty where the growing population led to a shortage of houses resulting in a deficit of 100,000 units and half a million people not being housed adequately (Mukiibi 2012). Mukiibi notes that urbanization is a precursor for development and has profound effects on the demand for housing. Kampala's growth rate is one of the fastest in the country at 5.6 percent (Mukiibi 2012) and has incorporated neighboring towns and rural areas in its growth (Karolien 2012). The increase in urban population can be attributed to rural-urban migration where people are searching for employment with better income (Mukiibi 2012), yet this rapid growth combined with informal and irregular housing provision has furthered the strain on existing infrastructure (Karolien 2012). The demand for housing due to people migrating from rural to urban centers presents an opportunity for mass timber investments.

The SPGS provided Uganda with initial infrastructure to develop productive mature pine plantations yet new investments ranging from replanting to mill improvements will be needed to sustain the industry (FAO 2020). Mass timber could provide the incentive for these improvements, but current trade restrictions on timber exports hinder investments in pine production and processing. A reason the export markets are important is because Uganda has large urban centers just outside its borders. Timber prices in Kenya are 25 percent higher than those in Uganda. Reducing the restrictions on exports could lift timber prices significantly, but with current export policies in place, investments in the sawmilling capabilities needed for mass timber are unlikely to happen as they would not be profitable in the long run (FAO 2020). It appears that developing an export market for timber products is a vital step for attracting forestland investors on top of domestic demand and capitalizing on the opportunity for mass timber to support the growing population and housing demand.

Binkley et al. (2020) note that developing countries often lack the needed capabilities to capitalize on the productive resources, an investor must be willing to invest in the manufacturing facilities or partner with a company that is willing to invest in the technologies with the understanding that this will increase the risk of the investment. The lack of supporting infrastructure from roads, electricity, and mill capabilities is a barrier for investment in many emerging markets (Binkley et al 2020).

While Uganda has set the foundation for and can benefit from mass timber investments, there are some challenges to seeing this through. A challenge presented in focus group 2 with forest land investors is the need for skilled labor that is required to process timber into mass timber products. Mills will also need the technology to produce mass timber products. These factors will be discussed more in the following sections.

Mass Timber

This section includes discussion on what mass timber is, historical uses of wood construction, the capabilities needed to create modern mass timber buildings, some benefits of building with wood, hindrances to mass timber, examples of recent mass timber construction for housing, and finally how emerging markets could use mass timber. This section will be followed by a list of factors that encourage or hinder mass timber developments for housing to accommodate urban expansion and data layers that could be useful to incorporate into se.plan.

What is Mass Timber

Mass timber, also known as solid or massive wood construction, is an advancement in wood building technology that exceeds the structural limits of light-frame wood construction (Mayo 2015). The components of mass timber consist of engineered wood products such as glue-laminated timber posts (glulam), beams and panels, laminated strand lumber (LSL), parallel strand lumber (PSL), laminated veneer lumber (LVL), cross-laminated timber (CLT), and nail/dowel laminated timber (Mayo 2015). These components are used for columns, beams, bracing, walls, floors, roofs, stairs, and elevator cores and are made from built-up small dimension lumber or other wood fiber such as veneers, strips, or chips (Mayo 2015). It is important to note that mass timber is not limited to large diameter sawlogs to create buildings. Wood-based composite products, also known as engineered wood (Dangel 2016), is capable of using younger trees, lower grade lumber, and a wide variety of tree species while removing the defects in the wood to create a more consistent, stronger, and predictable product (Mayo 2015). This aspect of engineered wood is a boon for forestland owners, managers, and investors looking for a market for their smaller trees and lower grade timber. Mass timber is able to utilize these products because the smaller dimension wood is reassembled using adhesive and pressure to create an engineered product that can have higher design values and less variability than the sum of its parts (Mayo 2015).

The following paragraphs briefly describe the different components of engineered wood. For a deeper understanding, see *Solid Wood* by Joseph Mayo.

Glulam is typically used for columns and beams and can be attached side by side to create curved sections, larger panels of timber, or block glued for thicker beams (Mayo 2015). Glulam products are about 10 percent less weight than steel and one-fifth the weight of concrete which increases efficiencies in transportation and construction (Mayo 2015). Typical species used for glulam products in the United States include spruce, fir, hemlock, and Douglas fir (Mayo 2015).

Laminated veneer lumber (LVL) products use thin layers of softwood veneer about 3-4mm thick that are glued together to make large panels or billets which are used for floors, roofs, walls, columns, and beams (Mayo 2015). A benefit to LVL is the capability to be made from small-dimension, rapid-growing species (Mayo 2015). This capability is beneficial when considering the growth rates of tree species in emerging markets such as Uganda.

Laminated strand lumber (LSL) is similar to LVL but is made from layering flakes of wood pressed together with adhesive. The flakes can be processed from small diameter tree branches (Mayo 2015).

Parallel strand lumber is created from wood strands and strips oriented in the same direction and combined with adhesive to form large billets. The product is used where high bending or withstanding compression stress is needed, such as long-span beams, columns, and header applications (Mayo 2015).

Cross-laminated timber (CLT) is likely the most well-known engineered wood product. CLT was originally developed to reduce waste in sawmills from dimensional lumber and has the additional benefit of using wood of smaller dimensions and lower grades to create a product with high structural grades (Mayo 2015). To produce CLT, mechanical presses and formaldehyde-free emulsion polymer isocyanate adhesives are needed (Mayo 2015). The presses are able to curb natural tendencies in wood to warp, which creates a more stable product (Mayo 2015).

Historical Use

While the above technologies are recent developments, there are historical uses of wood construction that still stand today. Understanding the use of wood historically helps demonstrate that these structures are capable of standing the test of time and can be renovated as needed with renewable products. Parts of Europe and Asia have long traditions of constructing buildings from wood with heights of four stories and above (Dangel 2016). Built over 950 years ago, the Sakyamuni Pagoda in China is one of the tallest multi-story wood structures at 67m and has survived an estimated 40 earthquakes without the use of steel or modern seismic bracing (Mayo 2015). In the late 1800s and early 1900s, parts of North America constructed buildings with wood reaching nine stories or 30 meters, which are still being used today (Mayo 2015). These buildings in North America could not pass modern building codes but have undergone renovation and modernization to meet current standards, yet the timber bones remain unchanged (Mayo 2015).

Capabilities Needed

For investors to determine if mass timber is a worthwhile investment in an emerging market such as Uganda, it is important to consider some of the capabilities that are needed to develop the product. This section focuses on the tree species and characteristics required as well as some of the milling and building systems needed. The section does not discuss infrastructure such as electricity and roads, as those factors are discussed elsewhere in the report.

Engineered wood was developed in a response to faster growth rates, smaller trunk diameters, and the increased proportion of juvenile wood with less strength than wood from mature, slow-growing trees needing a use instead of being wasted (Dangel 2016). The strength, stiffness, and fracture behavior of materials utilized in construction matters (Mayo 2015), and so different engineered wood products are made from different species. Glulam products typically include spruce, fir, hemlock, and Douglas fir (Mayo 2015), and CLT commonly uses spruce, pine, and fir (Syed 2020). LVL typically uses Douglas fir, larch, southern yellow pine, and poplar (Syed 2020). Pat Layton, Director of Wood Utilization and Design Institute at Clemson University, suggests using slash or longleaf pine as they have straighter and smaller branches with the capability to drop their limbs early (2023). She suggests growing the species at tighter spacing (6x8, 8x8) to produce denser and clearer wood; she also notes the desire to have more late wood, whose fibers are stiff and provide good strength (Layton 2023). While some of these species cannot be grown in Uganda, pine species are the most abundant plantation tree species globally, and have a typical rotation of 12-18 years (Jacovelli 2009, FAO 2020). Other tropical species include teak, which has an approximate 20-year rotation, and industrial hardwoods such as eucalyptus and acacia, which can be harvested less than 10 years after planting (Dangel 2016).

Certain mill capabilities and other products are needed to process the tree species in order to create and use engineered wood. Investors should consider if an emerging market has the needed capability to create the product when determining where to invest; if the capability is lacking, investors could consider funding the development of the capabilities needed. The manufacturing of engineered wood relies heavily on adhesives. A key issue for structural lumber is the ability of the adhesive to transfer loads between laminations, which is achievable due to the strong bonds that are created through the use of the adhesive and are greater than the wood could produce alone (Mayo 2015). While adhesives are largely used, there are other options which reduce the environmental footprint of a mass timber project, including using pieces of wood nailed, doweled, or dovetailed together (Mayo 2015).

A potential capability that could hinder investments in emerging markets is the use of computer numerical controlled (CNC) machines. A CNC machine is capable of cutting timber into any form with tools such as circular saws, chain saws, drills, and routers and moves sawmills further into high-tech capabilities (Mayo 2015). These high-tech capabilities allow for highly crafted, accurate, and repeatable structures that can be utilized to emphasize mass timber's prefabrication capabilities (Mayo 2015). The investment in mills with presses and CNC machines may be a large cost initially, but it could pay off with the need for rapid housing for growing populations in emerging markets.

Benefits

This section expands on the benefits that mass timber provides with opportunities to create value through reforestation via sustainable forestry management, generation of climate smart housing to assist with housing demand due to urban expansion and population growth, and what value building with wood has towards human health.

Forests offer essential ecosystem services for the health of the planet and humanity. Forests act as a system which uses solar energy through respiration to release oxygen into the atmosphere, store and utilize carbon for growth, stabilize the soil and purify water with their root systems, and provide wildlife habitat and food by their structure and reproduction systems. As trees mature, they compete for water, sunlight, and nutrients; with increasing age, both their growth and carbon sequestration rates decrease meaning that although older forests store more carbon than younger forests, the absorption rate is slower (Dangel 2016). There is a need to maintain these ecosystem services and keep forests productive through the carbon cycle and other nutrient systems. Mass timber can encourage sustainably managing forests to provide increased value to humanity. Mayo (2015) writes that "sustainably managed forests that contribute to the economy can also discourage the same land from being converted into other uses such as low-density suburban sprawl". Mass timber can serve as a tool to increase wood product value and thus discourage such conversion and maximize carbon captured by a forest and subsequently stored in forest products by harvesting before tree growth slows in later years (Mayo 2015).

Sustainably managed forests can provide environmental, social, and economic benefits (Binkley et al. 2020). Forestry has a well-developed supply chain from raw materials sourcing to market that stimulates economies at each touch point. An increase in local timber supply through plantations, reforestation, and afforestation might provide the opportunity for primary wood processing facilities to create jobs and provide domestic and export markets with products and economic activities (Binkley et al. 2020). Specifying wood as a construction material is not likely to harm the sustainability of forests where presently 0.42 gigatons of timber are removed from forests each year as roundwood while trees can convert 25-30 gigatons of carbon from the atmosphere into woody biomass each year (Mayo 2015). Standard buildings today use steel and concrete, which produce high levels of carbon dioxide emissions (Mishra et al 2022). Mass timber construction can keep carbon captured from the atmosphere within its wood for the lifetime of the structure (Dangel 2016).

The forests around the world are capable of providing building materials and sequestering carbon through sustainable forestry practices (Mayo 2015). To utilize mass timber, a greater demand for wood would be placed on forests, and commercial timber plantations would be needed to support this demand. Since 1990, the area of timber plantations has increased approximately 40 percent around the world while still only accounting for 5 percent of forest area globally yet producing 35 percent of global roundwood (Mayo 2015). Another benefit is afforestation of lands that were cleared for other uses such as agriculture and abandoned. From 2000 to 2006, 90 percent of forest plantations were established on previously cleared areas, meaning that plantations provide better environmental benefits and carbon mitigation than the previous land use (Mayo 2015).

Production of wood products does require energy, and the forest products industry is largely sustainable even away from the forests. Every tree harvested from the plantations can be 99 percent utilized at the mill where wood that is not captured as dimensional lumber is converted to other wood products or energy that fuels the mill (Mayo 2015). Biofuel accounts for more than 60 percent of the fuel used in the wood products industry, while steel, iron, and concrete use close to no biofuel. Furthermore, the wood can be deconstructed, reused, and burned for energy at the end of its life cycle (Mayo 2015). The primary goal is to achieve balance between society's ever-increasing needs and the preservation of the world's forests, which can be achieved by providing innovative and alternative means for generating revenue to discourage deforestation and contribute to economic development across the world (Dangel 2016).

Moving from the raw material and production centers into a key market for mass timber is the urban center. Shared Socioeconomic Pathway 2 projects the global share of the population living in urban areas could rise to 80% by 2100, which means an increase in urban living space will be needed (Mishra et al 2022). Innovative housing will be needed to accommodate the growth of urban populations, and mass timber provides an opportunity to use a renewable resource that stores carbon long term through the use of engineered wood for construction (Mishra et al 2022). The need for housing in urban centers is not a demand from the future, but a current dilemma. To meet pressing demands, mass timber is capable of providing quick accommodation in varied circumstances; the customized prefabricated capabilities of timber construction allows for the rapid implementation of quality, durable, and sustainable housing in line with environmental and energy standards (Dangel 2016). Other benefits of prefabrication include minimized noise pollution and disruption at construction sites, reduced particulate matter emissions, reduced on-sight costs, and reduced mistakes leading to harm/injury or increased costs (Dangel 2016, Mayo 2015).

The integration of more wood products into daily urban life can move society closer to reconnecting with nature. Utilizing wood products from our environment to construct buildings we work and live in could bring more value to the market by showing another utility of forests to the general population which is largely removed from surrounding forests. Some environments can be the cause of our distress while others provide the solution; the natural environment has particularly strong restorative effects for many people (Kaplan 2005). Mass timber provides an opportunity for a growing population to reconnect with the benefits of the natural environment.

Providing financial returns is a great motivator for stimulating investment in and demand for forest products. While financial returns are great for investors, human health and wellness should be considered when the product being invested in is living accommodations for the growing urban population. Since the urban population is expected to see continued growth throughout the world, and with people in industrialized countries such as the United States spending on average approximately 90 percent of time indoors where some pollutants are 2 to 5 times higher than outdoor environments (EPA 2021), our urban/indoor environments should promote health when possible. The high amount of time indoors is thought to be a leading cause of sick-building syndrome, which refers to acute health and comfort symptoms caused by time spent in buildings with poor air quality (Dangel 2016). These indoor health issues are ones that emerging markets should consider when developing their infrastructure. Mass timber construction offers an opportunity to create a healthier living situation in both emerging and industrialized markets.

Where we live, work, study, and play affects our performance, and it can be expected that some places are better than others in promoting mental and physical health (Bartlett et al 2005). Bartlett et al 2005 highlights that the quality of nature in our environment is not a new idea, but one that has seldom been integrated with the planning of our urban environments. Urban areas contain less green nature than rural places, which means there is the potential for reduced mental and physical well-being and that urban areas lacking contact with nature can leave the population less competent, more irritable, error prone, and impaired of judgment (Bartlett et al 2005).

Finding innovative ways to connect growing urban populations with nature can be achieved partly through mass timber. Using wood for construction offers benefits such as thermal comfort to inhabitants through balancing the moisture content of indoor environments and hygienic properties through antimicrobial and antibacterial properties; it can also lower the reactivity of the sympathetic nervous system of inhabitants, which is associated with reductions in blood pressure, heart rate, psychological stress, susceptibility to illness, and improved abilities to concentrate and perform creative tasks (Dangel 2016).

These improved health qualities apply not only to the individual but also the larger community. If people are under less distress mentally and physically, they are more likely to be civil with each other and take care of their environment (Bartlett et al 2005). With growing populations in dense urban centers, a less distressed community will be in much demand. A study carried out by Ulrich (1984) focused on a health care setting with a 200-bed suburban hospital where some rooms faced deciduous trees while others faced a brick wall. The study revealed that patients with tree views required less need for pain medicine, received fewer negative nurse notes, and spent 7.96 days vs 8.70 days in the hospital compared the patients with brick wall views (Bartlett et al 2005).

The benefits that trees can provide to human life are plentiful, whether left standing in a forest or sustainably harvested into wood products. Utilizing mass timber can help developing or industrialized countries house populations in growing urban areas and improve the quality of life for the inhabitants.

Hindrances

Every good product comes with its issues, and mass timber is no different. The literature review revealed that perception of fire risks, building codes, and cost were some issues to consider, while the focus groups highlighted the need for skilled labor to produce a high-tech product. The literature also mentioned the capabilities needed for mills to produce mass timber products, which could be a hindrance to investment in emerging markets as constructing a mill is an additional investment in bringing the product to market.

Fire and wood give the perception of a less than ideal match for safe housing in crowded urban centers, but this is a perception that mass timber has sought to overcome. The perception of fire risk in wood buildings is a limitation to increased wood use, but Mayo (2015) mentions two general strategies for protecting wood buildings from fire. The first option is to encase the wood materials with non-combustible materials, and the second is to coat the wood materials with fireproof or fire-retardant materials. The goal is to create a building that allows occupants enough time to escape in the event of a fire. This is accomplished by enforcing building codes that prevent the spread of fire from the room of origin. To meet these codes, load-bearing structures must maintain stability when exposed to a fire for a minimum amount and time while also preventing the spread of smoke and flames to other compartments or structures (Mayo 2015).

CLT offers good fire performance, comparable to non-combustible materials due to the thickness of the product and wood's constant char rates while maintaining structural integrity over the duration of fire exposure (Mayo 2015). CLT without encapsulation can meet a two-hour fire test, but this time is increased when exposed sides of the CLT are covered with gypsum board where 16mm of thickness provides an additional 30 minutes of fire resistance (Mayo 2015). Mayo further mentions that CLT typically performs better than glulam due to the joints within the CLT panels being offset, which helps prevent air and hot gases from penetrating the larger assembly. Numerous tests on CLT have been conducted to demonstrate the fire rating potential of the product. A study carried out by Zelinka et al. (2018) used a two-story structure where CLT was used for the floors, the perimeter walls of the living units, and the walls of the corridor and stairs while glulam was used for the beams and columns (Breneman 2022). The study contained five tests where natural fires were initiated with fuel packages in high residential settings. The first three tests did not use sprinklers, and tests four and five initiated sprinkler use at different times post fire. Results of the first three tests showed that while the contents were consumed, there were not structural failures, the fire was contained to the room of origin, and the CLT self-extinguished in exposed places (Breneman 2022). Breneman highlights that the results are crucial in demonstrating that the construction requirements placed on engineered wood buildings can contain a fire to the room of origin with no structural failure while preventing spreading throughout the building.

Building codes are put in place to ensure safety of the occupants and minimize harm to the environment in which the building is constructed. Although the intent of building codes is good, the implementation of them could hinder investments in certain projects. Mayo believes building codes are one of the greatest challenges to innovation within mass timber, noting that just seeking approvals can make clients hesitant to build with wood. Fortunately, building codes are adaptable and have seen steady change as more research is conducted on engineered wood and buildings are constructed after rigorous testing. The International Code Council approved a set of proposals to be implemented in the 2021 International Building Code (IBC), which contains three new construction types that permit the use of mass timber with one construction type allowing for 18 stories for business and residential occupants (Breneman 2022). This addition to the IBC can help increase the use of mass timber in construction. National codes should be updated to reflect this addition while further research should continue in order to expand the capabilities of mass timber construction to accommodate more people.

An innovative product doesn't come without a financial costs. Mass timber is perceived to be a high-cost endeavor and a limiting factor to implementing engineered wood in a project. Although a complete mass timber building is preferred from a climate mitigation perspective, it is advisable to use a mix of materials to maximize cost effectiveness (Mayo 2015). Here, we briefly discuss three mass timber projects that are for different housing accommodations in the United States. The housing projects include: the Canyons – for rent housing in Portland, OR; Barracuda Condos – for sale housing in Madison, WI; and Adohi Hall – student housing in Fayetteville, AR. While these are projects within the United States, they offer context for mass timber's capabilities and cost. Project information is from WoodWorks Mass Timber Business Case Study 2022.

The Canyons Apartments, completed in November 2020, is a six-story building with CLT apartments over ground level retail shops. The building contains 70 residential units ranging from 808 sq ft to 1090 sq ft with a gross building area of 113,314 sq ft with a net rentable area of 60,417 sq ft. The total cost of the project was $32 million. The duration from conception to construction completion was January 2018 to September 2020. The duration of the construction period alone was projected to be 10 percent faster than normal at 11 months but took 12 months due to COVID delays. Developers believe further costa could have been saved had more components been constructed with mass timber, but fire codes did not allow for the product in this situation. The building provided aesthetic and health benefits to occupants via an open-air double loaded CLT corridor, which provided fresh air throughout the building. The developer notes that although the open-air corridor created additional costs, future operating costs will be lower due to wood's thermoregulating capabilities, removing the need for heating or cooling.

The Barracuda Condos, completed in August 2020, is a seven-story mixed material building with the frame utilizing steel beams and columns and with glulam floors, roofs, and decks. There are five residential levels for condos and two for offices and parking. This building only has 19 units, ranging from 1,400 to 1,730 sq ft, and a gross building area of 42,000 sq ft with a net rentable area of 33,117 sq ft. The realized cost of the project was $11.73 million, and the duration lasted from conception in July 2018 to construction completion in August 2020. The duration of construction lasted 15 months with supply chain and COVID delays. A significant positive contribution to the project was that the glulam panels were locally produced. The study notes that although COVID issues increased cost, the project was still profitable.

Adohi Hall Student Housing, completed in 2019, was constructed to accommodate the growing student population which was estimated to increase by 10,000 in 10 years. Adohi Hall is a five-level CLT building with four levels for housing. There are 678 bed spaces across 339 rooms with a gross building area of 202,491 sq ft with 154,554 sq ft being residential living. The total cost of the project was $64.1 million, and the duration lasted from conception in November 2016 to completion of construction in

August 2019. The construction was completed 27 percent faster than normal, resulting in a 10-week reduction in construction time and a total period of 27 months. While Arkansas has an abundance of timber, the CLT and glulam products were made in Europe, which demonstrates mass timber's ability to be prefabricated and shipped to a distant site for easier construction. Regardless of the length of the supply chain, the project was completed on time and within budget despite a four-month construction delay. The developer notes the intent behind the abundance of wood used in the construction was meant to generate biophilia for the occupants. A large takeaway is the influence the project had on other investments in the area. Because Adohi Hall reduced resistance to mass timber, Walmart's future mass timber headquarters is seeing easier access to private investment.

Opportunities for Emerging Markets

While mass timber can be utilized in many industrialized countries, the focus of this project is emerging markets. The following will discuss some opportunities for emerging markets such as Uganda to use more engineered wood for construction. The main themes are urbanization and housing demand due to a growing population and higher growth rates offered by a tropical climate. It is important to note that forestland investors may need to invest in the mills in emerging markets to update the technology as mass timber requires mills to be equipped with presses and CNC machines. This may turn some investors away, but an opportunity is available for those willing to invest in the technology. Regardless of mass timber mill capabilities in emerging markets, mass timber can be prefabricated and shipped to countries to accommodate building needs thus still providing a potential solution to the growing urbanization and housing demand in emerging markets.

Uganda is within one of the least urbanized regions of Africa with 26 percent of the population living in urban areas, yet it has one of the highest urbanization rates in Africa at 4.5 percent (Mukiibi 2012). In 2008, it was reported that Kampala, the capital city of Uganda, faced a housing shortage of about 100,000 units with another 500,000 households lacking sufficient housing (Mukiibi 2012). According to a 2002 Census conducted by Uganda Bureau of Statistics, Kampala had an estimated annual population growth rate of 5 percent (Mukiibi 2012), and the 2014 Census projected the urban population of the country to be 11.4 million (UBOS 2023). A situation that supports the use of mass timber in Uganda is that around 60 percent of the population of Kampala lives in slums, with more than 70 percent of the units in the slums being built from materials not expected to last beyond three years (Mukiibi 2012). The growth in population means more housing will be needed to accommodate the growth. Not only residential buildings, but also commercial buildings can be constructed with mass timber.

Higher growth rates in emerging markets such as Uganda make it an appealing site for building with wood. Another way to consider growth rates is through rates of return. Forests typically produce slower returns on investment than agriculture does due to the longer growth period required to generate revenues, leading to deforestation and land-use change as a main option for making money in many developing countries (Dangel 2016). Dangel believes that providing alternative ways to generate revenue from the forest could lead to "green economic development." In Uganda, this type of development could include mass timber construction throughout the country sourced from plantations enrolled in the SPGS. The rotation age of the main pine species in the SPGS is 12-18 years, providing reliable supply to support the mass timber needs of accommodating a growing demand for housing. Engineered wood allows for a reduction in the need for large diameter trees, with composite products created from smaller diameter trees that Uganda, and other emerging markets in tropical climates, could take advantage of due to shorter rotations (Dangel 2016). Again, it cannot be stated enough that for an emerging market to take advantage of the opportunity mass timber presents, investment must be made in the mill. Dangel believes that investment in mass timber milling capacity will stimulate a growth in industrial capacity with the formation of a new market while following a global trend to move manufacturing to emerging markets where labor costs are low.

Conclusion

Innovative uses of wood can lead to an increase in stumpage prices for timber. Mass timber provides an opportunity to increase stumpage prices by being an innovative product that can mitigate climate change by using a renewable resource for construction, aid in afforestation/reforestation, and provide housing for growing urban populations across the world. To take advantage of the opportunity that mass timber presents, it is important that investors consider what is required to bring the product to market, especially in emerging markets. Mass timber is a product that will require investment in the production of the materials, meaning the mills will need to be able to produce the product. Investors need information on both the factors that encourage and hinder investment in a product such as mass timber. The following section lists the factors that were identified as important through the literature review and focus groups. It also includes a brief discussion on the choice of data layers and how they were manipulated to be prepared for se.plan.

Factors

A review of available relevant literature plus focus group participant feedback revealed factors related to investment in the potential for mass timber projects to accommodate housing in emerging markets. NVivo coding analysis revealed the following factors to be most important:

Factor	Investor Preference	Source(s)	% of Documents Coded in Nvivo	Total References in Nvivo
Housing Demand	Higher	Jacovelli 2009; Meetenmeyer 2012; Karolien 2012; Mukiibi 2012, 2015, 2021; Fritz 2015; Gourevitch et al 2016; Li et al 2019; Berkel 2019; Zhou et al 2019; Binkley et al 2020; Syed 2020; Mishra et al 2022; WoodWorks Mass Timber Business Case Study 2022; Potapov et al 2022; Focus Group 3	91%	77
Domestic Market Demand	Higher	Jacovelli 2009; Karolien 2012; Meetenmeyer 2012; Mukiibi 2012, 2015, 2021; Gourevitch et al 2016; Berkel 2019; FAO 2020; Binkley et al 2020; Syed 2020:; Mishra et al 2022; WoodWorks 2022; Focus Group 1-3	48%	32
Degree of Urbanization	Higher	Meetenmeyer 2012; Mukiibi 2012; Fritz 2015; Gourevitch et al 2016; Karolien et al 2012; Li et al 2019; Berkel et al 2019; Zhou et al 2019; Binkley et al 2020; WoodWorks 2022; Mishra et al 2022; Potapov 2022; Focus Groups 2-3	43%	38
Mill Capabilities	More	Jacovelli 2009; Howard 2019; Binkley et al 2020; Syed 2020; FAO 2020; Mishra et al 2022; Focus Groups 1-3	30%	15
Skill Labor Force	More	Gourevitch et al 2016; Syed 2020; Binkley et al 2020; Focus Groups 2-3	22%	11
Building Codes	More Performance Based	Mukiibi 2015; Howard 2019; Syed 2020; Breneman 2022; Focus Group 3	17%	7

Table 11: Factors relating to development of a mass timber marketplace.

Choosing Sources for Data Layers

We chose data layers for factors identified by the literature and NVivo as most important to mass timber developments for housing developments to accommodate urban expansion. We did not look for datasets for factors that were also important to other research subquestions, such as land titling and exchange rate risk (Table 12).

Praise Atwine provided us with a shapefile of urban and rural populations in Uganda. Although population density is already integrated into se.plan, we believe adding a layer that shows the percent of population living in slum housing will be useful for mass timber developments. Urbanization can be integrated into se.plan using the urban land extent projection dataset associated with the SSPs. This will be helpful for investors as the SSPs are tied to multiple metrics for decision making outside of se.plan.

Building codes will require more work to integrate as the best data source for global building codes we could locate comes from the International Codes Council's code adoptions by state, I-code, or country. The Code Adoptions page displays a global map with the option to select a country and be taken to the country's building codes. All countries are selectable, but country codes may not be available as was the case with Uganda. The site still serves as a useful tool for better understanding what codes are in place at the national level globally.

Factor	Dataset	Purpose	Level of Detail	Date	Format
Urbanization	Global 1-km Downscaled Urban Land Extent Projection and Base Year Grids by SSP Scenarios, v1: Shared Socioeconomic Pathways (SSPs) | SEDAC (columbia.edu)	Provide spatial urban land projection consistent with SSPs	Subnational	2021	Raster (30 arc second)
Housing Demand	Population living in slums (% of urban population) | Data (worldbank.org)	Provide the population living in slums which is the proportion of the urban population living in slum households.	National	2020	Tabular (csv) from source, but converted to raster
Building Codes	**Adoption Information Solution (iccsafe.org)**	Provide information on country building codes	National	Updated 2023	

Table 12: Geospatial data layers related to factors for developing a market for mass timber.

Data Manipulation and Final Layers

The manipulation of the Projected Global Urban Land Extent dataset for the urbanization factor consisted of pulling the data from NASA SEDAC data collections as a GeoTiff and integrating into ArcGIS Pro. The base year and each SSP we processed had their own map layer, with the SSP maps comprise of 10 different rasters for the 10-year increments of Projected Global Urban Land Extent. The value ranges from 0 to 1 and represents the fraction of urban land. Each raster layer contains the metadata provided by the source.

The data used for the housing demand factor required a few more steps for processing in ArcGIS Pro. First, the .xlsx file from by the World Bank needed to be transformed into a format better for ArcGIS Pro. This was done through the *Excel to Table* tool and resulted in the slum_table. This table contains the original information of the percentage of the national population living in slum housing and was connected with Esri's world countries feature through the portal in ArcGIS Pro and combined using the *AddJoin* tool. The data were joined by the 3-Digit ISO Code in the world countries layer and Country Code in the slum_table. The output symbology was manipulated to show five classes for the percent of population in slum housing for the year 2020, the most recent year of data. The resulting "% of Population in Slums" layer contains metadata on the world countries layer from Esri and the population living in slum housing from the World Bank.

How to Incorporate Data Layers into se.plan

We have gathered dozens of additional geospatial data layers, and it is not obvious exactly how each one can be incorporated into se.plan, or if they can all be incorporated in the same way.

It is, however, important to keep in mind that our focus group participants told us they would use se.plan solely as a "high level" or "first pass" tool that complements their due diligence process when considering a potential investment (Focus Group 1.31). With that in mind, we recommended keeping the user interface as simple as possible and making the outputs easy to interpret, similar to how se.plan currently works.

Recommendations

- **Create a new tool within se.plan:** Keep the original afforestation-reforestation (AR) tool as is, and add a variant for the downstream value chain that can assist with mill location siting decisions.
    - **Incorporate new data layers into the original AR tool when appropriate:** Many of the data layers, especially relating to environmental, land use, and government policy factors (subquestion one), can be folded into the existing se.plan questionnaire. We envision that these layers (Table 3) would go into the Constraints tab, where the user could threshold their tolerance for each constraint. For example, the Ease of Doing Business layer could be added to the "Socio-economic" tab.
- **For the wood processing facility location tool, use supply and demand scores:** The layers we found do not necessarily relate easily to a cost/benefit ratio like the one the se.plan AR tool uses. Instead, since three of the four subquestions have to do with supply (cost) or demand (revenue) attributes of a mill, it would be better to have a user questionnaire dealing with supply constraints and demand constraints, and then adding a tab for the government policy constraints (subquestion one).
    - For both supply and demand factors, the user could threshold the constraint and choose the weight of the constraint through the five-point no-importance/very important scale se.plan uses for the AR tool.

- **Have a heatmap output:** The wood processing facility location tool will have an output of a heatmap similar to the AR tool, where areas are ranked based on suitability for investment (on a 0-5 scale). These ranks will be based on a weighted sum of how many supply, demand, and policy/legal constraints an area meets.
  - For example, suppose the user selected areas with land titling process of less than 10 days, areas within 100km of a seaport, and areas within 200km of counties with high projected roundwood consumption, and weighted them as 5, 3, and 2, respectively. An area that meets all these criteria would have a score of 10. An area that meets the first two criteria would have a score of 8, the second two criteria a score of 5, the first and third criteria a score of 7, and none of the criteria a score of zero. The weighting algorithm could standardize the weights to be comparable across searches. Perhaps the maximum value should always be 10 and the minimum always be 0.

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Works Cited

Aggarwal, Safia. FAO (2023). Video call conversation with M. Wang regarding land tenure.

Aguilar, F. X. (2009). Spatial econometric analysis of location drivers in a renewable resource-based industry: The U.S. South Lumber Industry. *Forest Policy and Economics*, *11*(3), 184–193. https://doi.org/10.1016/j.forpol.2009.02.006

Bamwesigye D, Kupec P, Chekuimo G, Pavlis J, Asamoah O, Darkwah SA, Hlaváčková P. (2020). Charcoal and Wood Biomass Utilization in Uganda: The Socioeconomic and Environmental Dynamics and Implications. Sustainability. 12(20):8337. https://doi.org/10.3390/su12208337

Bamwesigye, Dastan & Darkwah, Samuel & Hlaváčková, Petra & Kupčák, Václav. (2017). FIREWOOD AND CHARCOAL PRODUCTION IN UGANDA. Department of Forest and Wood Products Economics and Policy, Mendel University in Brno. DOI:10.5593/SGEM2017H/33/S14.065.

Barlett, P. F. and R. F. Nash (2005). Urban Place: Reconnecting with the Natural World, MIT Press.

Binkley, C.S., Stewart, F.E. & Power, Samantha Elizabeth. (2021). Pension Fund Investment in Forestry (English). Equitable Growth, Finance and Institutions Insight Washington, D.C. *World Bank Group*. http://documents.worldbank.org/curated/en/855551613725437905/Pension-Fund-Investment-in-Forestry.

Breneman, Scott, WoodWorks. (2021). Tall Wood Buildings in the 2021 IBC – Up to 18 Stories of Mass Timber. https://www.woodworks.org/resources/tall-wood-buildings-in-the-2021-ibc-up-to-18-stories-of-mass-timber

Castrén, Tuukka, Marko Katila, Karoliina Lindroos, and Jyrki Salmi. (2014). *Private Financing for Sustainable Forest Management and Forest Products in Developing Countries: Trends and Drivers*. Washington, DC: Program on Forests (PROFOR).

Chai, A.; Moneta, A. (2010). "Retrospectives: Engel Curves". Journal of Economic Perspectives. 24: 225–240. doi:10.1257/jep.24.1.225. hdl:10072/34021.

Daigneault, A., Baker, J. S., Guo, J., Lauri, P., Favero, A., Forsell, N., Johnston, C., Ohrel, S. B., & Sohngen, B. (2022). How the future of the global forest sink depends on timber demand, forest management, and carbon policies. *Global Environmental Change, 76*, 102582. https://doi.org/10.1016/j.gloenvcha.2022.102582

Dangel, U. (2016). Turning Point in Timber Construction: A New Economy. Birkhäuser.

Dezember, R. (2021). *Despite Lumber Boom, few new Sawmills Coming*. The Wall Street Journal. https://www.wsj.com/articles/despite-lumber-boom-few-new-sawmills-coming-11621243982

Food and Agriculture Organization (FAO). (2018). "Forest Concessions Management." PROFOR: Innovation and Action For Forests, https://www.profor.info/knowledge/forest-concessions-management.

FAO. (2020). The State of Agricultural Commodity Markets 2020. Food and Agriculture Organization of the United Nations. Unlocking future investments in Uganda's commercial forest sector. https://www.fao.org/agrifood-economics/publications/detail/en/c/1261485/

FAO. (2022). The State of the World's Forests: Forest Pathways for Green Recovery and Building Inclusive, Resilient and Sustainable Economies. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/cb9360en/cb9360en.pdf

FAO (2022). "Forests." *Food and Agriculture Organization of the United Nations*, https://www.fao.org/forests/en.

FAO. (2019). Status of community-based forestry and forest tenure in Uganda. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/ca5773en/CA5773EN.pdf

FAO (2021). Modular Downstream Integrated Sawmill Model for Uganda. *Food and Agriculture Organization.* https://www.fao.org/documents/card/en/c/CB6346EN/

Favero, F. et al. (2020) Forests: Carbon sequestration, biomass energy, or both? *Sci. Adv., 6(13)* 67-92. https://doi.org/10.1126/sciadv.aay6792

Fritz, Steffen et al. (2015). "Mapping global cropland and field size." *Global change biology* vol. 21,5 : 1980-92. doi:10.1111/gcb.12838

Fu, C.H. (2021). A Step Beyond Timber: Considering Private Equity Investments in Wood Products Manufacturing in the United States. Timberland Investment Resources, LLC. https://www.tireurope.com/wp-content/uploads/2021/06/Sawmill-Private-Equity.2021-06-14-1.pdf

George, T. (2022). What Is a Focus Group? | Step-by-Step Guide & Examples. Scribbr. https://www.scribbr.co.uk/research-methods/focus-groups/

Gochberg, W. (2021). The social costs of titling land: Evidence from Uganda. *World Development*, *142*, 105376. https://doi.org/10.1016/j.worlddev.2020.105376

Government of Uganda, Forest Sector Support Department, et al. (2018). *Financial and Economic Assessment of Forest Landscape Restoration (FLR) in Uganda*, pp. 1–173.
FAO. (n.d.). FAO STATS. Faostat. Last Update January 19, 2023. from https://www.fao.org/faostat/en/#data/FO.

Gourevitch, Jesse D., et al. (2016). *Environmental Research Letters* 11. 114027. "Optimizing investments in national-scale forest landscape restoration in Uganda to maximize multiple benefits." https://iopscience.iop.org/article/10.1088/1748-9326/11/11/114027/meta

Griffin, J.W., Seale R.D., Owens, F.C., & Grace, L.A. (2020) Construction of an Economic Model for Prospective Forest Products Manufacturing Facilities. *Bioresources, 15(2)*, 3874-3887. https://doi.org/10.15376/biores.15.2.3874-3887

Howard, M. (2019). Assessment of the Ugandan Commercial Timber Plantation Resource and the Markets for Its Products. United Nations: Food and Agriculture Organization, Kampala.

Hurlbert, M.; Krishnaswamy, J.; et al. (2019). Chapter 7 : Risk management and decision making in relation to sustainable development. SPECIAL REPORT: SPECIAL REPORT ON CLIMATE CHANGE AND LAND. IPCC. https://www.ipcc.ch/srccl/chapter/chapter-7/

International Tropical Timber Organization (ITTO). (2022). Biennial review statistics. Biennial review and assessment of the world timber situation. https://www.itto.int/biennal_review/?mode=searchdata

Jacovelli, Paul. (2010). Uganda's Sawlog Production Grant Scheme: A Success Story from Africa. International Forestry Review. 11. 119-125. 10.1505/ifor.11.1.119.

Kallio M., Dykstra D. P., & Binkley C. S., (1987). The global forest sector: An analytical perspective. United States.

Kizito, S., Banana, A.Y., Buyinza, M. *et al.* (2012). Consumer satisfaction with wooden furniture: an empirical study of household products produced by small and medium scale enterprises in Uganda. *J Indian Acad Wood Sci* 9, 1–13. https://doi.org/10.1007/s13196-012-0068-1

LandMark. (2017). LandMark: The Global Platform of Indigenous and Community Lands.

Layton, Patricia. Director Wood Utilization + Design Institute (2023). Phone conversation with R. Caradine regarding Mass Timber

Li, X., et al. (2019). "Projecting Global Urban Area Growth Through 2100 Based on Historical Time Series Data and Future Shared Socioeconomic Pathways." Earth's Future **7**(4): 351-362. DOI: 10.1029/2019ef001152

Machen R.C.; Jones, M.T.; Varghese, G.P.; Stark, E.L. (2021). Investigation of Data Irregularities in *Doing Business 2018* and *Doing Business 2020*: Investigation Findings and Report to the Board of Executive Directors. WilmerHale, Wilmer Cutler Pickering Hale and Dorr LLP. Retrieved from https://www.occ.gov/publications-and-resources/publications/comptrollers-handbook/files/country-risk-management/pub-ch-country-risk.pdf

MacKeith, Peter B. Dean and Professor Fay Jones School of Architecture and Design (2023). Phone conversation with R. Caradine regarding Mass Timber

Mayo, J. (2016). Solid Wood: Case Studies in Mass Timber Architecture, Technology and Design. Routledge.

Meentemeyer, R. K., et al. (2013). "FUTURES: Multilevel Simulations of Emerging Urban–Rural Landscape Structure Using a Stochastic Patch-Growing Algorithm." Annals of the Association of American Geographers **103**(4): 785-807. DOI: 10.1080/00045608.2012.707591

Mishra, A., Humpenöder, F., Churkina, G. *et al.* (2022). Land use change and carbon emissions of a transformation to timber cities. *Nat Commun* **13**, 4889 https://doi.org/10.1038/s41467-022-32244-w

Mukiibi, S. (2012). The effect of urbanisation on the housing conditions of the urban poor in Kampala, Uganda. In *Second International Conference on Advances in Engineering and Technology* (pp. 37-42). https://www.researchgate.net/profile/Stephen-Mukiibi/publication/279183116_The_effect_of_urbanisation_on_the_housing_conditions_of_the _urban_poor_in_Kampala_Uganda/links/558cf1fe08aee43bf6ae4cbf/The-effect-of-urbanisation-on-the-housing-conditions-of-the-urban-poor-in-Kampala-Uganda.pdf

Mukiibi, S. (2015). The potential of local building materials in the development of low cost housing in Uganda. International Journal of Technoscience and Development (IJTD), 2(1), 84-92. https://www.technoscience.se/wp-content/uploads/2016/11/2015_9_The-potential-of-local-building-materials.pdf

Mukiibi, S., & Machyo, J. N. (2021). Housing Transformation in Kampala, Uganda: Causes and Opportunities. *East African Journal of Environment and Natural Resources*, *3*(1), 1-7. https://doi.org/10.37284/eajenr.3.1.266

Musinguzi, M., Enemark, S., & Mwesigye, S. P. (2021). Fit for Purpose Land Administration: Country Implementation Strategy for Addressing Uganda's Land Tenure Security Problems. *Land*, 10(6), 629. MDPI AG. Retrieved from http://dx.doi.org/10.3390/land10060629

New Generation Plantations. (2019). *Uganda's Timber Industry Revisited*. Retrieved April 8, 2023, from https://newgenerationplantations.exposure.co/ugandas-timber-industry-revisited

Nsita, Steve A, et al. (2017). *Forest Tenure Reform Implementation in Uganda: Current Challenges and Opportunities*. Center for International Forestry Research, Bogor, Indonesia, pp. 1–9.

Office of the Comptroller of the Currency (OCC). (2016). "Country Risk Management." Comptroller's Handbook. Retrieved from https://www.occ.gov/publications-and-resources/publications/comptrollers-handbook/files/country-risk-management/pub-ch-country-risk.pdf

Ofoegbu, C., Babalola F.D.. (2015). Private Investment in Plantation Forestry: A review of lessons from Uganda Sawlog production grant scheme. *Forest Research*: Open Access, s1. https://doi.org/10.4172/2168-9776.s1-001

Papaioannou, M. (2006). Exchange Rate Risk Measurement and Management: Issues and Approaches for Firms. *International Monetary Fund.* https://www.imf.org/external/pubs/ft/wp/2006/wp06255.pdf

Potapov, P., Hansen, M. C., Pickens, A., Hernandez-Serna, A., Tyukavina, A., Turubanova, S., ... & Kommareddy, A. (2022). The global 2000-2020 land cover and land use change dataset derived from the Landsat archive: first results. *Frontiers in Remote Sensing*, *3*, 18. https://doi.org/10.3389/frsen.2022.856903

Prestemon, J. & Abt, B. (2002). TIMBR-1: Timber Products Supply and Demand. *Southern Forest Resource Assessment.* https://www.researchgate.net/publication/266339866_TIMBR-1_Timber_Products_Supply_and_Demand

Qasim, Q. (2022). *Modernizing land administration to accelerate Uganda's economic growth*. World Bank Blogs. Retrieved February 25, 2023, from https://blogs.worldbank.org/africacan/modernizing-land-administration-accelerate-ugandas-economic-growth

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Riahi, Keywan; et al.. (2017).The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global Environmental Change, Volume 42, Pages 153-168. ISSN 0959-3780, DOI:110.1016/j.gloenvcha.2016.05.009 . https://www.sciencedirect.com/science/article/pii/S0959378016300681?via%3Dihub#sec0075

Sepal Development Team. (2022). "se.plan." *SEPAL*, United Nations Food and Agriculture Organization (FAO), Forestry Department. https://docs.sepal.io/en/latest/modules/dwn/seplan.html.

Syed, T. (2020). Identifying Mass Timber Research Priorities, Barriers to Adoption and Engineering, Procurement and Construction Challenges In Canada. https://tspace.library.utoronto.ca/handle/1807/99460

Tugume, Patience & Buyinza, Mukadasi & Kakudidi, Esezah & Mucunguzi, Patrick & Kalema, James & Kamatenesi, Maud & Namaalwa, Justine. (2016). Non-Timber Forest Products Trade and Community Livelihoods around Mabira Central Forest Reserve, Uganda. Journal of Agricultural Studies. 4. 1. 10.5296/jas.v4i4.9482.

Turyahabwe N., Kakuru W., Asiimw M., Byakagaba P., (2015). Proximate and underlying causes of illegal timber trade in Uganda. IntechOpen. https://www.intechopen.com/chapters/49148

Uganda Bureau of Statistics. (2023). Uganda Profile [Data]. https://www.ubos.org/uganda-profile/

United Nations (UN). (2021). Becoming #GenerationRestoration: ECOSYSTEM RESTORATION FOR PEOPLE, NATURE AND CLIMATE. https://wedocs.unep.org/bitstream/handle/20.500.11822/36251/ERPNC.pdf

United Nations, Department of Economic and Social Affairs, Population Division. (2022). World Population Prospects 2022: Data Sources. (UN DESA/POP/2022/DC/NO. 9). https://population.un.org/wpp/Publications

United Nations Statistics Division. (2021). SDG Indicators - Goal 11: Sustainable cities and communities. https://unstats.un.org/sdgs/report/2021/goal-11/

U.S. Environmental Protection Agency. (2021). Indoor Air Quality. In EPA's Report on the

Environment (ROE). https://19january2021snapshot.epa.gov/report-environment/indoor-air-quality_.html

Van Berkel, D., et al. (2019). "Projecting Urbanization and Landscape Change at Large Scale Using the FUTURES Model." Land **8**(10). DOI: 10.3390/land8100144

Vermeiren, K., Van Rompaey, A., Loopmans, M., Serwajja, E., & Mukwaya, P. (2012). Urban growth of Kampala, Uganda: Pattern analysis and scenario development. *Landscape and urban planning*, *106*(2), 199-206. https://www.sciencedirect.com/science/article/abs/pii/S016920461200093X?casa_token=ayksr5DCgTIAAAAA:ICbNTpBifmQJde4dtNMzm9ewtTiqZ6JIhAo9UzNkIns6GZ_9EbaV0X-o4rFpeZ2tEpt5B8geHM0

Walter, Max. (2021). "Adding Value to Uganda's Wood". Centre For Development Alternatives (Uganda). https://www.researchgate.net/publication/357528559_Adding_Value_to_Uganda's_Wood

Wang, T., Sun, F. (2022). Global gridded GDP data set consistent with the shared socioeconomic pathways. Sci Data 9, 221. https://doi.org/10.1038/s41597-022-01300-x

Wang, X., Meng, X. & Long, Y. (2022). Projecting 1 km-grid population distributions from 2020 to 2100 globally under shared socioeconomic pathways. Sci Data 9, 563. https://doi.org/10.1038/s41597-022-01675-x

World Bank. (2022). Population growth (annual %) - Uganda [Data set]. https://data.worldbank.org/indicator/SP.POP.GROW?locations=UG&most_recent_value_desc=true

World Bank. (2023). DataBank, World Development Indicators. Retrieved from https://databank.worldbank.org/reports.aspx?source=world-development-indicators

World Bank Group. (2021). CPIA Criteria 2021. Retrieved from https://thedocs.worldbank.org/en/doc/69484a2e6ae5ecc94321f63179bfb837-0290032022/original/CPIA-Criteria-2021.pdf

World Bank Group. (2023). Land Governance Assessment Framework. Retrieved from https://www.worldbank.org/en/programs/land-governance-assessment-framework

WorldPop and Center for International Earth Science Information Network (CIESIN), Columbia University . Global High Resolution Population Denominators Project - Funded by The Bill and Melinda Gates Foundation. (2020). The spatial distribution of population density in 2020 based on the country total adjusted to match the corresponding UNPD estimate, Uganda. (OPP1134076). https://dx.doi.org/10.5258/SOTON/WP00675

WoodWorks. (2020). "Mass Timber Business Case Studies - Woodworks: Wood Products Council." *WoodWorks*, https://www.woodworks.org/resources/mass-timber-business-case-studies/.

Zhou, Y., et al. (2019). "High-resolution global urban growth projection based on multiple applications of the SLEUTH urban growth model." Sci Data **6**(1): 34. DOI: 10.1038/s41597-019-0048-z

Zelinka, S. L., Hasburgh, L. E., Bourne, K. J., Tucholski, D. R., Ouellette, J. P., & Kochkin, V. (2018). *Compartment fire testing of a two-story mass timber building* (p. 476). United States Department of Agriculture, Forest Service, Forest Products Laboratory. https://www.researchgate.net/profile/Samuel-Zelinka/publication/326655049_Compartment_Fire_Testing_of_a_Two-Story_Mass_Timber_Building/links/5b5b27cba6fdccf0b2fa7220/Compartment-Fire-Testing-of-a-Two-Story-Mass-Timber-Building.pdf

Geospatial Data Sources (tabular, shapefile, and raster) Cited

Atwiine, P. (2022?) Uganda Plantations Shapefile. *FAO.*

Electricity Regulatory Authority (Uganda) (2023). Tariff Schedules. https://www.era.go.ug/index.php/tariffs/tariff-schedules

FAO. (n.d.). FAO STATS. Faostat. Last Update January 19, 2023. from https://www.fao.org/faostat/en/#data/FO.

Falchetta, G., Pachauri, S., Parkinson, S. *et al.* (2019). A high-resolution gridded dataset to assess electrification in sub-Saharan Africa. *Sci Data 6*, 110 (2019). https://doi.org/10.1038/s41597-019-0122-6

FAO (2020). Unlocking future investments in Uganda's commercial forest sector. *FAO.* https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1263200/

Gao, J. and M. Pesaresi. 2021. Global 1-km Downscaled Urban Land Extent Projection and Base Year Grids by SSP Scenarios, 2000-2100. Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/1z4r-ez63

Howard, M. (2019). Assessment of the Ugandan Commercial Timber Plantation Resource and the Markets for Its Products. United Nations: Food and Agriculture Organization, Kampala.

ICC Digital Codes. (2023). APA Standards Building Codes [Web page]. International Code Council. https://codes.iccsafe.org/codes/apa-standards

International Tropical Timber Organization (ITTO). (2022). Biennial review statistics. Biennial review and assessment of the world timber situation. https://www.itto.int/biennal_review/?mode=searchdata

Ministry of Lands, Housing and Urban Development (2016). State of the Land Use Compliance Report for Uganda's Urban Local Governments [PDF]. The Republic of Uganda. https://mlhud.go.ug/wp-content/uploads/2015/10/Land-Use-Compliance.pdf

Ministry of Lands, Housing and Urban Development (2015). Statistical Abstract Vol 3 [PDF]. The Republic of Uganda. https://mlhud.go.ug/wp-content/uploads/2015/10/MLHUD-STATISTICAL-ABSTRACT-2015.pdf

Our World in Data (2022). Civil society participation, 2022. OWID based on Varieties of Democracy project (v13) [CSV]. https://ourworldindata.org/grapher/civil-society-participation

Prindex (2020). Global Levels of Perceived Property Insecurity by Country [CSV]. https://www.prindex.net/data/

Wang, X., Meng, X. & Long, Y. (2022). Projecting 1 km-grid population distributions from 2020 to 2100 globally under shared socioeconomic pathways. Sci Data 9, 563. https://doi.org/10.1038/s41597-022-01675-x

Wang, T., Sun, F. (2022). Global gridded GDP data set consistent with the shared socioeconomic pathways. Sci Data 9, 221. https://doi.org/10.1038/s41597-022-01300-x

Weiss, D., Nelson, A., Gibson, H. *et al.* (2018). A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature 553*, 333–336. https://doi.org/10.1038/nature25181, and https://developers.google.com/earth-engine/datasets/catalog/Oxford_MAP_friction_surface_2019#description

World Bank. (2022). Urban population living in slums (% of urban population) [Data set]. World Bank Group. https://data.worldbank.org/indicator/EN.POP.SLUM.UR.ZS?view=map

World Bank. (2023). Global - International Ports, World Bank Data Catalog. https://datacatalog.worldbank.org/search/dataset/0038118

World Bank (2023). Labor force participation rate, total (% of total population ages 15+)

(modeled ILO estimate). https://data.worldbank.org/indicator/SL.TLF.CACT.ZS

World Bank. (2023). Uganda Roads, World Bank Data Catalog. https://datacatalog.worldbank.org/search/dataset/0041482

World Bank. (2023). DataBank, World Development Indicators. https://databank.worldbank.org/reports.aspx?source=world-development-indicators

World Bank. (2023). DataBank, Time required to register property (days). https://data.worldbank.org/indicator/IC.PRP.DURS

World Bank, Country Policy and Institutional Assessment (2021). CPIA property rights and rule-based governance rating (1=low to 6=high) [CSV]. https://data.worldbank.org/indicator/IQ.CPA.PROP.XQ

World Bank, Doing Business project (2017). Cost to export, border compliance (US$) [CSV]. https://data.worldbank.org/indicator/IC.EXP.CSBC.CD

World Bank, Doing Business project (2017). Cost to export, documentary compliance (US$) [CSV]. https://data.worldbank.org/indicator/IC.EXP.CSDC.CD

World Bank, Doing Business project (2017). Ease of doing business score (0 = lowest performance to 100 = best performance) [CSV]. https://data.worldbank.org/indicator/IC.BUS.DFRN.XQ

World Bank, Land Governance and Assessment Framework (LGAF) (2016). Boundary demarcation of communal land [CSV]. Land Portal Foundation. https://landportal.org/book/indicators/wb-lgaf2016-218

World Bank, Land Governance and Assessment Framework (LGAF) (2016). Customary tenure rights are (i) recognized and (ii) protected in practice [CSV]. Land Portal Foundation. https://landportal.org/book/indicators/wb-lgaf2016-112

World Bank, Land Governance and Assessment Framework (LGAF) (2016). Indigenous rights to land & forest are (i) recognized and (ii) protected in practice [CSV]. Land Portal Foundation. https://landportal.org/book/indicators/wb-lgaf2016-113

World Bank, Land Governance and Assessment Framework (LGAF) (2016). Registries information is up-to-date and reflect ground reality [CSV]. Land Portal Foundation.

https://landportal.org/book/indicators/wb-lgaf2016-632

World Bank, Land Governance and Assessment Framework (LGAF) (2016). Rural land tenure rights (i) recognized and (ii) protected in practice [CSV]. Land Portal Foundation. https://landportal.org/book/indicators/wb-lgaf2016-821

World Bank, Land Governance and Assessment Framework (LGAF) (2016). Land disputes are a small share of formal legal cases [CSV]. Land Portal Foundation. https://landportal.org/book/indicators/wb-lgaf2016-821

World Bank, World Governance Indicators (2018). Political stability and absence of violence/terrorism (index) [CSV]. Land Portal Foundation. https://landportal.org/book/indicator/wb-pvest

Appendix 1: Focus Group Participants

- **Focus Group 1: January 9, 2023**

1. Alfred Tumwebaze, Managing director, Bani Agro-foresters Ltd.
2. Dickson Langoya, Managing director, JC Holdings Ltd.
3. Alex Kyabawampi, SCR Manager, New Forests Kampala
4. Besesa Ponsiano, Managing director, Basepo (U) Ltd.

- **Focus Group 2: January 26, 2023**

1. Clark Binkley, Managing Director, International Forestry Investment Advisors, LLC
2. David Brand, Executive Chairman, New Forests, Pty, Ltd.
3. Blake Stansell, President and CIO, Bluesource Sustainable Forests Company (formerly President and CEO of The Forestland Group)

- **Focus Group 3: January 31, 2023**

1. Gerrity Lansing, Head, Tangible Assets Group, BTG Pactual
2. John Earhart, Chairman of the Board, Global Environment Fund
3. Richard Bin Mei, Professor of the Practice of Natural Resource Finance, Duke University (formerly Hargreaves Professor of Forest Finance, University of Georgia)

Appendix 2: Subquestion Three

2.1 Consumption Model Variables Table

Year	ConsIRWc	pcConsIRWc	ConsIRWnc	pcConsIRWnc	ConsSWc	pcConsSWc	ConsSWnc	pcConsSWnc	Population	PopDens	GDP	GDPpc
1990	100000	0.005686	1720000	0.097802	10160	0.000578	20300	0.001154	17586630	88.016766	15857175042	901.660809
1991	100000	0.005503	1794000	0.098724	10060	0.000554	20300	0.001117	18171935	90.946074	16737897687	921.085052
1992	100000	0.005319	1941850	0.103279	20000	0.001064	74950	0.003986	18801966	94.099224	17310058766	920.651530
1993	100000	0.005138	2093000	0.107538	30130	0.001548	76450	0.003928	19462958	97.407327	18751344894	963.437567
1994	149960	0.007451	2296000	0.114087	40007	0.001988	100020	0.004970	20125021	100.720790	19952112718	991.408293
1995	200008	0.009671	2499002	0.120837	50007	0.002418	150010	0.007254	20680831	103.502482	22251243312	1075.935648
1996	214000	0.010071	2594010	0.122074	54000	0.002541	160948	0.007574	21249572	106.348891	24269901601	1142.136020
1997	229050	0.010470	2693140	0.123104	57079	0.002609	171980	0.007861	21876935	109.488689	25507667035	1165.961641
1998	245003	0.010871	2796010	0.124059	61006	0.002707	184174	0.008172	22537658	112.795446	26758885822	1187.296649
1999	269001	0.011555	2906020	0.124833	67001	0.002878	197360	0.008478	23279247	116.506917	28914032672	1242.051887
2000	269010	0.011199	2906130	0.120984	67180	0.002797	197230	0.008211	24020697	120.217692	29822484786	1241.532866
2001	269000	0.010863	2905940	0.117349	67280	0.002717	196890	0.007951	24763325	123.934363	31368381337	1266.727361
2002	268860	0.010525	2905730	0.113749	67010	0.002623	196770	0.007703	25545090	127.846905	34107683508	1335.195277
2003	269001	0.010207	2905820	0.110258	66990	0.002542	196490	0.007456	26354736	131.898984	36315562089	1377.952034
2004	286999	0.010572	2957460	0.108946	66760	0.002459	195590	0.007205	27146084	135.859487	38787647140	1428.848711
2005	307000	0.010985	3014170	0.107855	23910	0.000856	98270	0.003516	27946588	139.865813	41243900153	1475.811650
2006	327300	0.011375	3077190	0.106946	23997	0.000834	92410	0.003212	28773227	144.002938	45691949359	1588.002255
2007	427569	0.014430	3357960	0.113330	24000	0.000810	92680	0.003128	29629804	148.289895	49535750771	1671.821750
2008	449960	0.014748	3438050	0.112687	23861	0.000782	91210	0.002990	30509862	152.694370	53849696408	1764.993116
2009	474980	0.015121	3499950	0.111419	23956	0.000763	93370	0.002972	31412520	157.211951	57512292851	1830.871667
2010	502790	0.015546	3588930	0.110969	23893	0.000739	92960	0.002874	32341728	161.289288	60754612566	1878.520918
2011	532900	0.016005	3677650	0.110454	69870	0.002098	279970	0.008409	33295738	166.046968	66460476474	1996.065577
2012	753840	0.021995	3618860	0.105588	79522	0.002320	319411	0.009320	34273295	170.922078	69010867754	2013.546341
2013	798750	0.022644	3799300	0.107710	131850	0.003738	307684	0.008723	35273570	175.910483	71486222591	2026.622839
2014	844008	0.023228	3981150	0.109563	131903	0.003630	306355	0.008431	36336539	181.211545	75136528811	2067.795417
2015	893999	0.023854	4201207	0.112100	132110	0.003525	306950	0.008190	37477356	186.900838	79034506631	2108.860258
2016	934998	0.024130	4382290	0.113096	131750	0.003400	303760	0.007839	38748299	193.239073	82813146623	2137.207278
2017	935020	0.023301	4380100	0.109156	138210	0.003444	310980	0.007750	40127085	200.115126	85406362066	2128.396869
2018	935160	0.022526	4365001	0.105142	131304	0.003163	307760	0.007413	41515395	207.038674	90790314035	2186.907147
2019	935020	0.021770	4381875	0.102025	128090	0.002982	306303	0.007132	42949080	214.188510	96636070871	2250.014922
2020	934490	0.021045	4388792	0.098836	107680	0.002425	316430	0.007126	44404611	221.447292	99488097436	2240.490237
2021	934960	0.020390	4394830	0.095844	131390	0.002865	307921	0.006715	45853778	229.601813	103006573931	2246.414111

2.2 R Code For Consumption Models

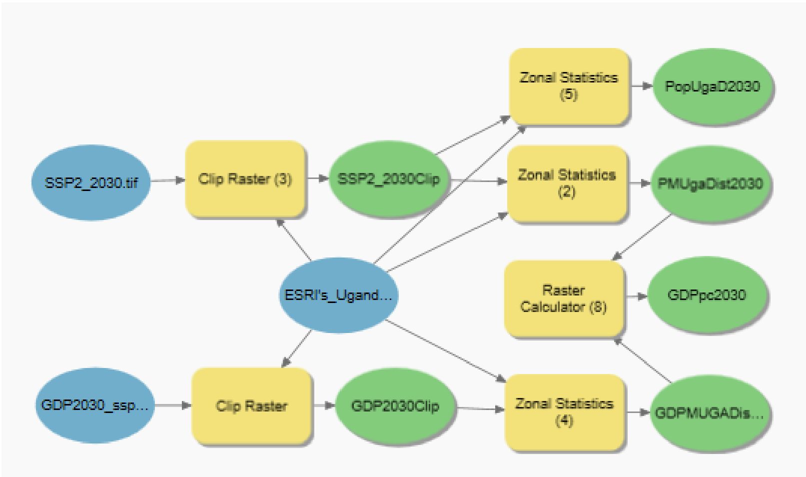
```
#Data
data <- read.csv("WoodDataAllfinal.csv", header = T)

#Data w/out 2005-2010
data2 <- read.csv("WoodDataAllfinal2.csv", header = T)

################################ pcConsIRWc

# First linear regression model
modelIRWc1 <- lm(pcConsIRWc ~ GDPpc , data = data)
modelIRWc2 <- lm(pcConsIRWc ~ PopDens , data = data)
modelIRWc3 <- lm(pcConsIRWc ~ PopDens + GDPpc , data = data)

# Summary 1
summary(modelIRWc1)
summary(modelIRWc2)
summary(modelIRWc3)

# Second linear regression model in ln
data$log_PopDens <- log(data$PopDens)
data$Log_GDPpc <- log(data$GDPpc)
data$Log_pcConsIRWc <- log(data$pcConsIRWc)
modelIRWc1.ln <- lm(Log_pcConsIRWc ~ Log_GDPpc , data = data)
modelIRWc2.ln <- lm(Log_pcConsIRWc ~ log_PopDens , data = data)
modelIRWc3.ln <- lm(Log_pcConsIRWc ~ log_PopDens + Log_GDPpc , data = data)
```

```
# Summary 2
summary(modelIRWc1.ln)
summary(modelIRWc2.ln)
summary(modelIRWc3.ln)

#Test
## Compare R-squared values
rsq_IRWc <- c(summary(modelIRWc1)$r.squared,
          summary(modelIRWc2)$r.squared,
          summary(modelIRWc3)$r.squared,
          summary(modelIRWc1.ln)$r.squared,
          summary(modelIRWc2.ln)$r.squared,
          summary(modelIRWc3.ln)$r.squared)
rsq_IRWc_max <- max(rsq_IRWc)
rsq_IRWc_max
##Best Model
if (rsq_IRWc_max == summary(modelIRWc1)$r.squared) {
  best_modelIRWc <- modelIRWc1
} else if (rsq_IRWc_max == summary(modelIRWc2)$r.squared) {
  best_modelIRWc <- modelIRWc2
} else if (rsq_IRWc_max == summary(modelIRWc3)$r.squared) {
  best_modelIRWc <- modelIRWc3
} else if (rsq_IRWc_max == summary(modelIRWc1.ln)$r.squared) {
  best_modelIRWc <- modelIRWc1.ln
} else if (rsq_IRWc_max == summary(modelIRWc2.ln)$r.squared) {
  best_modelIRWc <- modelIRWc2.ln
} else {
  best_modelIRWc <- modelIRWc3.ln
}

best_modelIRWc


################################ pcConsIRWnc

# First linear regression model
modelIRWnc1 <- lm(pcConsIRWnc ~ GDPpc , data = data)
modelIRWnc2 <- lm(pcConsIRWnc ~ PopDens , data = data)
modelIRWnc3 <- lm(pcConsIRWnc ~ PopDens + GDPpc , data = data)

# Summary 1
summary(modelIRWnc1)
summary(modelIRWnc2)
summary(modelIRWnc3)

# Second linear regression model in ln
data$log_PopDens <- log(data$PopDens)
data$Log_GDPpc <- log(data$GDPpc)
data$Log_pcConsIRWnc <- log(data$pcConsIRWnc)
modelIRWnc1.ln <- lm(Log_pcConsIRWnc ~ Log_GDPpc , data = data)
modelIRWnc2.ln <- lm(Log_pcConsIRWnc ~ log_PopDens , data = data)
modelIRWnc3.ln <- lm(Log_pcConsIRWnc ~ log_PopDens + Log_GDPpc , data = data)

# Summary 2
summary(modelIRWnc1.ln)
summary(modelIRWnc2.ln)
summary(modelIRWnc3.ln)

#Test
## Compare R-squared values
rsq_IRWnc <- c(summary(modelIRWnc1)$r.squared,
          summary(modelIRWnc2)$r.squared,
          summary(modelIRWnc3)$r.squared,
          summary(modelIRWnc1.ln)$r.squared,
          summary(modelIRWnc2.ln)$r.squared,
          summary(modelIRWnc3.ln)$r.squared)
rsq_IRWnc_max <- max(rsq_IRWnc)
rsq_IRWnc_max
```

```
##Best Model
if (rsq_IRWnc_max == summary(modelIRWnc1)$r.squared) {
  best_modelIRWnc <- modelIRWnc1
} else if (rsq_IRWnc_max == summary(modelIRWnc2)$r.squared) {
  best_modelIRWnc <- modelIRWnc2
} else if (rsq_IRWnc_max == summary(modelIRWnc3)$r.squared) {
  best_modelIRWnc <- modelIRWnc3
} else if (rsq_IRWnc_max == summary(modelIRWnc1.ln)$r.squared) {
  best_modelIRWnc <- modelIRWnc1.ln
} else if (rsq_IRWnc_max == summary(modelIRWnc2.ln)$r.squared) {
  best_modelIRWnc <- modelIRWnc2.ln
} else {
  best_modelIRWnc <- modelIRWnc3.ln
}

best_modelIRWnc


################################ pcConsSWc

# First linear regression model
modelSWc1 <- lm(pcConsSWc ~ GDPpc , data = data2)
modelSWc2 <- lm(pcConsSWc ~ PopDens , data = data2)
modelSWc3 <- lm(pcConsSWc ~ PopDens + GDPpc , data = data2)

# Summary 1
summary(modelSWc1)
summary(modelSWc2)
summary(modelSWc3)

# Second linear regression model in ln
data2$log_PopDens <- log(data2$PopDens)
data2$Log_GDPpc <- log(data2$GDPpc)
data2$Log_pcConsSWc <- log(data2$pcConsSWc)
modelSWc1.ln <- lm(Log_pcConsSWc ~ Log_GDPpc , data = data2)
modelSWc2.ln <- lm(Log_pcConsSWc ~ log_PopDens , data = data2)
modelSWc3.ln <- lm(Log_pcConsSWc ~ log_PopDens + Log_GDPpc , data = data2)

# Summary 2
summary(modelSWc1.ln)
summary(modelSWc2.ln)
summary(modelSWc3.ln)

#Test
## Compare R-squared values
rsq_SWc <- c(summary(modelSWc1)$r.squared,
             summary(modelSWc2)$r.squared,
             summary(modelSWc3)$r.squared,
             summary(modelSWc1.ln)$r.squared,
             summary(modelSWc2.ln)$r.squared,
             summary(modelSWc3.ln)$r.squared)
rsq_SWc_max <- max(rsq_SWc)
rsq_SWc_max
##Best Model
if (rsq_SWc_max == summary(modelSWc1)$r.squared) {
  best_modelSWc <- modelSWc1
} else if (rsq_SWc_max == summary(modelSWc2)$r.squared) {
  best_modelSWc <- modelSWc2
} else if (rsq_SWc_max == summary(modelSWc3)$r.squared) {
  best_modelSWc <- modelSWc3
} else if (rsq_SWc_max == summary(modelSWc1.ln)$r.squared) {
  best_modelSWc <- modelSWc1.ln
} else if (rsq_SWc_max == summary(modelSWc2.ln)$r.squared) {
  best_modelSWc <- modelSWc2.ln
} else {
  best_modelSWc <- modelSWc3.ln
}
```

```
best_modelSWc


################################ pcConsSWnc

# First linear regression model
modelSWnc1 <- lm(pcConsSWnc ~ GDPpc , data = data2)
modelSWnc2 <- lm(pcConsSWnc ~ PopDens , data = data2)
modelSWnc3 <- lm(pcConsSWnc ~ PopDens + GDPpc , data = data2)

# Summary 1
summary(modelSWnc1)
summary(modelSWnc2)
summary(modelSWnc3)

# Second linear regression model in ln
data2$log_PopDens <- log(data2$PopDens)
data2$Log_GDPpc <- log(data2$GDPpc)
data2$Log_pcConsSWnc <- log(data2$pcConsSWnc)
modelSWnc1.ln <- lm(Log_pcConsSWnc ~ Log_GDPpc , data = data2)
modelSWnc2.ln <- lm(Log_pcConsSWnc ~ log_PopDens , data = data2)
modelSWnc3.ln <- lm(Log_pcConsSWnc ~ log_PopDens + Log_GDPpc , data = data2)

# Summary 2
summary(modelSWnc1.ln)
summary(modelSWnc2.ln)
summary(modelSWnc3.ln)

#Test
## Compare R-squared values
rsq_SWnc <- c(summary(modelSWnc1)$r.squared,
          summary(modelSWnc2)$r.squared,
          summary(modelSWnc3)$r.squared,
          summary(modelSWnc1.ln)$r.squared,
          summary(modelSWnc2.ln)$r.squared,
          summary(modelSWnc3.ln)$r.squared)
rsq_SWnc_max <- max(rsq_SWnc)
rsq_SWnc_max
##Best Model
if (rsq_SWnc_max == summary(modelSWnc1)$r.squared) {
  best_modelSWnc <- modelSWnc1
} else if (rsq_SWnc_max == summary(modelSWnc2)$r.squared) {
  best_modelSWnc <- modelSWnc2
} else if (rsq_SWnc_max == summary(modelSWnc3)$r.squared) {
  best_modelSWnc <- modelSWnc3
} else if (rsq_SWnc_max == summary(modelSWnc1.ln)$r.squared) {
  best_modelSWnc <- modelSWnc1.ln
} else if (rsq_SWnc_max == summary(modelSWnc2.ln)$r.squared) {
  best_modelSWnc <- modelSWnc2.ln
} else {
  best_modelSWnc <- modelSWnc3.ln
}

best_modelSWnc
```

2.3 ArcGIS Consumption Layer Creation Models




ESRI's_Ugand...
Raster Calculator (3)
IRWncDistTot
Zonal Statistics (3)
DistIRWnc
pmugadist2030
Raster Calculator
RateC2IRWnc30
ESRI's_Ugand... (2)
gdppc2030
Raster Calculator (4)
RWcDistTot
Zonal Statistics (6)
DistIRWc
Raster Calculator (2)
RateC2IRWc_30
popugad2030
ESRI's_Ugand... (3)
Raster Calculator (9)
SWcDistTot
Zonal Statistics (7)
DistSWc
Raster Calculator (7)
RateC2SWc_30
ESRI's_Ugand... (4)
Raster Calculator (10)
SWncDistTot
Zonal Statistics (8)
DistSWnc
Raster Calculator (6)
RateC2SWnc_...