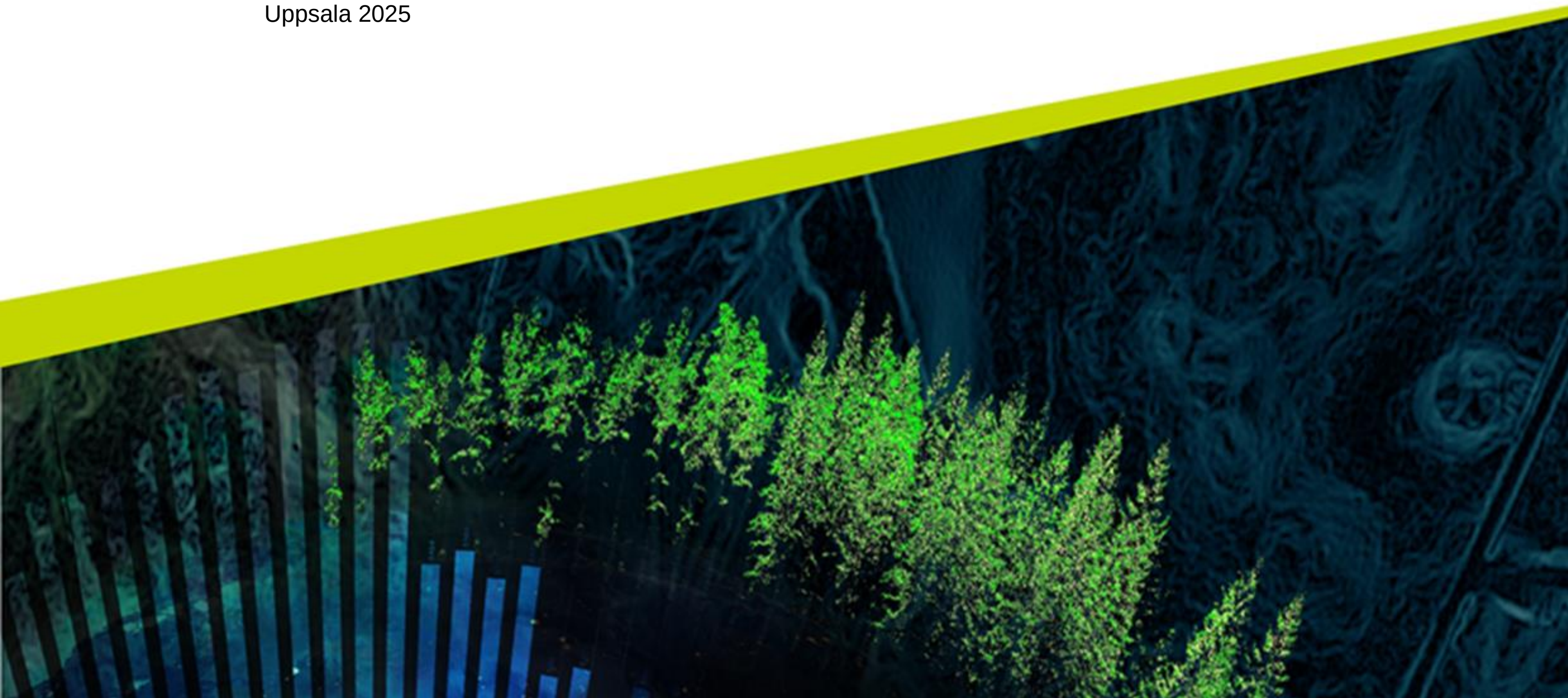
The adoption process of CT scanning in sawmills: motives, acquisition, challenges and benefits

Implementeringsprocessen av CT-scanning i sågverk: motiv, införskaffande, utmaningar och fördelar

Jakob Nowik

Degree project/Independent project • 30 hp
Swedish University of Agricultural Sciences, SLU
Faculty of Forest Sciences
Department of Forest Economics
Master Thesis • No 56
Uppsala 2025



The adoption process of CT scanning in sawmills: motives, acquisition, challenges and benefits

Jakob Nowik

Supervisor:	Anders Roos, Swedish University of Agricultural Sciences, Department of Forest Economics
Examiner:	Cecilia Mark-Herbert, Swedish University of Agricultural Sciences, Department of Forest Economics

Credits:	30 hp
Level:	A2E
Course title:	Master thesis in Forest Science
Course code:	EX0975
Programme/education:	Forest Science
Course coordinating dept:	Department of Forest Economics

Place of publication:	Uppsala
Year of publication:	2025
Title of series:	Master Thesis
Part number:	56

Keywords:	CT, innovation, optimization, sawmills, sustainability

Swedish University of Agricultural Sciences
Faculty of Forest Sciences
Department of Forest Economics

Summary

The Swedish sawmill industries are searching for new technologies that aim to meet a more competitive market, demands for efficiency, sustainability and higher costs. With new technologies like Computed Tomography (CT) where internal features of logs can be scanned, the sawmills can optimize yield, enhance product quality and achieve traceability throughout the whole production chain. The adoption of the technology has been limited due to high initial investment cost, uncertain investment returns and a complex implementation process.

This study explores factors that influence the investing decisions in CT technology, focusing on the motives, benefits, and challenges encountered by Swedish sawmills. To answer the study`s aim, a qualitative approach that consist of semi-structured interviews, with respondents from sawmills, both with and without CT technology. The interviews have been thematically analyzed to uncover key findings about implementation and operational impacts of CT technology.

The study found that when implemented in the right way, CT technology can improve yield, value recovery and make it possible to produce high quality products. Early adopters of the CT technology use it to achieve traceability in the whole process from log to product. The technology gives the possibility to know what products you can produce before the sawing. With new directives, necessary measures are needed to achieve traceability in the process.

Despite these advantages, the spread of the CT technology is very limited. Findings showed that sawmills with lower turnover might struggle with justifying the high cost and the complex utilization of the technology. The results revealed that an implementation of CT technology is a difficult process with large amounts of data received. If a sawmill can overcome the investment cost and the complicated implementation phase, then the investment can be beneficial. The technology is early in its innovation phase and in the future CT scanners might be smaller and easier to implement in existing sawmill systems which could give more sawmills the ability to use the benefits with CT technology.

Keywords: CT, innovation, optimization, sawmills, sustainability

Sammanfattning

Den svenska sågverksindustrin söker nya teknologier som syftar till att möta en mer konkurrensutsatt marknad, krav på effektivitet, hållbarhet och ökade kostnader. Med ny teknologi som datortomografi (CT), där trädstammars inre egenskaper kan skannas, kan sågverk optimera utbyte, förbättra produktkvalitet och uppnå spårbarhet genom hela produktionskedjan. Användningen av teknologin har dock varit begränsad på grund av höga initiala investeringskostnader, osäkra investeringsavkastningar och en komplex implementeringsprocess.

Denna studie undersöker faktorer som påverkar investeringsbeslut i CT-teknologi, med fokus på de motiv, fördelar och utmaningar som svenska sågverk möter. För att besvara studiens syfte har en kvalitativ ansats använts, där halvstrukturerade intervjuer genomförts med representanter från sågverk, både med och utan CT-teknologi. Intervjuerna har analyserats tematiskt för att identifiera viktiga insikter om implementering och driftsmässiga effekter av CT-teknologi.

Studien visade att när CT-teknologi implementeras på rätt sätt kan den förbättra utbytet, avkastningen på investeringar och möjliggöra produktion av högkvalitativa produkter. Tidiga användare av CT-teknologin använder den för att uppnå spårbarhet i hela processen från stock till färdig produkt. Teknologin gör det möjligt att veta vilka produkter som kan produceras innan sågningen. Med nya direktiv krävs nödvändiga åtgärder för att uppnå spårbarhet i processen.

Trots dessa fördelar är spridningen av CT-teknologi mycket begränsad. Resultaten visade att sågverk med lägre omsättning kan ha svårt att motivera de höga kostnaderna och den komplexa användningen av teknologin. Studien visade också att implementeringen av CT-teknologi är en svår process med stora mängder data som hanteras. Om ett sågverk kan övervinna investeringskostnaderna och den komplicerade implementeringsfasen kan investeringen bli lönsam. Teknologin befinner sig fortfarande i sin tidiga innovationsfas, och i framtiden kan CT-skannrar bli mindre och enklare att integrera i befintliga system, vilket skulle kunna ge fler sågverk möjlighet att dra nytta av CT-teknologins fördelar.

Keywords: Datortomografi, Hållbarhet, Innovation, Optimering, Sågverk

Table of contents

List of tables

List of figures

Abbreviations

CT	Computed Tomography	Page 12
EU	European Union	Page 13
SCA	Svenska Cellulosa Aktiebolaget	Page 13

1 Introduction

Chapter 1 introduces the background, problem, purpose, research questions, and the scope of this study.

1.1 Problem background

Forest products store large amounts of carbon dioxide and act as carbon sinks, unlike fossil-based products. The Swedish forestry sector stores large amounts of carbon dioxide and stored 47 million tons of carbon dioxide in 2022, which demonstrates the importance in reducing the effects of climate change (The Swedish Environmental Protection Agency 2024). By streamlining and optimizing the production of long-lasting products, the forest industry can grow while the forest continues to absorb carbon dioxide.

A key to a more sustainable industry is minimization of by-products and production waste, to better utilize resources. In the forestry industry, innovation and modernization have transformed how raw materials are used. In the pulp industry, significant modernization has occurred, including advancements in chemical processing and the adoption of renewable energy, demonstrating the substantial impact such changes can have on a sector. Innovations and modernizations in the pulp industry have made it more sustainable, both economically and environmentally (Bergquist & Söderholm 2018).

In 2023, the Swedish sawmill industry made record-breaking investments by expanding and modernizing its operations (Freij 2023). Innovations have always played a key role in driving economic growth and environmental sustainability in forestry. For sawmills it is crucial to meet growing competitiveness and demands for higher quality products. Innovations like computer tomographs (CT) might play a crucial role in sawmills to increase efficiency, sustainability and product quality. Technologies like CT technologies enable sawmills to maximize yield and grade logs based on their internal properties. Acquiring CT technology is one approach some sawmills have adopted to meet new requirements for efficiency and quality. CT technology could help sawmills to optimize yield, improve quality and better respond to market demands (Pernkopf et al. 2019).

CT technology has the potential to transform traditional sawmill processes by making them more efficient and economically profitable. By optimizing the sawing to each individual log depending on the internal characteristics, it can result in more efficient resource use. The result could be higher-quality boards and reduced waste. The technology also allows faster and more precise sawing decisions by analyzing the internal structure of logs. This enables sawmills to increase the value recovery of timber (Rais et al. 2017).

1.2 The Role of Computer Tomography in Modern Sawmills

The Swedish sawmill industry consists of approximately 140 sawmills in 2024. Over the past 50 years, the number of sawmills has declined while the total sawn timber production has increased to record levels (Swedish Forest Industries 2024). This change solidifies the industry's shift toward a more efficient, automated and productive future.

In sawmills, the process needs to be precise and rapid to maintain both quality and effectiveness. Different properties of the logs are continuously evaluated throughout the process. In the first step, logs are measured and sorted, depending on different features as form, diameter or number of twigs. Instruments such as laser scanners, 3D scanners or optical evaluations are used, which influences the final product`s quality. With instruments like CT scanners the sorting, grading and later sawing of the logs can be streamlined, optimized and automated. The next stage in the chain involves debarking and sawing the logs into different assortments (Figure 1). Afterward, the logs are dried before undergoing second grading and are then transported to storage, ready for shipment. Often the sorting and grading process depends on the operator`s expertise and may result in product variations (Fröbel & Bergkvist 2020).

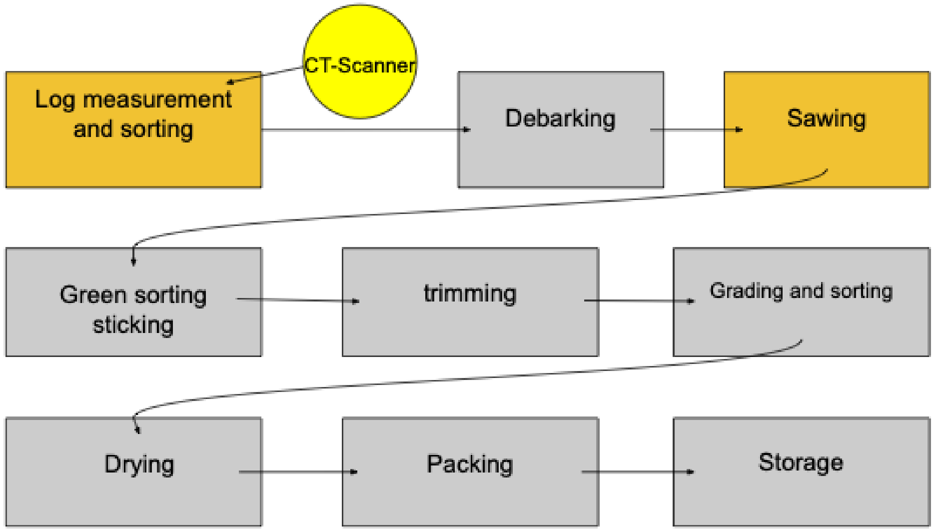


Figure 1. *Simplified explanation of the sawmill process.*

Over the past few decades CT technology has been undergoing research and development for usage in the sawmill industry. By using CT scanners, sawmill systems can visualize internal log features including knots, cracks and density variations, which are not possible to detect with traditional methods like laser scanning. At Luleå university, the CT Wood project conducted significant research on the possible advantages and uses of CT technology (CT WOOD 2024). These projects and the researchers in them have paved the way for the development of the first industrial CT scanners made specifically for sawmills. The Italian company Microtec is, as of 2024 the only producer of CT scanners made specifically for sawmills (Microtec 2024b).

The adaptation of this technology requires changes and adjustments to existing workflows and infrastructure. For example, sorting and measurement systems must integrate the CT scanner and use the information it provides to sort and classify the logs. This also requires specialized personnel training to effectively use the technology. Only a limited number of Swedish sawmills have adopted this cutting-edge technology. Norra Skog installed the first integrated industrial CT scanner for sawmills in Scandinavia during the year 2018 and purchased a second CT scanner to another sawmill in 2024 (Norra Skog 2024). Similarly, the companies SCA (Svenska Cellulosa Aktiebolaget) and Fiskarheden have invested in CT scanners from Microtec. These investments aim to improve yield and product specialization (L.O.A.B 2018; L.O.A.B 2020).

CT scanners not only optimize the use of the natural resources but also provide a system to trace logs from start to end which new directives require. New deforestation legislations from the EU (European union) sets a greater responsibility on producers and their traceability of timber (European Union 2023). With the use of CT technology there is a well-functioning system that can meet the markets demand on sustainability work (Persson 2023). Despite the advantages with the CT scanners, the technology has not achieved a breakthrough in the Swedish sawmill industry. High initial investment costs, infrastructure modifications, and concerns about return on investment are inhibiting sawmills from investing in the technology. However, with rising timber prices and more legislations affecting the sawmill industry the benefits of the CT technology may outweigh the drawbacks and risks.

Despite the growing interest of CT technology in the sawmill industry, there is a lack of research on the factors influencing investment decisions and the challenges associated with implementation. Existing studies mostly focus on technical capabilities and potential benefits of CT technology.

This knowledge gap is critical to address, as understanding these factors can create more informed decision-making and support the adoption of CT technology. A better understanding of this area can contribute to the development of targeted strategies, such as policy incentives or technological advancements, that lower barriers and promote sustainable and efficient use of resources in the sawmill industry. By addressing this gap, the study aims to provide insights that align with both industry needs and sustainability goals.

1.3 Aim and delimitations

The aim of this study is to identify factors related to investment decisions regarding computed tomography (CT) systems for Swedish sawmills. The study seeks to understand the motives behind the acquisition of CT-technology. The benefits and challenges under implementation and potential opportunities the technology can offer. The research questions used to answer the aim are:

- What are the motives for acquiring an CT scanner?
- What are the main benefits of the CT technology?
- What challenges and difficulties arise during the implementation phase?
- What inhibits some sawmills from implementing CT technology?

The study is focused on all Swedish sawmills with CT technology and two organizations without CT technology in their sawmills. The research is qualitative and operational performance data from CT technology are outside the scope of this research.

2 Literature review

Chapter 2 introduces the excising research of CT technology in sawmills.

A literature review was conducted to establish what prior research has studied. The primary databases used were Web of Science, and Google Scholar. They provide access to a wide range of peer-reviewed articles, industry reports, and technical papers related to sawmill operations and computed tomography (CT) technology.

The search process was guided by a combination of keywords to refine the results and ensure relevance. The following keywords were used in search of literature:

- "Sawmill"
- "CT"
- "Computed tomography"
- "CT-LOG"
- "Optimization"
- "Lumber grading"
- "Log scanning"

The literature review is the foundation of the thesis, founding the importance by integrating previous work with the field by finding research and framing that knowledge as a background to the own research (Bryman & Nilsson 2018). By researching scientific articles and industry reports of CT implementation in sawmills the foundation of the review will establish a better understanding. One of the key advantages with conducting a literature review is to allow the research to align with the studies research questions, so that they are relevant to the subject. This process helps to retain the context and relevance of the current study (Creswell & Creswell 2018).

2.1 Economical value

One of the primary drivers for adoption of the CT technology for sawmills is the potential for economic efficiency. Studies have shown that a CT scanner in the sawline could improve both the yield, resource use and optimize sawing strategies. Lundahl and Grönlund (2010) found that CT technology in sawmills can increased volume yield, which, could increase the economic profitability. Rais et al. (2017) presented that with the use of an industrial CT scanner the lumber recovered value could be enhanced by 4 to 20% depending on species and quality of the log. In research by Pernkopf et al. (2019) results indicated that in an CT integrated process where the sawing strategies and log optimization are used, the yield could be improved by 5 to 42% under varying conditions. Fredriksson et al. (2017) highlighted that, if utilization of the technology is made correctly, CT technology could achieve a payback period of less than one year.

2.2 Optimization of saw angle

Another driving factor for the sawmill industry is the optimization of the sawing angle, which can be increased with CT technology, by analyzing internal features of the logs before the sawing. CT scanners provide information that helps in the alignment before sawing, significantly improving value recovery. Optimized log rotation strategies have been shown to increase value recovery by an average of 13% (Berglund et al. 2013). Another study presented that the value could be enhanced with 15 to 24%, depending on wood species and log quality, through optimized sawing processes and detailed insights into the internal structure of log (Gergeľ et al. 2019). Fredriksson (2014) demonstrated that the CT could enhance the sawing operation by optimizing sawing parameters like rotational position and alignment with a 13 to 21% increased value recovery.

CT technology could also be used with other technologies to further improve operational efficiency. By combining optical scanning and CT scanning during the cutting process, value recovery of the log could be enhanced by up to 5% (Rummukainen et al. 2021). Combining CT and 3D scanning technologies in sawmills has proven to improve log grading accuracy, increasing board grade prediction from 57 to 66%, significantly increasing value recovery and operational efficiency (Oja et al. 2004).

2.3 Quality

With the help of CT technology, quality can be improved. The technology provides detailed information about the internal properties of the wood, allowing the sawmill to tailor its sawing to specific products with specific internal characteristics, such as heartwood timber. Ji et al. (2021) used CT technology to create predictive models for knot characteristics, demonstrating how economic value recovery and sawing yield could be calculated and how the sawing process could be optimized. The findings indicated improvement in lumber value recovery when logs were optimally processed.

As presented, optimized sawing with CT technology can provide precise data on the internal properties of the wood, which can be used to enhance sawing yield. However, errors in sawing angles can cause significant reductions in yield. Fredriksson (2016) presented that with an optimization method that decreases these errors, value yield could be increased by approximately 2% compared to other optimization strategies and up to 11% compared to traditional sawing methods.

In addition to improving the quality of sawn timber, the technology also supports traceability initiatives by assigning unique "fingerprints" to logs, ensuring that each board can be traced back to its source (Johansson 2015).

2.4 Relevance for this study

The studies in this chapter have covered insights in technological, economic, and operational aspects of CT technology in the sawmill industry. It highlights the potential to optimize yield, improve product quality, and use traceability. With these insights a foundation for this study is laid out.

3 Theory

Chapter 3 presents the theoretical frameworks that form the basis for analyzing investments in CT technology within sawmills. By using established theories, we can better understand and explain the factors influencing decisions to invest in new technology, such as CT scanners.

The theories chosen in this study have been based on sawmills` adoption of the CT technology. The technology is relatively new and untrialed, and different users are at different stages of the adoption stage. A theory that is well suited for new innovations and their expansion into new industries is Diffusion of innovation theory (Chapter 3.1).

The technology is not broadly implemented in the Swedish sawmill industry, and a big question is how investment in the technology could be justified. Investment theory provides understanding behind investment motives (Chapter 3.2).

By investing in CT scanners, organizations work towards a more streamlined and sustainable production which is in line with the Lean theory that emphases reduction of waste and effectivization of production (Chapter 3.3).

3.1 Diffusion of innovation

The Diffusion of Innovation Theory, introduced by Rogers in 1962, explains how new ideas, tools, or technologies spread through groups of peoples. According to Rogers (1962), there are five key steps in the adoption process: awareness, interest, evaluation, trial, and adoption. Each one of the stages represents a point where people or organizations assess the value and likelihood of adopting an innovation. In the case of sawmills and CT technology, this theory explains why some organizations use CT technology and others do not. Early adopters moved from awareness to adoption, recognizing the potential for increased efficiency and process tracking. Their decision was the result of a thoughtful balance of benefits, such as improved efficiency and product quality, against barriers such as costs and difficulties in implementation.

Rogers (1962), also introduces the concept of innovation attributes that include relative advantage, compatibility, complexity, testability, and observability. Relative advantage in the CT scanner context could be how good it could optimize the sawing process and improve quality on the products. Compatibility refers to how well the CT scanners can adapt to the current workflows. Complexity is how difficult the technology is to understand and use. Testability reflects on to which extent the technology could be tried on small scale before full adaption. Lastly, observability is how visible the benefits of the technology are to others in the industry. If other competitors demonstrate clear advantages from using CT scanners, it could create a ripple effect, making others willing to adopt it as well.

The social dynamic and organization culture is also an important part of the diffusion process. Organizations that emphasize innovation and long-term sustainability might be more motivated to adopt new technology. While smaller organizations or sawmills focused on standard products might wait with the adoption process due to greater risk considerations and less resources.

3.2 Investment Theory

Investment theory provides an approach to understand how organizations evaluate, prioritize, and implement high investment projects. According to Maccarrone (1996) the investment process consists of six steps: opportunity identification, appraisal and feasibility studies, selection of viable projects, authorization, implementation, and post-implementation analysis. This framework is important for organizations on evaluating the value of implementing CT technology.

Investment decisions often revolve around maximization the economic return and minimizing the risks. Fredriksson et al. (2017) highlighted that CT technology could significantly improve the yield and product quality which makes the CT system a strategic investment. However, the initial cost for the CT technology is a critical consideration, especially for smaller organizations and sawmills. During the process principles like risk versus return are analyzed, the investors seek balance between the return and the risk they are willing to make. Higher risk is associated with higher reward and lower risk with lower reward (Grubbström & Lundquist 2005).

3.3 Lean Management

In The Toyota Way, Liker (2021) breaks down the core principles of Toyota Production Systems, which established the manufacturer Toyota as a global benchmark for efficiency, quality and innovation. These principles emphases reduction of waste, a culture of constant improvement and just in time production. By minimizing waste (Muda), fostering innovation through continuous improvements (Kaizen), and optimizing timing in the process (Heijunka). Toyota developed an effective, adaptable and costumer-based production that had offered competitiveness, operational superiority and employment empowerment.

The “4 P” model presented by Liker (2021) provides a strategy framework that industries like sawmills can adopt.

- The first P, Problem Solving focuses on identifying inefficiencies and creating long term sustainable solutions. In the sawmill industry this could be to make the sorting more efficient.
- The second P, People and Partners highlights the trust within the company and with external collaborators. The trust with partners and suppliers is important to ensure seamless integration and future innovation.
- The third P is Process, which focus on having a just in time production with continuous improvements. The CT scanners with real time data enable sawmills to optimize sawing strategies and grading decisions. By waste reduction (Muda) in the sawing process and making the logs processed efficiently, sawmills can improve their productivity and quality. The CT technology is also enabling autonomation (Jidoka) by automation in the sorting and optimization processes.
- The fourth P, Philosophy is the most challenging one to achieve. It focuses the perspectives where long term sustainable growth is more important than short-term gains.

3.4 Conceptual framework

The conceptual framework in Figure 2 illustrates the process and factors influencing the adoption of CT technology in sawmills. It consists of the theoretical concepts presented in chapter three that explain the investment decision, implementation process, outcomes, and comparative analysis of organizations with and without CT technology. This structured approach provides a roadmap for exploring the phenomenon and answering the research questions.

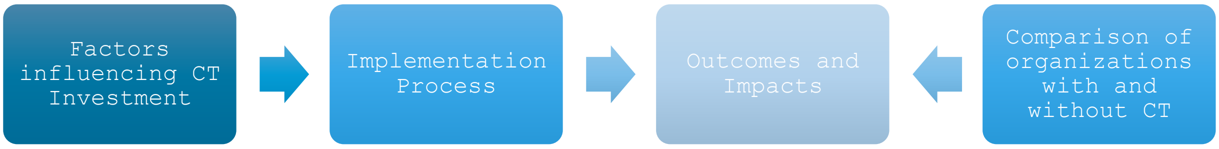


Figure 2. *Illustration of the conceptual framework of the thematic analysis.*

The conceptual framework aligns with the graph's structure, progressing logically from the factors influencing investment decisions to implementation, outcomes, and the comparative analysis of organizations. This process highlights the motivations and barriers to CT adoption, explores how implementation impacts operational efficiency and strategic goals and provide a comparative lens to evaluate the impact of CT on competitiveness and sustainability.

4 Method

Chapter 4 outlines the research design, data collection, and analysis methods, including a qualitative approach, semi-structured interviews, participant selection, and thematic analysis, to explore factors influencing investment in CT technology.

4.1 Research design

The aim with the study is to identify factors behind investments in CT scanner for Swedish sawmills, including benefits, motivations, challenges, and outcomes associated with such investments. This was achieved through a qualitative approach combined with semi-structured interviews and a literature review to collect both practical and theoretical data. This approach allowed for in-depth explanation directly from the users and stakeholders to get their perspective, while being flexible and able to adopt to different specific contexts of sawmills in Sweden.

Qualitative research was considered suitable due to the limited prior research on this topic and the complex decision-making process. While quantitative methods focus on measurable variables, qualitative research is better suited for uncovering complex choices in decision making processes in specific contexts (Bryman & Bell 2015).

4.2 Data collection methods

4.2.1 Selection of respondents

Participants for the interviews were selected by a purposive sampling approach, which is common in qualitative research to ensure their involvement and knowledge in the researched subject (Bryman & Bell 2015; Gibbs 2018). The selection targeted respondents from Swedish sawmills with significant positions in the organization and possessing knowledge in implementation and management of CT scanners in sawmills. Participants from organizations with and without CT technology were included to allow a comparative analysis of perspectives. By focusing on respondents that had a lot of knowledge about the technology, the study ensures that answers reflect the full scope of reflections and considerations when investing in CT technology. In the table belove the respondents are presented with their organization and CT scanner status in their organization.

Table 1: Respondents name, organization and organizations CT status

Respondent	**Organization**	**Has CT technology?**
Ante Vernersson	SCA	Yes
Johan Oja	Norra Skog	Yes
Martin Eriksson	Fiskarheden	Yes
Per Andersson	Derome	No
Tomas Turpers	Moelven Dalaträ Ab	No

The recruitment process was conducted systematically. Initially, a list of potential organizations was assembled using information from organizations official websites. In the process of selecting respondents, the organizations provided assistance by directing me to the most appropriate individuals with the relevant expertise and experience. This ensured that the interviews were conducted with key decision-makers or technical specialists who had in-depth knowledge about the adoption and use of CT technology in respective sawmill.

When in contact with the correct individual, participants were presented with the aim of the study and with the interview questions. The respondents worked in organizations that have different capacities in their production, sawmills with CT technology had an annual production capacity between 300 000 to 550 000 cubic meters sawn timber a year and the respondents from sawmills without CT technology had a capacity between 150 000 to 450 000 cubic meters. Data regarding the production capacity were gathered from the official websites of the respective organizations, providing insights into their production capacity.

4.2.2 Semi-structured Interviews

Semi-structured interviews were conducted to gain insights into respondents' perspectives and opinions on CT technology. An interview guide with open-ended questions was used in the interviews. This format allowed respondents to elaborate on their experiences and perspectives, providing both structured insights and the flexibility to explore new and unexpected factors. This approach ensured that data collection was both detailed and reflective of the participants' unique contexts (Robson 2002, p 290-291).

The interviews were guided by four main themes. The questions that were used are presented in Appendix 1. Four out of five interviews were held online using Microsoft Teams, while one interview took place on sight at a sawmill (Fiskarheden). Each interview lasted between 20 and 40 minutes and was audio-recorded with the participants' consent to ensure accurate transcription and analysis.

4.3 Analysis method

Thematical analysis was used to collect the material obtained from the interviews. This approach allows for the identification of recurring topics (Braun & Clarke 2022). The steps in the analysis were, firstly transcription of the interviews and reading through the interviews multiple times to gain a deep understanding of the answers and look for potential patterns in the answers. Secondly answers related to different themes were put into separate groups. Lastly the themes were analyzed groupwise and interpret within the theoretical framework and the objective of the study, this involved connecting themes to existing literature and the research questions. All interviews were conducted in Swedish, the quotes presented in the thesis have been translated into English.

Thematic analysis was chosen for the semi structured interviews as it allows for the extraction of meaningful insights while preserving the complexity and diversity of the participants` responses (Gibbs 2018). The method enables the categorization of data into overarching themes, such as motivations for investment, perceived challenges, and future opportunities related to CT technology in sawmills.

4.4 Quality of the research

According to Bryman and Bell (2015, p 399-401) validity in qualitative research can be divided into internal and external validity. Internal validity refers to how well the finding align with the research questions and the theoretical framework. The themes identified in the analysis were cross referenced with the theory of the study, such as theory of innovation to ensure coherence and alignment. The study focuses on a small sample of Swedish sawmills, the findings are not context specific for decision making in sawmills. The themes and insights in the qualitative study could form a foundation for future quantitative research.

The reliability of this study was maintained by having a consistency throughout the data collection and analysis processes. All the interviews followed a semi-structured format which was guided by themes to ensure comparability between the responses. Transcripts of the interviews were sent back to the respondents for verification, reducing the risk of misrepresentation or misinterpretation. This process allowed the participants to review their statements and correct any inaccuracies reassuring that the data reflected their perspective the correct way. The questions were phrased in a neutral way to achieve a response that reflected the respondents own perspective. The phrasing of the questions was made to avoid asking leading questions.

According to Bryman and Bell (2015) trustworthiness is established through credibility, transferability, dependability and confirmability which are key criteria for qualitative studies. Credibility was achieved using triangulation, by using more than one source of data and then cross-checking the findings. Triangulation was conducted by comparing data from the literature review and the interview data. By refining the themes in collaboration with the participants, the analysis accurately reflected their responses. Transferability was addressed by presenting a detailed account of the methods used for data collection, analysis and the design of the interview guide, the thematic coding process and selection criteria of participants. Dependability was achieved by maintaining a transparent research process, a clear description on methodological choices, and how the data was collected and later analyzed. By sending the transcripts of the interviews to the respondents and allowing them to validate them, confirmability was strengthened and the risk of misinterpretation minimized.

The interpretation bias occurs when the researchers subjective understanding of the responder's answers influences the analysis (Porter 2007). To minimize that risk, interviews were transcribed verbatim and reviewed by respondents to validate answers. In a qualitative study the answers are specific to the participants which means that they cannot be generalized for all sawmills and or industries. This is a limitation but opens opportunities for deeper insight and varied perspective within the studied organization. Readers are encouraged to consider how the insights can be applied in other settings or industries. Participants were limited in how much information they could share about the CT technology or sawmill data due to confidentiality and competitive concerns.

4.5 Ethics and moral

In this study participants were ensured that they were treated with respect and their data was handled responsibly. Qualitative interviews bring researchers closer to the individual making it more important to treat them with the utmost respect (Henricson 2012). Before each interview, participants were informed about the purpose of the study, their role, and their rights, including the option to remain anonymous and the ability to withdraw at any time without consequences (Bryman & Bell 2015). Consent to record audio was obtained before the interviews, and participants were provided with a copy of their transcript afterward, allowing them to review, correct, or withdraw their responses. Confidentiality was maintained and audio recordings were deleted after transcription. These measures ensured that participants could speak freely in a respectful, non-intrusive environment, creating trust and accuracy while upholding a high ethical standard.

5 Background

Chapter 5 provides a brief introduction to Computed Tomography and how it can be used in sawmills.

5.1 Computed tomography

The modality CT is broadly used in the field of medical imaging. A conventional x-ray system produces a 2D image where anatomical information is overlapped. CT systems on the other hand, produces a 3D volume of the unknown object. This makes it possible to see inside the object. See Figure 3A for a conventional x-ray of a patient and Figure 3B for a CT image of a patient (Nowik 2020)

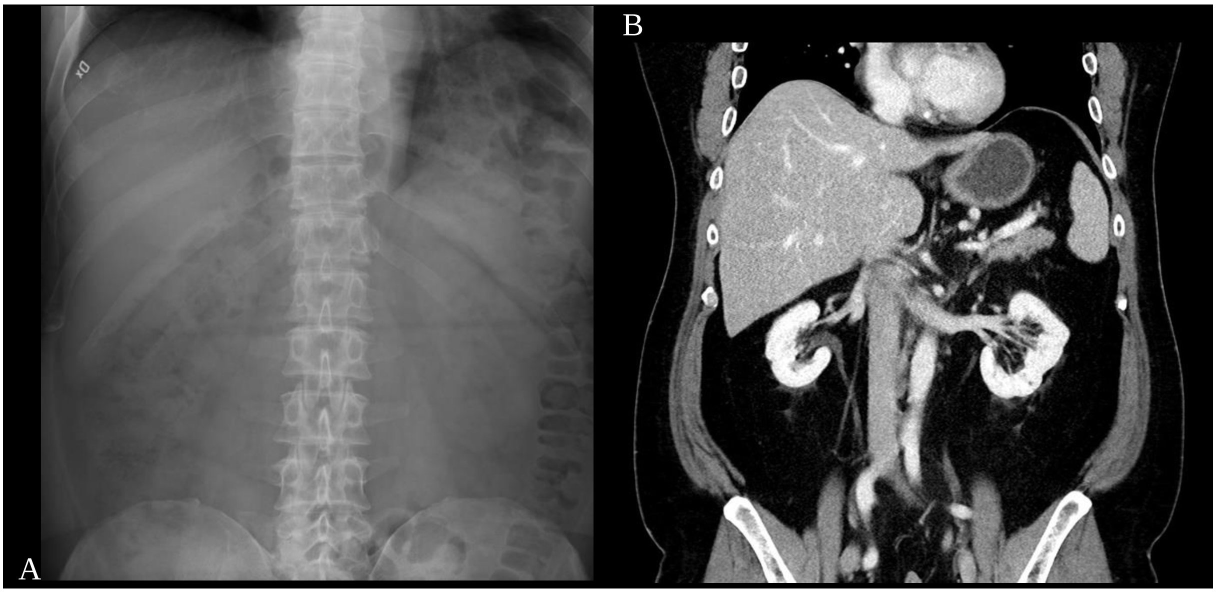


Figure 3. A conventional x-ray image (A) and a CT image (B) of a patient. Reproduced with permission.

When the first commercialized CT came in 1972 (Hounsfield 1973), the field of medical imaging was revolutionized. This was the first time medical doctors could see inside a patient’s body. Even though conventional x-ray existed from 1895 (RONTGEN 1895), it took until 1972 for CT technology to come. An important aspect for the long time was that the creation of a CT image requires a computer to calculate the image (Figure 4).

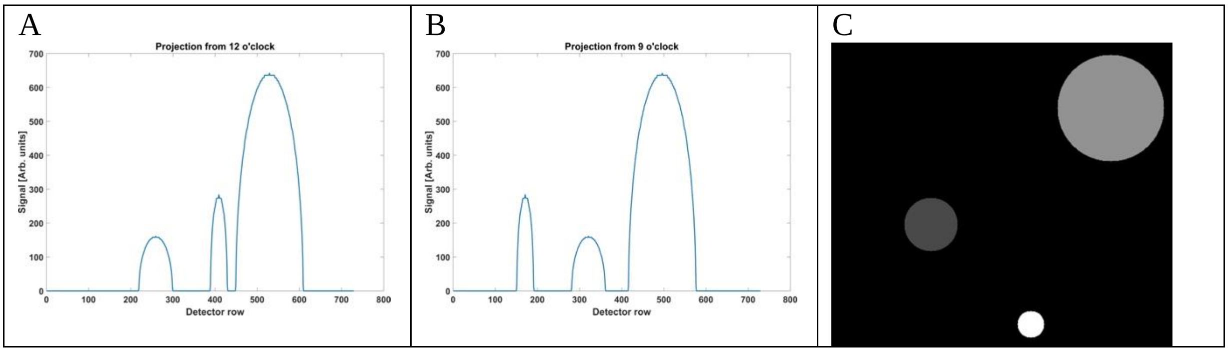


Figure 4. *An example of how a CT image is created. 2 projections are shown, from 12 o'clock (A) and from 9 o'clock (B). 180 such projections were used to create the CT image (C). Reproduced with permission.*

A CT system works by rotating an x-ray system around an unknown object while collecting data around it, so called projections. When you have projections around an unknown object, it can be reconstructed (calculated) via a computer. See Figure 4A For an example of a projection from 12 o'clock, Figure 4B for 9 o'clock and 4C for a reconstructed images using 180 such projections (Nowik 2020).

5.1.1 Computed tomography in sawmills

The CT concept in sawmilling began with scientist using medical CT scanners to examine logs and revealing the potential that the CT scanner could have for the sawmilling industry. With precision similar of medical CT scanners for tissues and bones, industrial CT scanners can visualize knots, cracks, fungi and density variations in wood. These possibilities were identified to have a possible economic benefit for sawmills (Hodges et al. 1990). Researchers, including those involved in initiatives like the ongoing CT WOOD project at Luleå Technical University (CT WOOD 2024), have explored various ways to adapt CT technology for industrial use. The Italian company Microtec officially presented the first ever CT scanner for sawmills in 2011 and later released the fingerprint system in 2019. As of 2024, Microtec remains the only retailer offering industrial CT scanners for sawmills (Microtec 2024a).

In 2018, the Swedish forest owner association Norra Skog made a significant step in the technological advancement of the Swedish sawmill industry by acquiring the first sawmill CT scanner. The CT was integrated into their sawline in 2019. That same year, Fiskarheden invested in a CT scanner, which was implemented in the sawline 2020. SCA became the third organization to invest in a CT scanner in 2020, integrating it to their sawline later that year. Since then, Norra Skog has acquired another CT scanner for one of their sawmills. The early adopters of the technology primarily used the CT to analyze internal structures like knots and density variations to precise the cutting of the logs and maximize yield and quality (Olofsson et al. 2019).

Now sawmills in Sweden primarily use the CT scanner at the start of the sawline, during the sorting and grading of the timber to maximize the use of the imaging data in the process. The CT scanner generates images of internal features (Figure 5), providing sawmills the ability to optimize and plan sawing and sorting based on internal features and desired products.

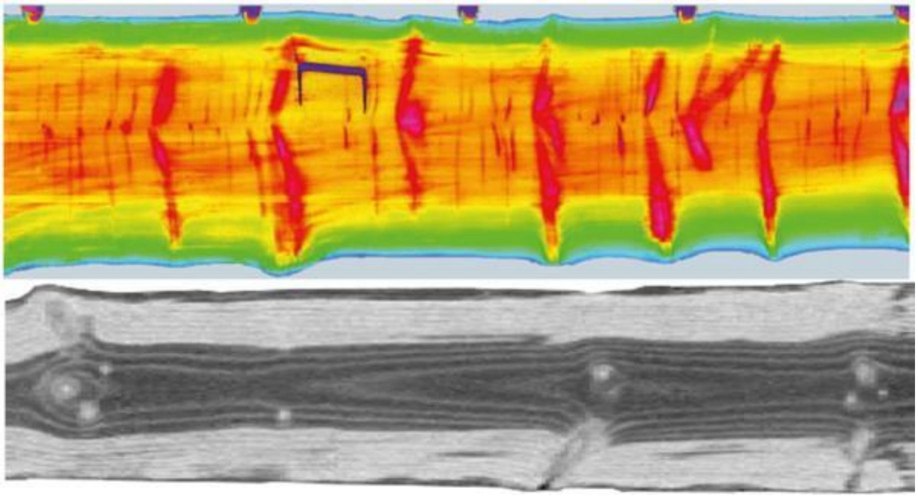


Figure 5. *CT image of internal features of a log. Image courtesy of Microtec, used with permission.*

In the sawline, the timber passes through the CT tube, where it is scanned at high speed. The images produced resemble the images in (Figure 5) and the images in (Figure 6). The X-ray tubes inside the scanner continuously rotate, capturing multiple images per minute. These images are then combined by the computer to reconstruct the log. The data created optimizes the sawing and sorting based on the internal features of the log and desired product specifications. The right figure in (Figure 6) provides a detailed image of the heartwood and juvenile wood, where the darker area is heartwood, and the lighter area is juvenile wood. Some products on the market specialize in containing almost exclusively heartwood in the board. With the help of CT technology, sawing can be optimized to achieve the specific characteristics in the final product.

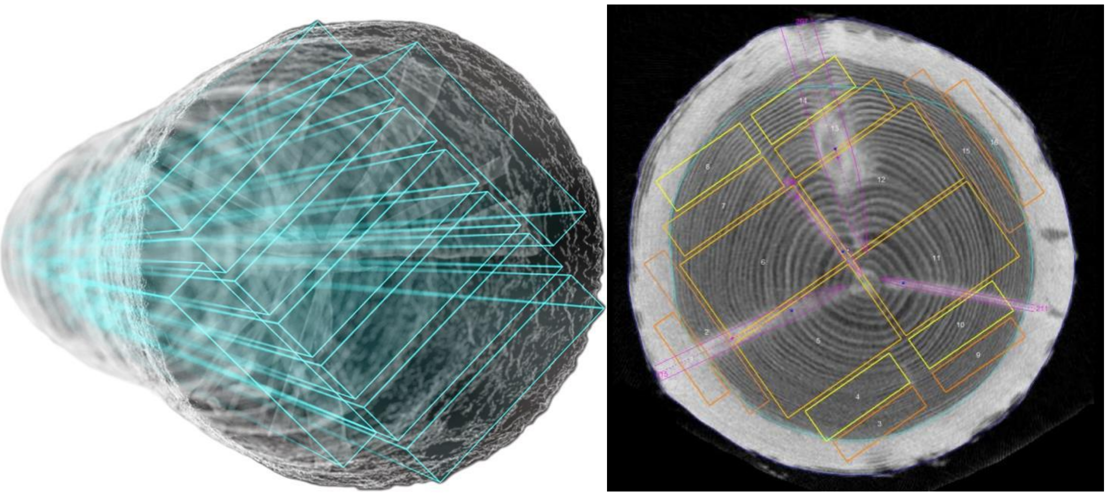


Figure 6. *An CT image of a log with a planned sawing map and an image of one slice of an CT image. Image courtesy of Microtec, used with permission.*

The most recent implementations of the CT technology have emphasized sorting and fingerprint systems. By using fingerprint technology, sawmills can optimize the process and trace an individual log from raw material to a sawn board, making identification of each individual board possible. The CT technology allow sawmills to have a more automated sorting process, improved product quality and enables traceability throughout the process (Johansson 2015).

6 Results

Chapter 6 presents the findings from the interviews. The results are divided into themes to provide a clear structure and facilitate connection to the theoretical framework

6.1 Implementation factors

Different factors influence the implementation of CT technology into sawmills. Factors as, size limitations, economical barriers and complexity in being able to master the use of technology. In Table 2 factors that have been mentioned are summarized.

Table 2: Thematic analysis of respondents' answers on implementation

Category	**With CT-Technology**	**Without CT-technology**
Implementation Challenges	- High initial investment and ongoing maintenance costs. - Complexity in fully utilizing the data and integrating into workflows. - CT scanner size	- High investment cost perceived as too risky. - Space constraints in existing sawlines for CT integration.

The process of implementing CT technology has been expressed as complex due to different factors. The factor of size and space has been mentioned by two respondents from a sawmill with and one without CT technology. One major challenge identified is the substantial infrastructure adjustments required to accommodate the CT scanners. These machines are large and often complex to fit in existing processes, as described by one respondent.

"*It's not entirely trivial to integrate it into an existing log sorting station. You might not even have enough space for it. In Kåge, we built a new log sorting station, and it was easy to plan for placing a CT there.*"

– Johan Oja, Technical Manager, Norra Skog

This quote explains the logistical difficulties faced by sawmills, particularly older facilities with limited space or older infrastructure. Respondents from sawmills without CT technology shared similar concerns, explaining physical constraints and compatibility issues as significant deterrents. Apart from infrastructure concerns respondents also mentioned, complexity of using the data generated by CT scanners. While the technology provide insights into the internal characteristics of logs, sawmills must invest in systems that are compatible to the CT scanners and can process the data effectively.

6.2 Factors influencing investment decisions

The decisions to invest in CT technology are driven by different factors that are influenced by operational benefits, investment cost and perceived risk. This section explores the different factors influencing the investment decisions and highlights the difference between sawmills with and without CT technology. Table 3 below presents a summarize of the different investment factors mentioned.

Table 3: Thematic analysis on respondents' answers on factors relating to investment decisions in CT scanners

Category	**With CT-Technology**	**Without CT-technology**
Motives for Investing in CT-technology	- Maximize value yield and sorting accuracy. - Optimize raw material utilization and reduce waste. - Enhance traceability and product quality.	- Current technology meets production needs. - Focus on incremental improvements rather than large-scale technological changes. - No significant expected improvement in yield or value. - Focus on standard products with consistent quality and lower complexity.

Respondents with experience in CT technology highlighted the potential to increase economic value through improved yield and resource optimization. Before making the investment, companies and the forest owner association conducted detailed calculations to assess the technology`s feasibility. However, only one out of three respondents had been directly involved in these investment decisions.

"We saw an opportunity to improve both the average value and the yield, that is, the average value of the products and the yield."

– Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

A critical factor was to maximize yield and minimize waste due to rising raw material prices. Respondents with CT scanners confirmed that they had improved the yield. In contrast the respondents without CT scanners in their sawline explained that the CT scanner most likely would not pay off for their sawmills.

"When 70% of a sawmill's costs are for raw materials, it becomes absolutely necessary to make the best possible use of them."
– Johan Oja, Technical Manager, Norra Skog

"Our absolute largest expense is raw materials."

– Martin Eriksson, Production Supervisor, Fiskarheden Trävaru AB

Traceability was also highlighted as an important factor, not only to meet market demands but also an important factor when it comes to trace logs during the process. This was important to understand the sawline and to see where there are possibilities to optimize the sawline, and to quickly address issues that may arise during the sawing process.

The purpose is to enable tracking of logs and products from timber sorting to the sawmill, through green sorting, and to the planing mill, so that we can monitor what happens to the products at each stage of production.

– Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

For respondents without a CT scanner, the benefits of the technology were perceived differently compared to those with CT scanners. When asked about the potential benefits of the CT scanner, both respondents mentioned that their current production would not change too much. They focused their production on other strategies that would not benefit as much from the CT technology. One respondent explained that their systems life expectancy was still far from over but explained that in the future when the sawmill must buy a new measuring frame, the investment calculation would be much more favorable.

"But if you combine it with needing to physically replace the measurement frame due to its age, then the calculations make sense, and you also gain additional advantages with it."

- Tomas Turpers, CEO, Moelven Dalaträ AB

Respondent highlighted the importance to calculate decisions regarding the investments on CT technology to ensure a reasonable payback time.

"It is a significant investment, so you must make careful calculations to ensure a sufficient payback period."

- Johan Oja, Technical Manager, Norra Skog
-

6.3 Main benefits with CT-technology

The thematic analysis of the respondents' answers reveals a difference on perceived benefits with the CT technology. The differences are summarized in Table 4 below.

Table 4: Thematic analysis on respondents' answers on the main benefits of CT technology

Category	With CT-Technology	Without CT-technology
Main Benefits	- Improved precision and yield optimization. - Special products and products with better quality - Reduced production of consequence products. - Enhanced traceability and data-driven decision-making.	- Optimizing rotation and yield - Special products and products with better quality

Respondents from sawmills with CT-technology have identified benefits related to optimizing value yield, increasing sorting accuracy and utilizing raw materials more effectively. Product quality was also an important motive. A respondent highlighted the increase of yield in the quote below.

"Yes, absolutely, it has. I don't remember the exact figure, but we're talking in whole percentages at least."

- Martin Eriksson, Production Supervisor, Fiskarheden Trävaru AB

The respondents highlighted the importance of valuing the wood and explained that the raw timber prices represent the largest cost for sawmills, making it important to maximize the use of the resource. One respondent highlighted that the forestry sector is one of the only sectors working long-term and sustainably. Also highlighting the importance of efficient handling of the raw material.

"The entire forestry industry is founded on this. You can try to find another industry where you think two generations ahead and still aim to generate a profit."

– Martin Eriksson, Production Supervisor, Fiskarheden AB

Respondents with CT technology highlighted its ability to improve product quality and enable production of specialized products by analyzing internal features of logs before sawing. One respondent from a sawmill without CT technology acknowledged that CT technology could give more specialized products like knot-free wood or heartwood timber which they could not produce with the current system. The CT scanner give possibilities to see inside of the timber before it is sawn which gives possibilities to optimize the sawing and maximize the value and quality.

"We have seen an increase in both value and yield compared to the old technology."

– Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

Another important factor for the respondents with CT technology was the ability to use the CT technology for traceability from log to board which is a growing important factor in the sawmilling industry. All respondents from sawmills with CT technology reported that they are working on the development of the traceability at their facilities. The respondents also explained the growing demands for traceability in the market. The traceability also enabled a better control in the production giving possibilities to monitor every stage more efficient.

“the purpose is to enable tracking of logs and products from timber sorting to the sawmill, through green sorting, and to the planing mill, so that we can monitor what happens to the products at each stage of production.”

– Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

"You can see it both as an economic gain and as a sustainability issue."

– Johan Oja, Technical Manager, Norra Skog

A few of the key differences are that sawmills with CT technology have a larger focus on maximization on value yield, larger focus on traceability and focus on special high value products. Sawmills without CT technology had a larger focus on their current technology and how to maximize the yield with that, their production was focused on standard products and not special high value products, this made them believe that CT technology could not give the same advantage in production. They viewed their current systems as sufficient to meet the existing production needs.

"For us, it’s perhaps more about being able to rotate a log with damage so that the damage ends up in fewer planks."

– Per Andersson, Development Manager, Derome

6.4 Barriers to adopting CT Technology

Adopting CT technology involves several significant barriers, respondents have identified different factors influencing the adoption of the technology. Factors relating to financial, infrastructural, and operational have been mentioned. Table 5 provides a summarized overview of the factors.

Table 5: Thematic analysis on respondents' answers on barriers in adopting CT technology

Category	**With CT-Technology**	**Without CT-technology**
Inhibiting Factors	- Risk of downtime if the CT system fails. - Infrastructure limitations - Special products - Sawmill size	- Unclear ROI (Return on Intrest) for current operations and product lines. - Too expensive in relation to other similar technologies - Effective yield optimization using existing laser and camera systems. - No compatible systems - Current production is cost-effective for standard products.

Financial barriers were the most mentioned factor by all respondents, regardless of whether their organization had adopted the technology or not.

"Compared to the alternatives, it's an expensive piece of equipment that requires very significant adjustments to production and the product portfolio for it to work optimally."

– Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

For sawmills without CT technology the cost was particularly large to prohibitive. Respondents had doubt if the investment could pay of within a reasonable timeframe, given their current production focus and infrastructure. One respondent added that CT scanners are too expensive in comparison to other available technologies.

Beyond financial considerations, respondents also pointed to significant infrastructural challenges that complicate the adoption of CT technology. One respondent noted that a CT scanner is a large machine that must fit within the existing sawline, making the integration process complex and costly.

"It's not entirely trivial to integrate it into an existing log sorting station. You might not even have enough space for it. In Kåge, we built a new log sorting station, and it was easy to plan for placing a CT there."

– Johan Oja, Technical Manager, Norra Skog

In addition to the space constraints, respondents highlighted that older equipment in sawmills is not compatible with CT scanners. To fully utilize the technology other parts of the sawline must also be compatible with the machine.

"We were a bit too old of a facility to handle this properly if you calculated it now. It becomes more about splitting the logs, and sure, we might get a little extra money for it."

– Tomas Turpers, CEO, Moelven Dalaträ AB

The respondents without CT technology saw their current systems as sufficient enough, and a new investment was not wanted while the current system was in good shape. One respondent explained that when current systems comes to the end of the lifecycle, the CT technology would become a more attractive option for sawmills.

"Many are now in a position where they need to purchase a new measuring frame, so it makes sense for us to invest the additional millions to acquire a CT scanner."

– Tomas Turpers, CEO, Moelven Dalaträ AB

The capacity size of sawmills also impacts the probability of adopting CT technology. One respondent highlighted the key consideration: sawmills with larger turnovers benefit more from small percentage gains in efficiency and yield compared to smaller sawmills.

"If it's a company with a turnover of a billion like ours, then one percent will be at the million level."

– Martin Eriksson, Production Supervisor, Fiskarheden Trävaru AB

Implementing CT technology requires significant effort, specifically in handling the huge amounts of data it generates. Understanding how to effectively use this data to create economic value involves a steep learning curve, wide research, and careful control. As one respondent noted:

"These advantages, which are the major benefits, require a lot of time, extensive research, and a high level of control."

– Martin Eriksson, Production Supervisor, Fiskarheden AB

7 Analysis and discussion

Chapter 7 presents the results, focusing on economic benefits, quality improvements, traceability, and the implementation process, analyzed in the context of existing theories.

The economic benefits have been the primary drivers for the acquirement of the CT technology. Other drivers that have been mentioned multiple times are quality aspects, traceability, optimization and access to new data. Respondents have explained how their organizations investment have been positive for their yield and value recovery, which aligns with different studies like Pernkopf et al. (2019) which states that an investment in CT technology might give an economical value gain. Similarly studies like Ji et al. (2021) that shows how the CT technology can be used in identifying internal characteristics of wood to optimize sawing and achieve better quality products. The motives mentioned by respondents align closely with the findings of these studies.

Motives to optimize and maximize the use of the logs reflects Liker (2021) Lean theory, which highlights minimizing waste and maximizing resource efficiency. This suggests a shift in the sawmill industry towards a more sustainable and resource effective industry. Respondents emphasized that optimization through CT technology directly improved value recovery and yield, which are the key economic indicators for sawmills. This is aligning with Rogers (1962) Diffusion of Innovation Theory, which states that adoption decisions are often influenced by a technology`s ability to generate measurable and observable benefits. The potential economic gain is supported by Fredriksson (2014), who reported that CT scanning in sawmills could increase value recovery by between 13 to 21% compared to sawing with only external log measurements. Small percentage increases for sawmills with large turnovers can result in substantial economic returns. For example, improving yield by a few percentages in, a sawmill with a turnover of a billion could generate millions in added revenue. Given that raw material presents the largest expense for sawmills, which respondents in the result highlighted.

"Our absolute largest expense is raw materials."

– Martin Eriksson, Production Supervisor, Fiskarheden Trävaru AB

By optimizing the sawing of every log, better recourse efficiency could be achieved, a CT investment can support Liker`s (2021) Lean principles of resource efficiency, this approach not only increases profitability but also promotes sustainability goals, as highlighted by one respondent.

"You can see it both as an economic gain and as a sustainability issue."

– Johan Oja, Technical Manager, Norra Skog

The integration of the CT technology exemplifies the Lean approach of continuous improvement (Kaizen) which means that the process is working towards an economically and ecologically sustainable process, not only within sawmills but across the entire supply chain.

Despite the significant benefits, CT technology comes with a significant investment cost that remains a key consideration. Depending on sawmill capacity and size, payback periods for CT investments vary, as production capacity and market conditions influence returns. According to Fredriksson et al. (2017) the payback time of an average-size sawmill that maximized the use of the CT technology, would be just over a year. Though CT scanners offer significant economic benefits, cost sensitivity remains a decisive factor in investment decisions. Subsidies and policy incentives aimed at promoting sustainable practices could help reduce the cost barrier, especially for smaller sawmills.

"It is a significant investment, so you must make careful calculations to ensure a sufficient payback period."

- Johan Oja, Technical Manager, Norra Skog

With the investment another advantage of CT technology is mentioned in the results. The ability to detect internal log features and improve product quality. Respondents consistently highlighted the role of the CT scanner in the optimizing sawing process. Features as knots, rot, and cracks can be detected and analyzes using high-resolution data, allowing sawmills to increase yield.

"We have seen an increase in both value and yield compared to the old technology."

- Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

With the improved product quality, the sawmill industry can meet higher customer demands for better quality products. Multiple studies confirm the observations made by the respondents with the CT technology. Berglund et al. (2014) presented that CT scanners not only can optimize the yield but also the value of the sawn timber using the internal features, aligning with the respondents' answers. Hyll et al. (2022) presented that CT-image gives valuable information about density, knots and other internal features like fungi which is helpful to keep a steady quality and quantity of the products.

Another benefit mentioned in the results was that CT technology made traceability possible, which is increasingly important for meeting consumer and regulatory demands for sustainability. Fingerprint technology allows each log to receive a specific ID which makes boards traceable to the original logs (Johansson 2015). With the help of traceability, the process can be tracked and optimized which was mentioned by one respondent in the result.

"the purpose is to enable tracking of logs and products from timber sorting to the sawmill, through green sorting, and to the planing mill, so that we can monitor what happens to the products at each stage of production."

- Ante Vernersson, Technical Manager, Bollsta Sawmill, SCA

To achieve traceability in the process and realize a higher product value a sawmill needs to adjust large parts of the process to fully use the advantages. Although the advantages of CT technology are evident, challenges obstruct its adoption. These include high costs, infrastructure limitations, and the complexity of integrating data from the CT scanner into the manufacturing processes. Organizations that invest in CT technology can benefit from the technology if they overcome the steep learning curve and operational changes.

"These advantages, which are the major benefits, require a lot of time, extensive research, and a high level of control."

- *Martin Eriksson, Production Supervisor, Fiskarheden Trävaru AB*

The most frequently cited challenge among the respondents was the high cost of acquiring the CT technology. In addition to the initial investment, there are cost of associated infrastructure upgrades to utilize the CT technology. Larger sawmills with infrastructure that are functional with CT technology are better positioned to absorb the costs and achieve a faster return on the investment than smaller sawmills or sawmills with less compatible infrastructure. The size of the CT scanner might influence where in the sawline it can fit, the need for substantial infrastructure changes can deter adoption.

"It's not entirely trivial to integrate it into an existing log sorting station. You might not even have enough space for it."

– Johan Oja, Technical Manager, Norra Skog

The sawmills that have CT technology are sawmills with a high capacity and large turnover which might affect that they have acquired the technology. If investments increase the yield with a few percentages, it could make a large economic impact. Whereas smaller sawmills would not get the same large economic impact. For large sawmills small percentages can give a larger economical yield which makes the investment more justifiable.

"If it's a company with a turnover of a billion like ours, then one percent will be at the million level."

– Martin Eriksson, Production Supervisor, Fiskarheden Trävaru AB

The challenges of CT adoption can be viewed through Rogers (1962), Diffusion of Innovation Theory. Larger sawmills, with their financial and operational advantages, align with the "early adopters" category, motivated by the clear relative advantage of CT technology. Smaller sawmills, however, fall into the "laggard" category, challenged by complexity, high costs, and lack of compatibility with existing systems.

The results of this study suggest that the implementation of CT technology is most viable as part of a larger renewal or modernization project at a sawmill. Findings highlights that the operational and economic benefits of CT scanners are clear. Replacement of existing infrastructure is not financially feasible solely for the adoption of this technology. Instead wait until the excising instruments are in need for a change.

7.1 The future of CT technology

The future of CT technology is moving towards more automation, better traceability and even more optimized sawing. Respondents were positive about the development and highlighted that future CT systems will most likely have a sorting and classification that is fully automated. With this development, the sawing operations will be more streamlined and improve overall efficiency. Traceability allows to keep track of wood from the forest to the final product. Respondents from sawmills with and without the technology acknowledge the growing demand of traceability. The innovation within traceability is on constant development and with technologies like CT technology the progress will keep moving towards a more traceable process.

If the trend of declining numbers of sawmills continues as it has in recent years, there will be less sawmills but the ones remaining will have larger production capacity and a greater competition for raw materials (Freij 2023). It will increase the need for innovations that can streamline, accelerate, and optimize sawmills to ensure they remain competitive. However, with continued development, CT technology is expected to become more affordable and easier to implement in sawmills. Smaller sawmills that right now do not have the possibility to make an investment economically defensible would be able to invest in the technology if it became more affordable and easier to adapt. New advancements, such as remote control, may eventually be introduced to the sawmill industry. CT technology could potentially be offered as a service, managed remotely from a central headquarters where hiring skilled personnel is easier, and where sawing and product selection can be centrally controlled.

7.2 Limitations of the study

The number of respondents were few. This study included five respondents from different types of organizations. Three sawmills that have implemented CT technology and two that use alternative technologies. This sample provided insights but is relatively small and limited to Swedish sawmills. The research involves three organizations that currently have CT scanners integrated into their sawline and two organizations using alternative technologies. A significant limitation of this study is that operational performance data and results from CT technology are outside the scope of this research.

A limitation of this study is tied to the scope of the research questions of this study, which were focused on motivations relating the investment, implementation, barriers and challenges of the adoption of CT technology in Swedish sawmills. These questions provide a wide insight in the adoption of CT technology, however they do not cover the full aspect of the adaptation. The exclusion of quantitative data on production efficiency, yield, or economic returns limits the ability to measure the impact of CT technology comprehensibly.

This study is focused on Swedish sawmills and does not extend its findings to sawmills in other countries. Its findings may not be fully generalized to other sawmill operations in Sweden or other countries. Due to differences in geographical regions and infrastructural differences the outcome of the adoption and implementation could come out differently.

Respondents were strategically selected based on their expertise and familiarity with CT technology rather than through random sampling. While this approach ensured that participants had knowledge and could provide relevant views on CT technology, it also introduces the possibility of selection bias.

Time and recourses were a limitation of the study, with a larger sample size including more sawmills could have provided a comprehensive understanding of the factors. The competitive sawmill industry also might be a limit for data collection, some respondents may have hesitated to share detailed or sensitive information about their processes. The number of sawmills that have implemented the CT technology in Sweden is limited to four sawmills in three organizations which may make the data collection harder due to strong competition and confidentiality. This limited the scope of certain responses, the study was still able to gather insights by focusing on general decision-making processes and broader operationality.

8 Conclusions

Chapter 8 addresses and provides answers to the research questions outlined in Chapter One, summarizing the key findings and their implications. Recommendation for future studies are presented.

Implementation factors

The implementation of CT scanners is influenced by different factors, including sawmills current situation, readiness to adopt the technology and capacity to utilize data generated from the CT system. Important considerations are to include what infrastructure modifications are needed to implement the scanners in the sawmill.

Motives for Investment in CT Technology

Motives for investment in CT technology for sawmills were found. Respondents and different scientific reports have together given a broad picture of what organizations have as motives when investing in new technology. Economical aspects have been repeatedly mentioned by respondents and reports to be the most important factor. Additionally factors like sustainability and traceability have also been discussed. Increasing regulations on traceability, increasing raw material costs and bigger focus on sustainability guides organizations to invest in CT technology.

Benefits of CT Technology

With scientific reports and answers from respondents benefits for the implementation have been found and discussed. The main benefits found were improvement of yield by optimized sawing. Enabling production of high value products and production of special assortments. With the technology traceability has been made possible which is a large factor due to rising directives from governmental authorities. The data that is generated by CT technology gives organizations possibilities to streamline the production ad gives a possibility to prepare for an automatization of the industry.

Barriers to Implementation

Barriers for the CT technology have been high initial cost with limitation in the current production line which gives more costs. Alternative technologies may be less expensive, but they do not offer the same level of benefits as CT technology. The big size of the sawmill has been a physical limitation for sawmills with limited space. Large amount of data to process is another factor influencing organizations to invest or not. To achieve all benefits from the CT scanner the data processing and optimization from that data must undergo a long and demanding process which some organizations might not be able to handle.

Recommendations for future studies

The sawmill industry is undergoing change and development. Large amounts of money are being invested in sawmills to increase capacity with new technology that could reshape the future of sawmill operations. Within the specific area of CT technology, future studies could explore whether organizations that have adopted the technology have achieved increased value yield. Not all the data generated by the CT scanners are used right now, future studies could involve how that data could be used. Future studies could explore how sawmills are implementing traceability systems, particularly considering new EU directives requiring greater accountability and transparency in timber sourcing and processing. This research could examine the technological challenges associated with achieving full traceability, as well as its implications for market competitiveness and sustainability certifications. Research could also analyze whether timber with traceability is more profitable than timber without it. Expanding the sample to include more organizations, including those in other countries or with varying operational scales, could provide a broader perspective on CT adoption in the overall sawmill sector. A larger sample might uncover additional factors influencing adoption, such as regional regulatory frameworks, market dynamics, or resource availability.

References

Berglund, A., Broman, O., Grönlund, A. & Fredriksson, M. (2013). Improved log rotation using information from a computed tomography scanner. Computers and electronics in agriculture, 90, 152-158.

Berglund, A., Johansson, E. & Skog, J. (2014). Value optimized log rotation for strength graded boards using computed tomography. European Journal of Wood and Wood Products, 72, 635-642.

Bergquist, A.-K. & Söderholm, K. (2018). The Greening of the Pulp and Paper Industry: Sweden in Comparative Perspective. I: Särkkä, T., Gutiérrez-Poch, M. & Kuhlberg, M. red.) Technological Transformation in the Global Pulp and Paper Industry 1800–2018: Comparative Perspectives. Springer International Publishing. 65-87. https://doi.org/10.1007/978-3-319-94962-8_4

Braun, V. & Clarke, V. (2022). Thematic analysis : a practical guide. SAGE.

Bryman, A. & Bell, E. (2015). Business research methods. 4. uppl., Oxford University Press.

Bryman, A. & Nilsson, B. (2018). Samhällsvetenskapliga metoder. Tredje upplagan uppl., Liber.

Creswell, J.W. & Creswell, J.D. (2018). Research design: qualitative, quantitative, and mixed methods approaches. Fifth edition. uppl., SAGE.

Federation, S.F.I. (2024). Markets and products. https://www.forestindustries.se/forest-industry/statistics/markets-and-products/ [28 October]

Fredriksson, M. (2014). Log sawing position optimization using computed tomography scanning. Wood Material Science & Engineering, 9(2), 110-119.

Fredriksson, M. (2016). Handling positioning errors when optimizing sawing of Scots pine and Norway spruce logs using CT scanning. Journal of wood science, 62, 400-406.

Fredriksson, M., Broman, O. & Sandberg, D. (2017). The Use of CT-scanning Technology in Wood Value-Chain Research and in Wood Industry: A State of the Art. Pro Ligno, 13(4), 533-539.

Freij, J. (2023). Skog & Ekonomi. (Nyheter från Danske Bank).

Fröbel, J. & Bergkvist, P. (2020). Att välja trä. (En faktaskrift om trä).

Gergeľ, T., Bucha, T., Gejdoš, M. & Vyhnáliková, Z. (2019). Computed tomography log scanning–high technology for forestry and forest based industry. Central European Forestry Journal, 65(1), 51-59.

Gibbs, G. (2018). Analyzing qualitative data. 2nd edition. uppl., SAGE Publications Ltd.

Grubbström, R.W. & Lundquist, J. (2005). Investering och finansiering : [metodik och tillämpningar]. 2., [rev.] uppl. uppl., Academia adacta.

Henricson, M. (2012). Vetenskaplig teori och metod: från idé till examination inom omvårdnad. Studentlitteratur.

Hodges, D.G., Anderson, W.C. & McMillin, C.W. (1990). The economic potential of CT scanners for hardwood sawmills. Forest Products Journal 40 (3): 65-69.

Hounsfield, G.N. (1973). Computerized transverse axial scanning (tomography): Part 1. Description of system. The British journal of radiology, 46(552), 1016-1022.

Hyll, K., Joevenller, S., Svennerstam, H., Nordström, M., Broman, O., Oja, J. & Sandberg, D. (2022). X-ray computed tomography for the detection of damage in Scots pine trunks

caused by blister-rust fungus Cronartium pini (Willd.). Wood Material Science & Engineering, 17(6), 1022-1024.
Ji, A., Cool, J. & Duchesne, I. (2021). Using X-ray CT scanned reconstructed logs to predict knot characteristics and tree value. Forests, 12(6), 720.
Johansson, E. (2015). Computed Tomography and Fingerprint Traceability in the Wood Industry. Luleå tekniska universitet.
L.O.A.B (2018). Fiskarheden investerar i CT-Log. https://www.loab.se/?p=2093 [28 October]
L.O.A.B (2020). CT Log till SCA Bollsta tar röntgen till nästa nivå. https://www.loab.se/?p=2844 [26 May]
Liker, J. (2021). The toyota way. Esensi.
Lundahl, C.G. & Grönlund, A. (2010). Increased yield in sawmills by applying alternate rotation and lateral positioning. Forest Products Journal, 60(4), 331-338.
Maccarrone, P. (1996). Organizing the capital budgeting process in large firms. Management decision, 34(6), 43-56. https://doi.org/10.1108/00251749610121489
Microtec (2024a). Historia och Varumärke. https://www.microtec.eu/sv-se/om-oss/Vår%20historia [22 November]
Microtec (2024b). CT Log. https://www.microtec.eu/en/products/ct-log [9 October]
The Swedish Environmental Protection Agency (2024). Nettoutsläpp och nettoupptag av växthusgaser från markanvändning (LULUCF). https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-nettoutslapp-och-nettoupptag-fran-markanvandning/
Norra Skog (2024). Avdelning Kåge Sågverk. https://karriar.norraskog.se/departments/kage-sagverk [10 October]
Nowik, P. (2020). Optimizing computed tomography: quality assurance, radiation dose and contrast media. Karolinska Institutet (Sweden).
Oja, J., Grundberg, S., Fredriksson, J. & Berg, P. (2004). Automatic grading of sawlogs: A comparison between X-ray scanning, optical three-dimensional scanning and combinations of both methods. Scandinavian Journal of Forest Research, 19(1), 89-95. https://doi.org/10.1080/02827580310019563
Olofsson, L., Möller, C.-J., Wendel, C., Oja, J. & Broman, O. (2019). New possibilities with CT scanning in the forest value chain. I: 21st international nondestructive testing and evaluation of wood symposium, Freiburg, Germany, September 24-2, 2019, US Department of Agriculture. 569-576.
Pernkopf, M., Riegler, M. & Gronalt, M. (2019). Profitability gain expectations for computed tomography of sawn logs. European Journal of Wood and Wood Products, 77(4), 619-631. https://doi.org/10.1007/s00107-019-01414-x
Persson, V.I. (2023). Välinvesterade sågverk ökar skogens värde. SCA. https://www.sca.com/sv/media/artiklar/sca/valinvesterade-sagverk-okar-skogens-varde/
Porter, S. (2007). Validity, trustworthiness and rigour: reasserting realism in qualitative research. Journal of advanced nursing, 60(1), 79-86.
Rais, A., Ursella, E., Vicario, E. & Giudiceandrea, F. (2017). The use of the first industrial X-ray CT scanner increases the lumber recovery value: case study on visually strength-graded Douglas-fir timber. Annals of Forest Science, 74(2), 28. https://doi.org/10.1007/s13595-017-0630-5
Robson, C. (2002). Real world research. Blackwell.

Rogers, E.M. (1962). Diffusion of innovations. Free Press of Glencoe.
RONTGEN, W.C. (1895). Uber eine neue Art von Strahlen. Sitzungsber. Physikal. Med. Gesellsch. Wurtzburg, 132-141.
Rummukainen, H., Makkonen, M. & Uusitalo, J. (2021). Economic value of optical and X-ray CT scanning in bucking of Scots pine. Wood Material Science & Engineering, 16(3), 178-187.
European Union, E.P.a.C.o.t.E. "Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010". Official Journal of the European Union.
CT WOOD. (2024). CT WOOD. https://www.ltu.se/forskning/forskningsamnen/trateknik/ct-wood [2024-10-09]

Acknowledgements

I want to thank the respondents that took their time to participate in the interviews, Microtec and Siemens Healthineers for help with technology-specific details and images that I have been allowed to use in the report.Lastly, I want to thank my surporvisor Anders Roos.

Appendix 1 Interview question

In the Appendix, the interview questions are presented

Interview questions translated from the original language, Swedish.

Questions if respondent have access to CT technology

I would like to start by asking if it would be okay for me to record the audio from the interview to facilitate transcription afterward?
Yes/No

You can, of course, decide if you want to remain anonymous in the interview. Do you want to be anonymous in the interview?
Yes/No

Would it be okay for me to mention in the report that I interviewed a representative from … (Company)?
Yes/No

You can change your mind regarding anonymity during the interview, and I would appreciate it if you contacted me within two weeks from today about it.

- How long have you been working in the forestry industry and in the sawmill sector?
- What is your current role, and what positions have you held previously?
- When did … (Organization) acquire your CT?
- Were you involved in the purchase of the CT for your sawmill?

If Yes:

- What was your role?
- What investigation or evaluation did you conduct before the purchase?
- What potential did … (Organization) see before deciding to invest in CT technology?
- How much did the cost of CT technology influence your decision to invest?
- What were the main reasons for deciding to invest in CT technology?

- Where in the sawline do you use the CT?
- Has it been difficult to adapt the CT technology to the existing sawline?
- Did you encounter any challenges during installation?

If Yes:

- How did you solve them?
- What knowledge or skills did you need to acquire to manage the CT technology?

- How has the CT affected work routines?
- What results have you seen after implementing the CT?

- How has the value recovery changed since you installed the CT log?
- Have you observed any changes in sawing yield after the implementation?
- How does the CT log affect your competitiveness in the market?
- Do your customers notice any improvements in quality or other factors since you invested in the CT log?
- Has the CT log met your expectations?
- With the experience and knowledge you have today about CT technology, would you make the same investment again? Why or why not?
- Why do you think CT technology has not been more widely adopted in Swedish sawmills?
- Do you see any future development opportunities with CT technology, such as traceability or specialized products?

Questions if respondent do not have access to CT technology

I would like to start by asking if it would be okay for me to record the audio from the interview to facilitate transcription afterward?
Yes/No

You can, of course, decide if you want to remain anonymous in the interview. Do you want to be anonymous in the interview?
Yes/No

Would it be okay for me to mention in the report that I interviewed a representative from … (Company)?
Yes/No

You can change your mind about anonymity during the interview, and I would appreciate it if you contacted me within two weeks from today regarding this.

- How long have you worked in the forestry and sawmill industries?
- What is your current role in the company, and what previous positions have you held?
- What does your sawline look like?
- What does your sorting process look like today?
- What measurement instruments do you use?
- How do you optimize cutting?
- How do you work with traceability?
- What is your sawing yield?
- Are you satisfied with the sawing yield?
- Do you believe you can improve the sawing yield?
- Have you previously considered investing in CT technology (CT Log)?

If yes:

- What made you consider CT technology, and what were the main reasons for not proceeding with the investment?
- How do you think CT technology would affect your existing work routines and production lines?

- What do you think would be the biggest challenges in implementing CT technology?
- Why do you think CT technology has not been more widely adopted in Swedish sawmills?
- What factors do you consider most important when potentially investing in new technology, such as CT?
- How does the cost of CT technology influence the decision not to invest in it?

- Do you see any future opportunities with CT technology, for example, in traceability or specialized products?

Previous reports in this series

1. Lindström, H. 2019. Local Food Markets - consumer perspectives and values

2. Wessmark, N. 2019. Bortsättning av skotningsavstånd på ett svenskt skogsbolag - en granskning av hur väl metodstandarden för bortsättningsarbetet följts

3. Wictorin, P. 2019. Skogsvårdsstöd - växande eller igenväxande skogar?

4. Sjölund, J. 2019. Leveransservice från sågverk till bygghandel

5. Grafström, E. 2019. CSR för delade värderingar - En fallstudie av kundperspektiv hos skogs- och lantbrukskunder inom banksektorn

6. Skärberg, E. 2019. Outsourcing spare part inventory management in the paper industry - A case study on Edet paper mill

7. Bwimba, E. 2019. Multi-stakeholder collaboration in wind power planning. Intressentsamråd vid vindkraftsetablering

8. Andersson, S. 2019. Kalkylmodell för produkter inom korslimmat trä - Fallstudie inom ett träindustriellt företag. Calculation model for products within cross-laminated timber - A case study within a wood industrial company

9. Berg Rustas, C. & Nagy, E. 2019. Forest-based bioeconomy - to be or not to be? - a socio-technical transition. Skogsbaserad bioekonomi - att vara eller inte vara? - En socio-teknisk övergång

10. Eimannsberger, M. 2019. Transition to a circular economy - the intersection of business and user enablement. Producenters och konsumenters samverkan för cirkulär ekonomi

11. Bernö, H. 2019. Educating for a sustainable future? - Perceptions of bioeconomy among forestry students in Sweden. Utbildning för en hållbar framtid? - Svenska skogsstudenters uppfattningar av bioekonomi

12. Aronsson, A. & Kjellander, P. 2019. Futureshandel av rundvirke - Möjligheter och hinder för en futureshandel av rundvirke. A futures contract on roundwood - Opportunities and barriers for a futures trade on roundwood

13. Winter, S. 2019. Customers' perceptions of self-service quality - A qualitative case study in the Swedish banking sector. Kundernas uppfattning om självbetjäningskvalitet

14. Magnusson, K. 2020. Riskanalys av hybridlärk (Larix X marschlinsii) - Möjligheter och problem. Risk analysis of hybrid larch (Larix X marchlinsii) - Opportunities and problems

15. Gyllengahm, K. 2020. Omsättningslager för förädlade träprodukter - en avvägning mellan lagerföring - och orderkostnad. Levels of cycle inventory for processed wood products - a trade-off between inventory - and order cost

16. Olovsson, K. 2020.Ledtider i sågverksindustrin – en analys av flöden och processer. Lead times in the sawmill industry – an analysis of flows and processes

17. Holfve, V. 2020. Hållbart byggande – Kommuners arbete för flerbostadshus i trä. Building in a sustainable way –Municipalities' work for wooden multistory constructions

18. Essebro, L. 2020. Ensuring legitimacy trough CSR communications in the biobased sector. Att säkerställa legitimitet genom CSR kommunikation i den biobaserade sektorn

19. Gyllengahm, K. 2020. Making material management more efficient – reduction of non-value-adding activities at a wood products company. Effektivisering av materialflödet – reducering av icke värdeadderande aktiviteter på ett trävaruföretag

20. Berg, E. 2020. Customer perceptions of equipment rental – Services for a circular economy. Kunders uppfattning av maskinuthyrning – Serviceutbud och cirkulär ekonomi

21. Emerson, O. 2020. Impacts of environmental regulations on firm performance – the development of a new perspective. Påverkan av miljökrav på företags prestanda – utvecklingen av ett nytt perspektiv

22. Essebro, L. 2020. Communicating a climate friendly business model. Att kommunicera en klimatvänlig företagsmodell

23. Halldén, A. 2020. Skogens roll i klimatfrågan – En medieanalys av Dagens Nyheter 2010–2019. The role of forests in the climate discourse – a media analysis of Dagens Nyheter 2010-2019

24. Gebre-Medhin, A. 2020. Swedish FES-related policy: Integration of national objectives and factors affecting local actors' policy respons

25. Tanse, K. 2020. The Swedish policy framework for Forest Ecosystem Service. A study of integration of objectives, policy instruments and local actor's knowledge about policies and policy objectives

26. Braunstein, G. 2020. Promoting sustainable market development – A case study of wooden multi-story buildings. Att främja en hållbar marknadsutveckling – En fallstudie om flervåningsbyggande i trä

27. Saati, N. 2021. Corporate social responsibility communication in apparel retail industry. Företagens sociala ansvars kommunikation i textila detaljhandeln

28. Fakhro, I. 2021. Leadership Contribution to Organizations During Pandemic Disruption – A case Study of Private Swedish Organizations. Ledarskapsbidrag till organisationer under pandemisk störning - en fallstudie av privata svenska organisationer

29. von Heideken, F. 2021. Municipal Construction Strategies – The promotion of wooden multi-storey construction. Kommunala byggstrategier – Främjandet av flervåningshus i trä

30. Tiwari, V. 2021. The Challenges in Public Private Partnerships and Sustainable Development. Utmaningar i hållbara utvecklingsprojekt mellan privata och publika aktörer – ej publicerad

31. Söderlund, M. 2021. Att skapa mervärde i en produktlinjeutvidgning. To create added value in a product line extension

32. Eriksson, P. 2021. Wood procurement using harvest measurement. For improved management of forest operations. Virkesanskaffning med hjälp av skördarmätning – För en förbättrad verksamhetsstyrning

33. Olsson, M. & Sparrevik, G. 2021. Commercial forestland investments. A comparative analysis of ownership objectives. Kommersiella skogsmarksinvesteringar -En jämförande studie av ägarmål

34. Dahl, P. 2021. Improving sawmill scheduling through Industry 4.0 A CASE study at VIDA AB. Förbättring av sågverksplanering genom Industry 4.0 – En fallstudie på VIDA AB

35. Leijonhufvud, E. 2022. Råvaruförsörjning av grot - Försörjningskedjan vid Södra Skog Raw material supply of logging residues -The Supply Chain at Södra Skog

36. Nytell, A. 2022. Young Consumer perceptions of Wooden Multistorey Construction Unga konsumenters uppfattningar om flervåningshus i trä

37. Ljudén, A. & Nyström, A. 2022. Digitaliserings potential Kartläggning och analys av arbetsprocesser. The potential of digitalization – Mapping and analysis of business processes

38. Rubensson, N. 2022. Processeffektivisering vid hyvling - En analys av operatörernas förutsättningar. Process streaming in planning- An analysis of the operations conditions

39. Eriksson, P. 2022. The Forest Sector's Adaptation. Taxonomy and Emerging Carbon Markets. Skogssektorns hållbarhetsanpassning – Taxonomin och kolmarknader

40. Olander, C. 2022. I'll have what he's having - Can a bank increase financial equality? Jag tar det han får – Kan en bank öka finansiell jämställdhet?

41. Färnström, I. 2022. Market development for multi-story wood construction – Views of architects and structural engineers. Marknadsutveckling för träbygge i flervåningshus. Arkitekter och byggnadsingenjörers perspektiv

42. Andersson, S. 2023. Hållbarhetscertifiering – Effekter på värdekedjan av byggmaterial. Green certificate – A case study on effects in the value chain of building materials

43. Sköld, C. 2023. Lönsamhet i skogsmarksgödsling för privata markägare i norra Sverige. En jämförelse av lönsamheten i två olika gödslingsstrategier. Profitability in forest fertilization for forest owners in Sweden. A comparison of two different forest fertilization regimes

44. Sjölund, A. 2023. Bankens roll vid generationsskifte av skogsfastigheter – En studie av intressenters tjänstebehov. The role of the bank in the succession of forest properties – A study of stakeholders´ service needs

45. Hurtig, A. & Häggberg, E. 2023. Ökad kolsänka i den svenska skogen – Ett intressentperspektiv. Increased carbon sink in the Swedish forest- A stakeholder perspective

46. Berrebaane, D. A. 2023. “No pay, no care?” – Insights from a preliminary review of payment for ecosystem services payment suspensions

47. Lundberg, E. 2023. Private label effect on small producer business development
A multiple-case study from a producer perspective. Handelns egna märkesvarors inverkan på små producenters affärsutveckling – En fallstudie från ett producentperspektiv

48. Mattsson, J. 2023. Local food networks – value creation and the role of the producer. Lokala livsmedelsnätverk – värdeskapande och producentroll

49. Grele, E. 2023. Skogssektorns anpassning till EU taxonomin – Redovisning av hållbarhetsinformation. The forest sector´s adaptation to EU taxonomy – Reporting of sustainability information

50. Rudolph, A-C., 2023. Marketing of meat alternatives - A comparison between Germany and Sweden. Marknadsföring av köttalternativ - En jämförelse mellan Tyskland och Sverige

51. Nazarali, A. & Stefanov, N. 2024. Aquaculture in Northern Sweden – Exploring conditions for sustainable aquaculture. Vattenbruk i norra Sverige – Undersökning om förutsättningar för hållbart vattenbruk

52. Persson, E. 2024. Communication Responsible Forestry – Companies in forest supply chains. Kommunikation ansvarsfullt skogsbruk – Företag i skogliga försörjningskedjor

53. Hernblom, C. 2024. Towards Biodiversity Credits A qualitative case study in Yayasan Sabah Forest Management Area Borneo Malaysia. Mot krediter för biologisk mångfald - En kvalitativ fallstudie i Yayasan Sabah Forest Management Area, Borneo Malaysia

54. Johannesson, K. & Näslund, R. 2024. Smart specialisering för regional tillväxt- Skoglig bioekonomi i Värmland. Smart spesation for regional growth – forest bioeconomy in Värmland

55. Lindqvist, A. 2024. Investing in refined birch - Perceptions and attitudes behind the choice. Att investera i förädlad björk – Uppfattningar och attityder bakom valet

56. Nowik, J. 2025. The adoption process of CT scanning in sawmills: motives, acquisition, challenges and benefits**.** Implementeringsprocessen av CT-scanning i sågverk: motiv, införskaffande, utmaningar och fördelar