Innovation in the Global Forestry Industry: Past, Present and Future Trends

Abstract

In the global forestry industry, there has been a steady increase in productivity during the approximately 50 years leading up to the early 2000s, after which productivity flattened out or even decreased. Based on this assumption that increased productivity takes place alongside innovation and the implementation of improved equipment and processes, this study seeks to understand what type of innovation drove the improved productivity during the early phases of productivity improvement and to provide some recommendations for the innovation that should be the focus of future research efforts in the industry to improve the productivity again, effectively lifting the sector out of its stagnation. A qualitative, deductive exploration into innovation in the forestry industry on a global level was carried out. Historic trends in patent frequency, representing innovation in different technology classes and subclasses were analysed and various deductions made about focus areas for innovation over time in the past and into the present. From a process point of view, this research found that forestry is an industry that is undergoing an evolution into a more integrative industry. Important technologies that will shape its role in the future see it having a broader global impact in industries beyond those s it currently serves, particularly in food and energy. It also should fulfil a stronger role in providing ecosystem services to integrate with human activities as well as mitigate the impact of those activities. From a non-process point of view, a wide range of findings was discussed, and various technologies identified as key. Also, that a clear and coordinated effort for innovation in the forest industry is required. The findings from this study have useful implications for the study of innovation in numerous other industries.

Keywords: Forestry innovation, innovation, forestry, patents, citations, bibliometrics, forestry technology

Introduction

In the global forestry industry, there has been a steady increase in productivity during the approximately 50 years leading up to the early 2000s, after which productivity flattened out or even decreased (Figure 1). According to a recent report by McKinsey and Company, the increase in productivity was driven by innovation in the mechanisation of machinery (Allott et al., 2020). The McKinsey study evaluated data from Sweden, an industrialized nation with a long history of innovation in the forestry supply chain. Such a trend might not hold for developing nations or even other developed nations. The trends and assumptions made by McKinsey were therefore compared against a measure of forest productivity using FAO (Food and Agriculture Organization of the United Nations) data across a variety of different countries both in the developing and the developed world (Figure 2). It was clear from the trends that developed countries such as Germany, the United States of America and Austria followed a similar trend to that shown by Sweden in the McKinsey study, with minimal improvement in productivity over the last approximately 20 years to date. Developing countries showed lower productivity in general, except for Uruguay which shows a trajectory over the last 10 years similar to that shown by Germany a decade earlier. The forestry industry in Uruguay is relatively young, having started operations of scale approximately 25 years ago, mainly driven by large plantation forestry projects implemented by long-standing forestry companies from Scandinavian countries such as Finland and Sweden (XXI, 2020). This could explain the rapid increase in productivity, as the prevailing technologies of the parent companies are implemented in their projects in Uruguay. The expectation is that the trend will flatten once these technologies and processes complete implementation, similar to what has happened in Sweden.

To address this question of productivity, various studies have concluded that to ensure efficient operations, businesses operating in the global market have to work on developing novel innovations while at the same time ensuring that they understand and implement the best of currently available resources and technology (Wong & Ngai, 2022). Effectiveness in innovation is therefore relevant to most organisations or industries that want to stay ahead and retain a competitive advantage, or even just maintain a market position. Technology, and the context in which businesses operate is changing rapidly and innovation is required to build and maintain a competitive advantage. (Yanhong & Runhua, 2007). Also, innovation and research and development (R&D) are often processes that required substantial resources. Organisations need to understand where to focus their resources within the wide range of knowledge sources available to them (Abbas et al., 2014) to be able to prevent wasted efforts, lost opportunities and lost time. This seems to have been the case for the forestry industry over the last 20 years as it has struggled to direct innovation efforts to improve productivity.

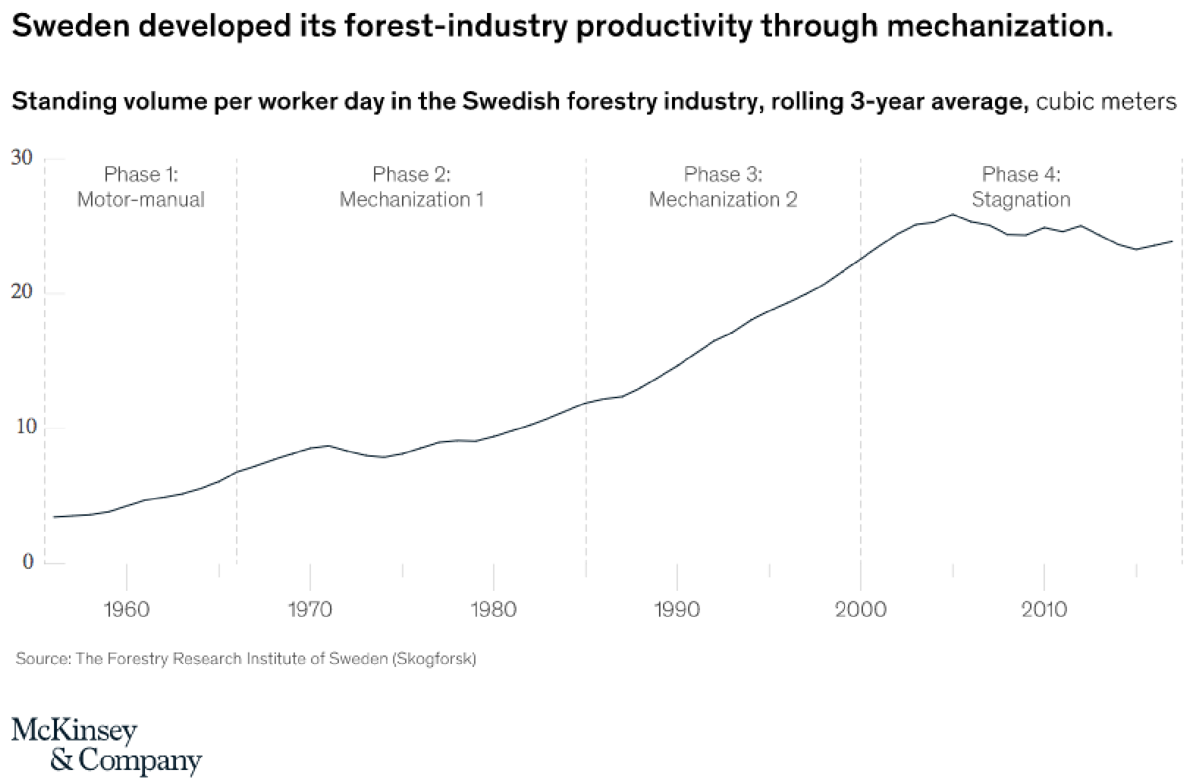

Figure 1. An evaluation of forestry productivity over time in Sweden with the assumptions regarding the drivers behind the trends. (Allott et al., 2020)

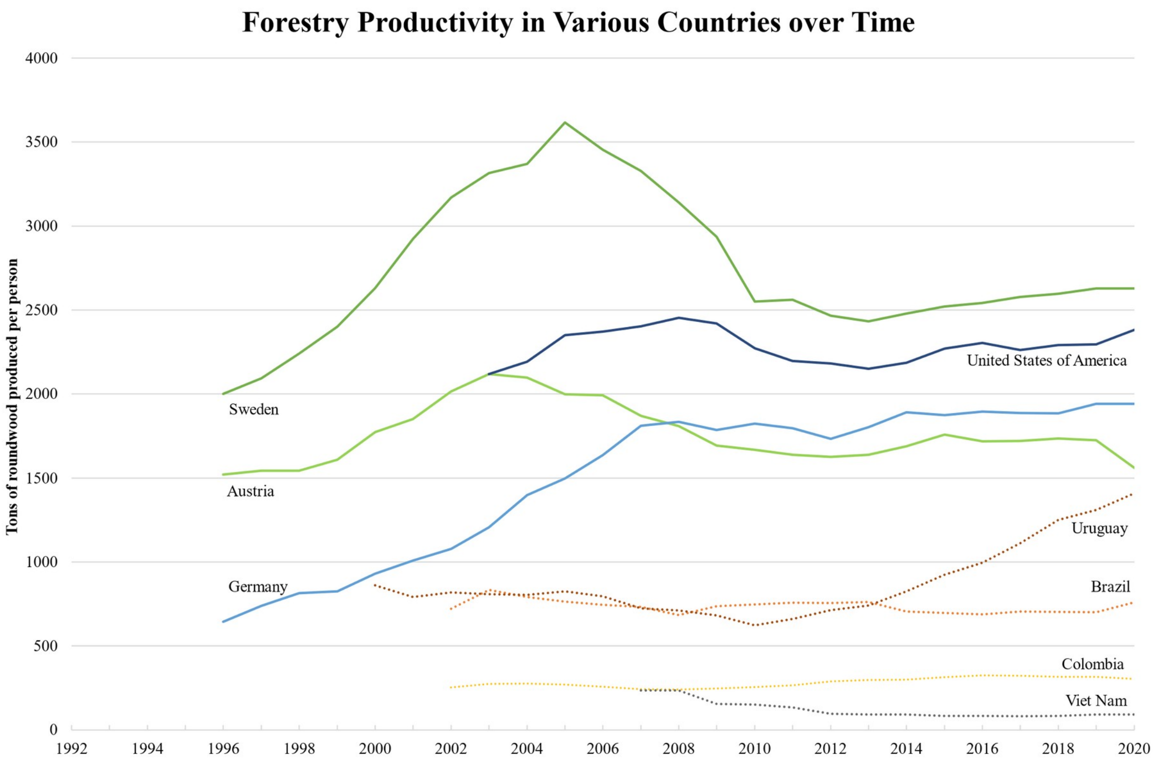

Figure 2. Forest productivity for various countries over time (5-year moving average). FAOSTAT (2022)

The innovation process, centred around the creation of knowledge, has become the central function of R&D efforts in recent decades, key to the competitive survival of businesses, innovation in itself being a competitive endeavour. This competitive nature of innovation is highlighted by Lazzarotti et al. (2011) who describe the necessity for effective innovation as a result of product lifecycles becoming ever-shorter, new products and technologies being introduced continually faster than before, methods and technologies driving up speed of innovation as well as the need to be constantly exploring to develop new knowledge. They point out that not only is the innovation process important in itself but also the application and implementation of the innovation in the greater business process.

Both the implementation of known technologies and innovations as well as the directed investigation process of exploring novel innovation are essential to ensuring competitive success and efficiency in global markets (Wong & Ngai, 2022; Yalcinkaya et al., 2007). As a guide for R&D in the forestry industry in the future we need to answer the question about the past:

Which classes of innovation and types of technology have driven productivity increase in the past?

Based on this assumption that increased productivity takes place alongside innovation combined with the implementation of improved equipment and processes, this study seeks to understand what type of innovation drove the improved productivity during the early phases of improvement and to provide some recommendations for the innovation that should be the focus of future research efforts in the industry to improve the productivity again, effectively lifting the sector out of its stagnation.

Literature review

Patent analysis in innovation

Albino et al. (2014) refer to patents as output-based indicators of innovation and underscore the value of patent data for understanding the dynamics of innovation. They point out that there are both advantages and disadvantages to using patent data as a source. Shortcomings include the lack of patents being able to cover the full innovation portfolio as some innovations are not patentable or necessarily patented because a patent may not be the best way to protect the innovation. Also, the value of patents differs between regions or industries, where in some cases a patent would carry a high innovative value and in others, a patent may not have much value, and all patents may not be implemented. Advantages of using patents as a data source include the benefit that data are available globally, over long timeframes, with a richness of information linked to each patent that allows for a wide range of analyses to be carried out. Patents also tend to reflect economic value and relevance of work. In addition to the base patent information, citation data linked to patents provide a rich source of measuring the value of patents over time by being a direct measure of their impact (Albino et al., 2014).

Krestel et al. (2021) studied the various tools required to assist with the automation of patent analysis methods because of the enormous growth of data. They also refer to the richness of the content of patent data but explain that to be able to carry out efficient analysis of patent data, intelligent tools such as machine learning are required because of the complexity and volume. Among the types of automated analysis that can be carried out on patent data, they describe the use of patent bibliographic data to analyse patent quality and market value as well as using patents to forecast technology trends. Patents are “a major source to predict upcoming technologies” (Krestel et al., 2021, p. 14) but they point out that such a methodology should be assisted by domain expertise. In their overview of state of the art technologies in patent analysis, (Abbas et al., 2014) substantiate this by explaining that analysing patent data is worthwhile to "manage the complexities of searching and inter-relating patent information" (Abbas et al., 2014, p. 1).

Innovation in forestry

In their investigation into the literature published about innovation in the forest sector, Weiss et al. (2020) describe how innovation research within the industry has grown (Figure 3) and built up a sound reputation as a research field, still gaining momentum. They do however highlight the lack of variety in the methodology of research, pointing to the predominance of qualitative case study approaches. They found that although case studies provide a sound understanding of how innovation is carried out within the industry in terms of process or systems, such a qualitative approach falls short in providing analytical insights on a broader level outside of single firms. A more quantitative approach across a wider sector or countries is recommended to provide more depth into the understanding of "innovation processes, innovativeness, innovation patterns and success factors that up-to-date is mostly limited to certain countries and industries" (Weiss et al., 2020). This finding motivates an effort to find a more quantitative, broader approach to analysing innovation in the forestry sector on a global level, across the entire forestry supply chain.

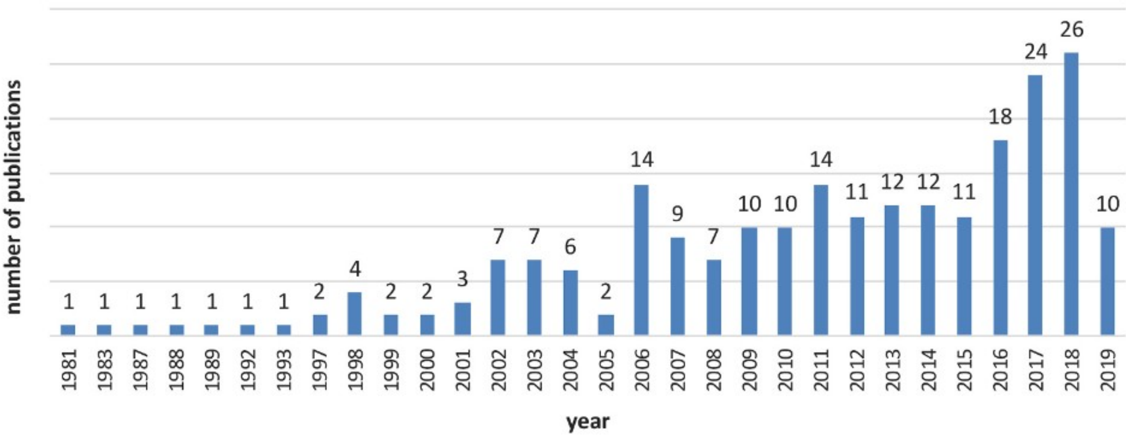

Figure 3. The number of forestry innovation-related publications per year as analysed by Weiss et al (2020)

When evaluating the existing innovation research in forestry, Weiss et al. (2020) also found the trends driving innovation in forestry were organizational structure changes at a large scale, changing patterns of competition on a global scale, changing demands from society (e.g. sustainability, chain of custody monitoring, carbon neutrality etc.) and the creation of new markets and competitive new entrants into existing markets. They found that the perceptions depicted by these studies were that innovation within the industry was fairly restricted and had not reached its full potential as well as being an industry that lagged behind others in terms of innovativeness (Weiss et al., 2020). This perception of a lack of innovation in the industry strengthens the view that there is likely a link between stagnation in productivity and the effectiveness of innovation in the industry.

Christensen et al., (2011) describe how the size of the company has an impact on the type of innovation carried out. Where companies are bigger, they are usually more innovative, but their innovation is more driven by process improvements, with smaller forestry companies taking a broader approach to innovation, including both process and product innovation in their innovation efforts. This is a useful consideration in the context of this study because smaller companies are then perhaps more likely to be working on what could potentially be a potential ICTC, while larger companies are likely doing similar process innovation as their competitors, albeit in isolation and internally, an unnecessary duplication of efforts as far as the industry in general is concerned.

Several studies reinforce the understanding that for companies to be successful in innovation, a clear and explicit strategy needs to be created and implemented, accompanied by a culture and environment in the organization that promotes and supports innovation (Bull & Ferguson, 2006; Nybakk et al., 2011). When studying collaboration for innovation in the industry, Guerrero & Hansen (2018) described those factors that work towards improved collaboration in the industry as well as those challenges that hamper collaborative innovation within the industry. They found that the need for cost reduction, competition and competitiveness within the industry and the requirement for environmental sustainability were some of the key reasons behind effective collaborations. Non-collaborative business culture, lack of trust and difficulties in putting a monetary value to the collaborations from both the cost and savings perspective were found to be some of the main hindrances to effective collaboration amongst players within the industry.

Methods

At a high level, the methodology followed in this study was a qualitative, deductive, and explorative approach where the historic trends in patent frequency, representing innovation in different technology classes and subclasses were analysed and various deductions made about focus areas for innovation over time in the past and into the present.

Historic innovation trends were analysed, evaluating the innovativeness (patent activity) of the industry as a whole over time, as well as the diversity of the innovation activity (spread of patents across technologies). The objective was to understand what type of innovation was driving productivity in the past and what type of innovation has been taking place over the last 20 years, potentially providing some insight into why productivity has stagnated.

Patent data preparation

Patent data for the study were extracted from three databases:

1. PATSTAT worldwide patent statistical database. ("PATSTAT Global - 2022 Spring Edition"). This is the base database containing all global patent data and information related to the patent directly.
2. Organisation for Economic Co-operation and Development (OECD) Citations Database. Citations of patents are stored and organized within this database along with dates.
3. World Intellectual Property Organisation (WIPO) International Patent Classification (IPC) database. Information describing each classification at the different levels of patent classification are stored within this database. These levels can be described as shown in Figure 5.

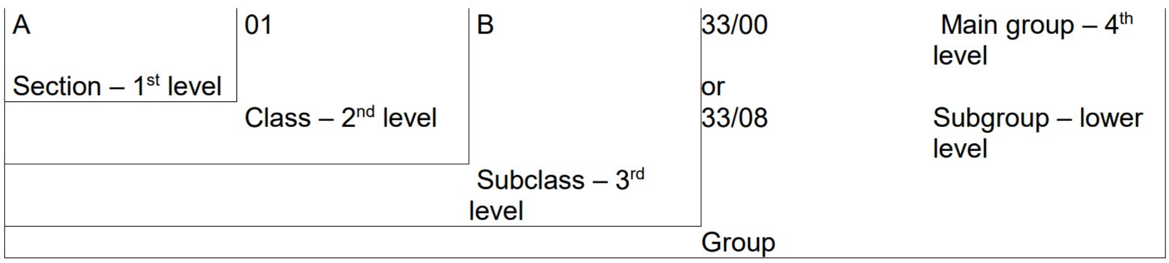

Figure 4. WIPO IPC patent classification breakdown.

All patent information related to forestry (with the word "forestry" in the abstract of the patent information) was extracted from the PATSTAT database. In total 17 606 patents were downloaded of which 17 588 fell in the time period after 1 969 and were used in subsequent analyses.

Each patent application was linked to its related IPC (International Patent Classifications) descriptions. One patent can have several patent classifications at any of the different classification levels. A link was also made between the patents and the number of subsequent patents that cited each patent as well as the date of citation to track the patent citation activity over time.

Reclassification of patent data

In the initial data exploration phase, attempts to analyse trends using existing IPC classifications at different levels were made. Although some trends can be seen, it was not intuitively clear from the classification descriptions what was happening in the innovation landscape over time in a way that could be qualitatively described. In order to improve the descriptive power of the analysis, the patents dataset at the maingroup level was reclassified manually, considering the title of the individual patents within each maingroup. Each patent was therefore able to be reclassified into one or more of 42 clear technological groups based on the maingroup classification. The technologies used for this classification are:

1. Analytics
2. Animals
3. Bioenergy
4. Biotech
5. Chemical
6. Cleaning
7. Communications
8. Construction
9. containers
10. Data Capture
11. Electronic
12. Energy
13. Ergonomic
14. Fertilizer
15. Fire management
16. Food
17. Laboratory
18. Liquid application
19. Macromolecular
20. Manual
21. Mechanical
22. Mechanical Forestry specific
23. Medical
24. Metallurgy
25. Microbiology
26. Movement systems
27. Mushroom cultivation
28. Navigation systems
29. Nursery
30. Pest control
31. Plant protection
32. Process
33. Remote sensing
34. Security
35. Shipping
36. Software
37. Soil management
38. Specialized silviculture
39. Tree cultivation
40. Vegetation control
41. Waste management
42. Water management

Grouping data into time periods

For the analysis of the technology trends over time, the data were grouped into 10-year time periods for both the patent and the keyword data to be able to identify the general shift of the broader trends over time, smoothing out short term tendencies. For the analysis of the dynamics of innovation, the data were grouped into 2-year periods to create slightly larger time groupings than a single year for patent citations and classifications to account for any lags in the administration process for patent registrations.

Analysing trends and tendencies

Using the reclassified patent dataset, a visual representation of the development of the technological landscape was created. To do this, it was necessary to understand which technologies are more current and have received more attention, i.e., weighted towards more recent years both in terms of volume of work as well as novelty of the technology. To calculate this weighting, a ranking of one to six was assigned to each decade in the time frame between 1970 and 2022. The total count of the occurrences of each technology in each period was multiplied by the weighting for that period, resulting in a higher number for those technologies that have more occurrences in more recent times as follows, where wt is the weighting of 1 to 6 depending on the period, n_p is the number of times a given patent class/keyword occurrences within the period and n is the total number of patent applications in all classes within the period:

$$\frac{wt * n_p}{n}$$

Once the weighting was calculated for each technology, an alluvial diagram was generated for both absolute occurrences of each technology per period as well as the percentage of innovative output that each technology occupies within a given time period. Within the diagram, a size and colour scaling show the development of the innovative performance as well as the novelty of each technology. Moving from the bottom left to the top right, technologies increase in the currency of innovation effort. From these diagrams, it is possible to gain insights into the shifting priorities of innovation over time, both for patents.

Results

After data analysis, the final outputs for innovation trends were alluvial graphs showing the flows of technologies over time for patents, both in absolute numbers as well as proportion of innovation output per period.

Innovation Trends over time

Patent data in reclassified form and cleaned, weighted by currency and frequency, were represented in alluvial graphical format, with more current technologies coloured in redder hues and older technologies that have not shown high levels of activity in recent years in blue hues.

Absolute occurrences of patent applications are shown, followed by a representation of these same numbers as proportions of total activity per period.

Patent activity trends

Figure 5 shows absolute patent application numbers. Patent activity increased dramatically in the years after 2010. Tree cultivation technologies, chemical, pest control, mechanical, process and analytics technologies are prominent areas of patent activity.

When considering the proportion of patent activity for each technology over time (Figure 6), technologies related to improving volumes and protecting trees, such as specialized silviculture, fire management and tree cultivation are more current. Analytics-related technologies has shown consistent innovative performance but has dropped in the rankings of currency in recent years to be replaced by assistive technologies such as remote sensing and data capture.

Critical to the discussion is the change in chemical innovation and mechanical innovation over time. In the early periods, chemical research made up a substantial bulk of innovation, linked to general mechanical innovation, to be replaced by forestry specific mechanical innovation in the 90s, itself replaced by tree cultivation and pest control technologies in the years after 2000. Innovation focused on ergonomics lost the focus of innovation efforts by 2000. A classification for “other” is included for those patent classes that fall below the top 20.

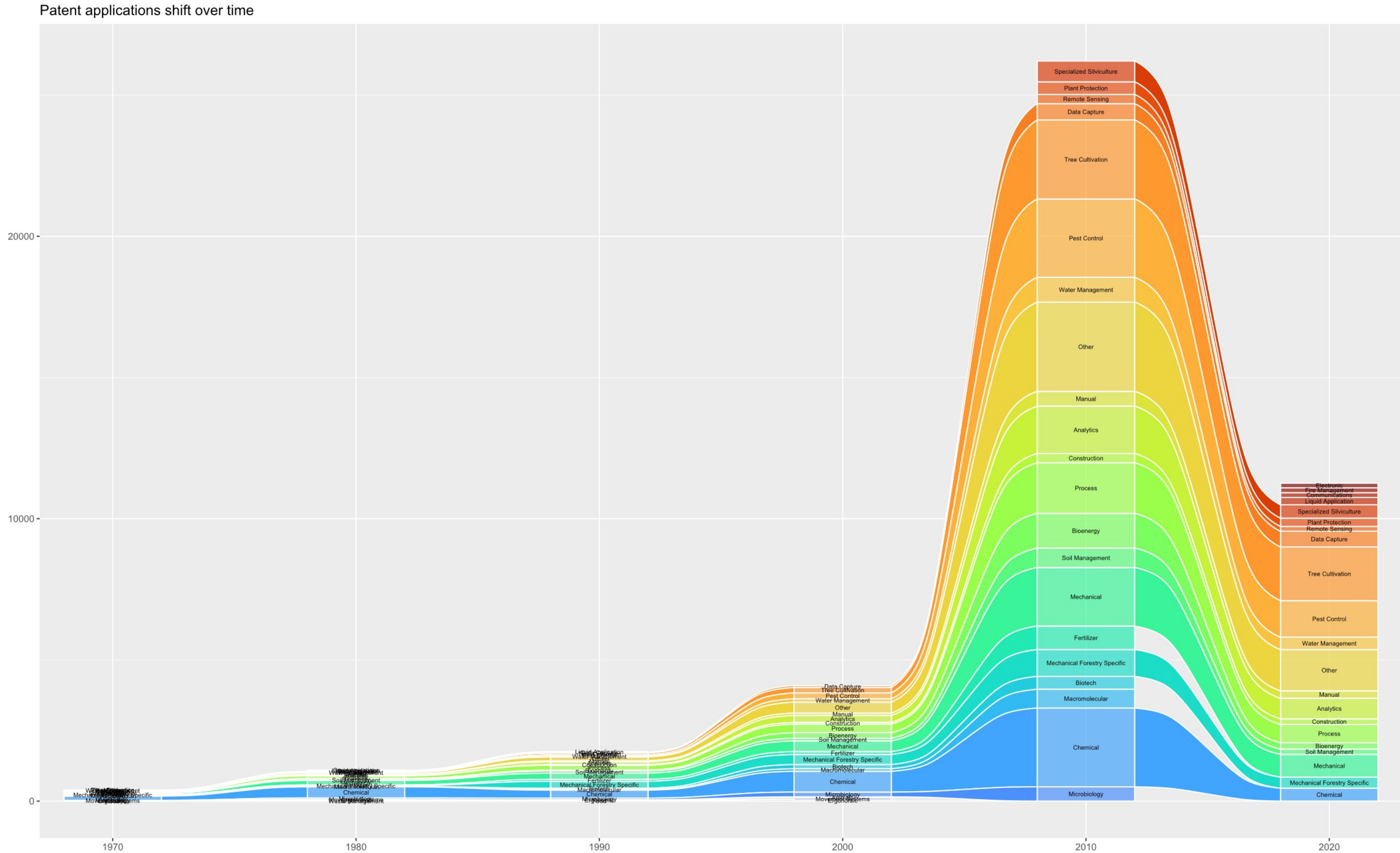

Figure 5. Absolute numbers of patent applications over time. Currency of the research is shaded from red (current) to blue (older).

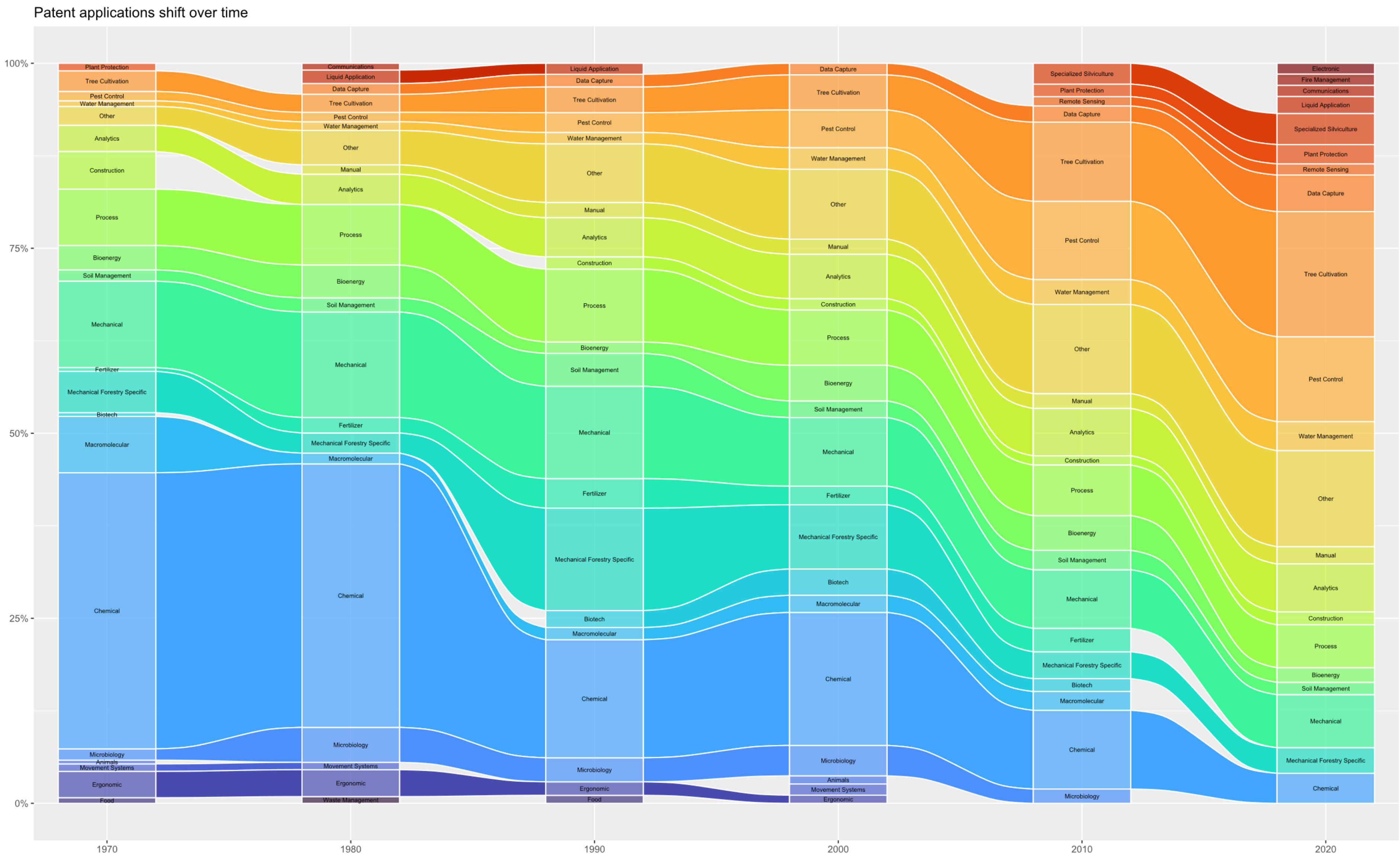

Figure 6. Patent activity over time as a percentage of total patent activity per decade. Currency of the research is shaded from red (current) to blue (older).

Discussion

Considering the exploratory nature of this study, certain conclusions are factual, based on statistical modelling and some are more subjective, based on tendencies and observations as guided by analysis of the data from the different perspectives. However, the observations made within this discussion can be seen in the results of the data analyses.

Trends and tendencies

The trends and tendencies analysis evaluated the historic development and flow of innovation from both a patent application data.

Patent data trends

General trends in patent data over time showed a decrease in historically important areas such as chemicals and mechanical which were replaced by sustainability topics such as climate change accompanied by technologies in analytics over time. Tree cultivation efficiency aided by specialized silvicultural tools is receiving a lot of attention in recent years while technologies such as ergonomics have lost focus.

The reduction in chemical and mechanical innovation to be replaced by sustainability and biological aspects of forestry indicates a broader shift within the industry away from seeking productivity at all costs towards a more responsible practice with a consideration for environmental and social impacts. This shift is expected to come at a cost to productivity. An overview of how this interaction has played out over time is shown in Figure 7, where the patent trend analysis has been overlaid with forestry productivity data.

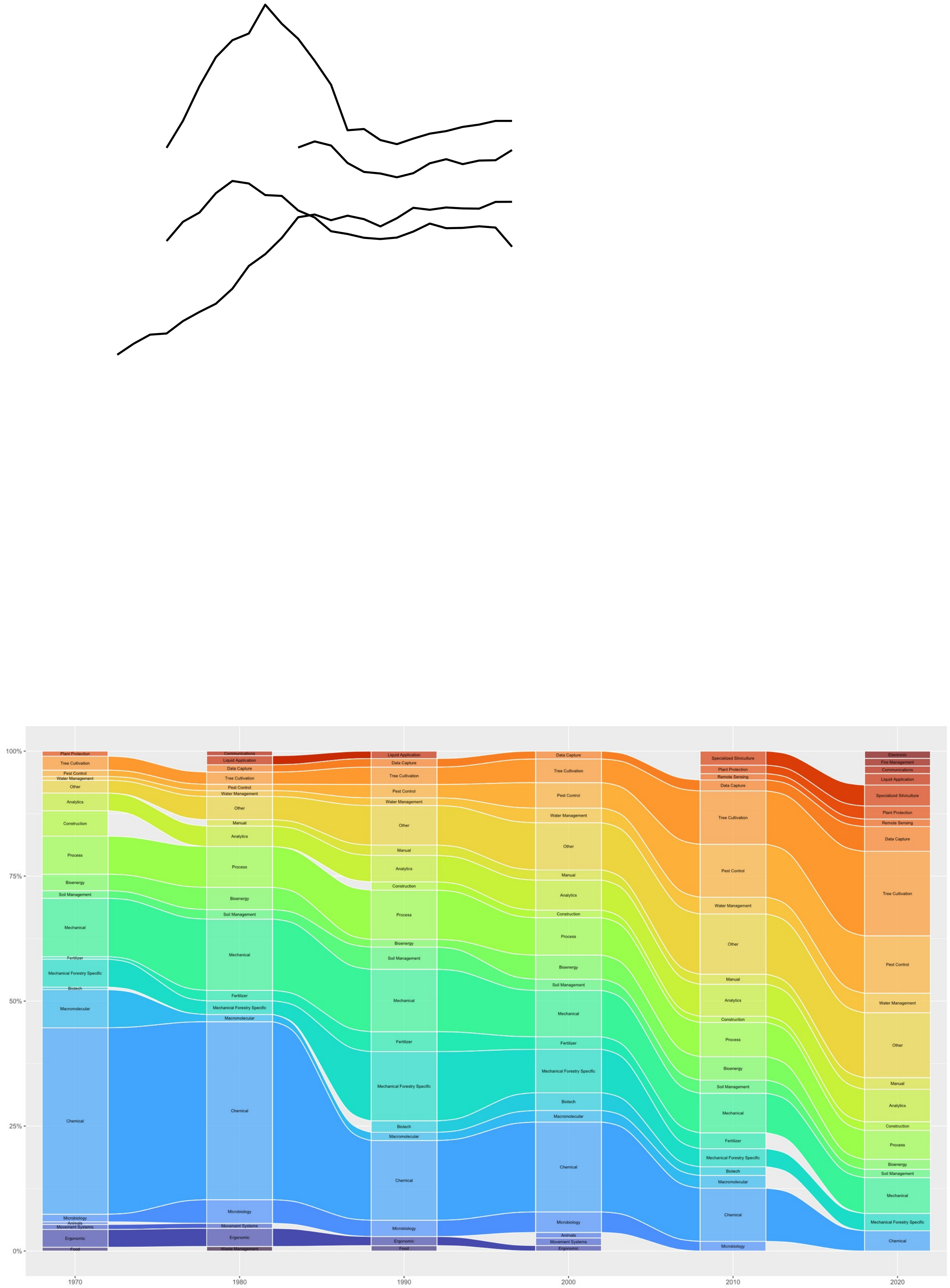

Figure 7. Patent application trend data from Figure 6 overlaid with productivity trends (black lines) from Figure 2 (from top to bottom: Sweden, USA, Austria, and Germany) to show the relationship between productivity and innovation activity.

Implications for research policymakers and managers

The definitions of productivity appear to have been reset. Where in the past, productivity may have been measured in terms of fibre produced per unit cost or per person, productivity has become a measure that includes fibre with a wide range of additional ecosystem services. Although this is not a new concept, it is clear from this research that the shift has already started and that the future of research should embrace this trend and set out to accelerate it and embed integrated forestry innovation into mainstream forest research. Conscious decisions need to be made as to which areas of research are intellectual property with competitive advantage and should be maintained proprietary as opposed to those areas of research that promote the sustainability and newfound holistic nature of the industry. The industry requires quality, radical innovation and not high patent numbers.

Within those areas of competitive advantage, a more strategic approach could be taken. Mechanisms that ensure the highest level of collaboration between the necessary parties to minimize duplication and fragmentation of work and maximise the value of innovation. These mechanisms would be more efficient for the industry as a whole through industry level focus groups, information sharing at conferences, centralized forestry knowledge management institutes etc. A more coordinated approach in general, mapped out by the various stakeholders and adapted over time, guided by a strong set of principles would be the ideal industry-level innovation strategy.

Despite the changes in focus taking place, foundational considerations of forestry such as the operating model of the forestry operation, the economics, stakeholders and role of forestry in society need to be strongly maintained. Forestry should play a central role in resolving the current desperate situation for sustainability and climate change. Education related to forestry both for talent development within the industry and education related to forestry in the context of the wider society, integrating into wider stakeholder groups with all stakeholders understanding the value of forests is key to achieving this vision.

Recommendations for future research

Research carried out in this project has the potential to be advanced on various fronts. Key to consolidating the outcomes would be a roadmap for the forest industry on a global level, centred around:

- The integration of forestry into society by ecosystem services
- Identifying regional recommendations as well as the best mechanisms for innovation coordination. Good examples of industry-level innovation could likely be adopted from other industries e.g., the semiconductor industry.
- Identifying more clearly the content within clusters of innovation around optimizing existing operations and minimizing impact while maximizing value, biomaterials, bioenergy, food and integration with agriculture.

Research into the dynamics of innovation could be furthered, with additional variables included such as duration of dominance of a specific patent, testing of different time periods for sensitivity, broadening the dataset and refining the manual classification. In addition, carrying out specific case studies of selected dominant designs in forestry could help to validate these findings as well as provide a deeper understanding of the dynamics.

Conclusion

This study was a qualitative, deductive exploration of innovation in the forestry industry on a global level. Historic trends in patent frequency, representing innovation in different technology classes and subclasses were analysed and various deductions were made about focus areas for innovation over time in the past and into the present.

From a process point of view, this research found that forestry is an industry that is undergoing an evolution into a more integrative industry. Important technologies that will shape its role in the future see it having a broader global impact in industries beyond those that it currently serves, particularly in food and energy. It also should fulfil a stronger role in providing ecosystem services to integrate with human activities as well as mitigate the impact of those activities.

From a non-process point of view, a wide range of findings was discussed, and various technologies identified as key. In summary:

- A clear and coordinated effort for innovation in the forest industry as a whole or at least less fragmented parts (e.g., larger geographies) is required.
- Sustainable methods for achieving high yields (controlling pests in a sustainable way, efficient soil management and preparations)
- Low-impact, high-efficiency harvesting methods
- Take relevant learnings from agricultural sciences and find ways of collaboration between these two industries.
- Improving the basics things from things like innovations in manual tools and ergonomics to understanding the stakeholders and the economics of the forestry operations, as well as selecting the best business model for the operation depending on the circumstances and stakeholders.
- Roadmapping more clearly the way forward within an extremely broad analytical and digital technologies landscape.
- Focus on enabling spatial and communications technologies.

Over the last 50 years, the forestry industry has gradually shifted from achieving higher productivity at all costs with a short-term vision to a longer-term vision of responsible, sustainable practice. It is transforming into an industry that is contributing to global societal and environmental sustainability, but this transformation has negatively impacted its productivity. It is critical for both society and the planet that this transformation continues. However, to ensure the economic sustainability of the industry, innovation in the assistive technologies discussed needs to be effectively carried out, providing the tools to facilitate the right balance between the societal, environmental, and economic impacts in the future of the industry.

Alternative value streams will also increase productivity not directly related to the volume of fibre as a traditional measure, but the sum of all value produced by the forest both tangibly as sources of revenue as well as intangibly when considering the mitigating impact that deeply integrated forestry will have on the negative impacts of society.

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