KARL-FRANZENS-UNIVERSITÄT GRAZ
UNIVERSITY OF GRAZ

Future Conditions for Circular Economy, Forest Biomass Use and Technologies





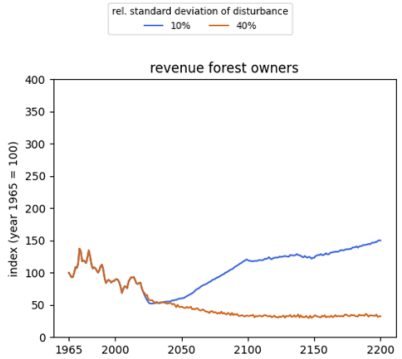
Future forest value chains and biomass use, important research fields:

1. Climate change and forest disturbances (e.g., Asada et al., 2023; García- Jácome et al., 2025; Boiger et al., 2025)
2. Adaptation and forest conversion (e.g., Hoeben et al., 2023; Hoeben et al., 2025; Boiger et al., submitted)
3. Management of increasing complexity (Yavorskaya et al., submitted; Brudermann et al., submitted)
4. Orientation towards carbon management (Boiger et al.,2024; Boiger et al., 2025)

Climate change and forest disturbances

Research in this direction:

- Value chain resilience on a national level (Asada et al., 2023)
- Value chain resilience on a local level (García- Jácome et al., 2025)
- Risk of abandoning management after disturbances (Boiger et al., 2025)





Mitig Adapt Strateg Glob Change (2025) 30:69
https://doi.org/10.1007/s11027-025-10258-1

ORIGINAL ARTICLE

When forest disturbances hit wood value chains: simulating tipping points in roundwood markets

Theresa Boiger[1] · Annechien Brudermann[1] · Raphael Asada[1] · Johannes Mohr[1] · Rupert Seidl[2,3] · Elias Hurmekoski[4] · Tobias Stern[1]

Received: 6 December 2024 / Accepted: 15 September 2025 / Published online: 16 October 2025
© The Author(s) 2025

Abstract

Increasing forest disturbances caused by climate change will present challenges for the resilience of wood value chains. In recent decades, Europe has experienced a rise in forest disturbances, including storms, droughts, and bark beetle infestations, which have a significant impact on harvesting practices and lead to reduced roundwood prices. This presents significant challenges for forest owners. A lack of profitability may lead to reduced motivation to manage forests resulting in forest management abandonment. The combination of increasing forest disturbances and forest management abandonment may lead to market fluctuations and potential tipping points. In this study, we investigate the reversing feedback mechanisms of climate change-induced forest disturbances in the context of resilience of the Austrian wood value chain. We use a System Dynamics forest sector model (FOHOW) to explore the occurrence of tipping points in wood value chains. The results indicate that the resilience of wood value chains is endangered when forest disturbance events fluctuate and forest owners are likely to abandon management. In case of a tipping point, the wood value chain faces consequences that involve structural market changes like reduced roundwood and product production as well as reduced profitability for forest owners and industry. This would likely lead to environmental and social consequences along wood value chains, e.g., increasing greenhouse gas emissions or a shift in working conditions. Nevertheless, the resilience of wood value chains can be manipulated to strengthen value chain resilience by adopting climate-fit forestry, improving flexibility of forest owners and adapting circular economy approaches to make use of secondary raw material sources.

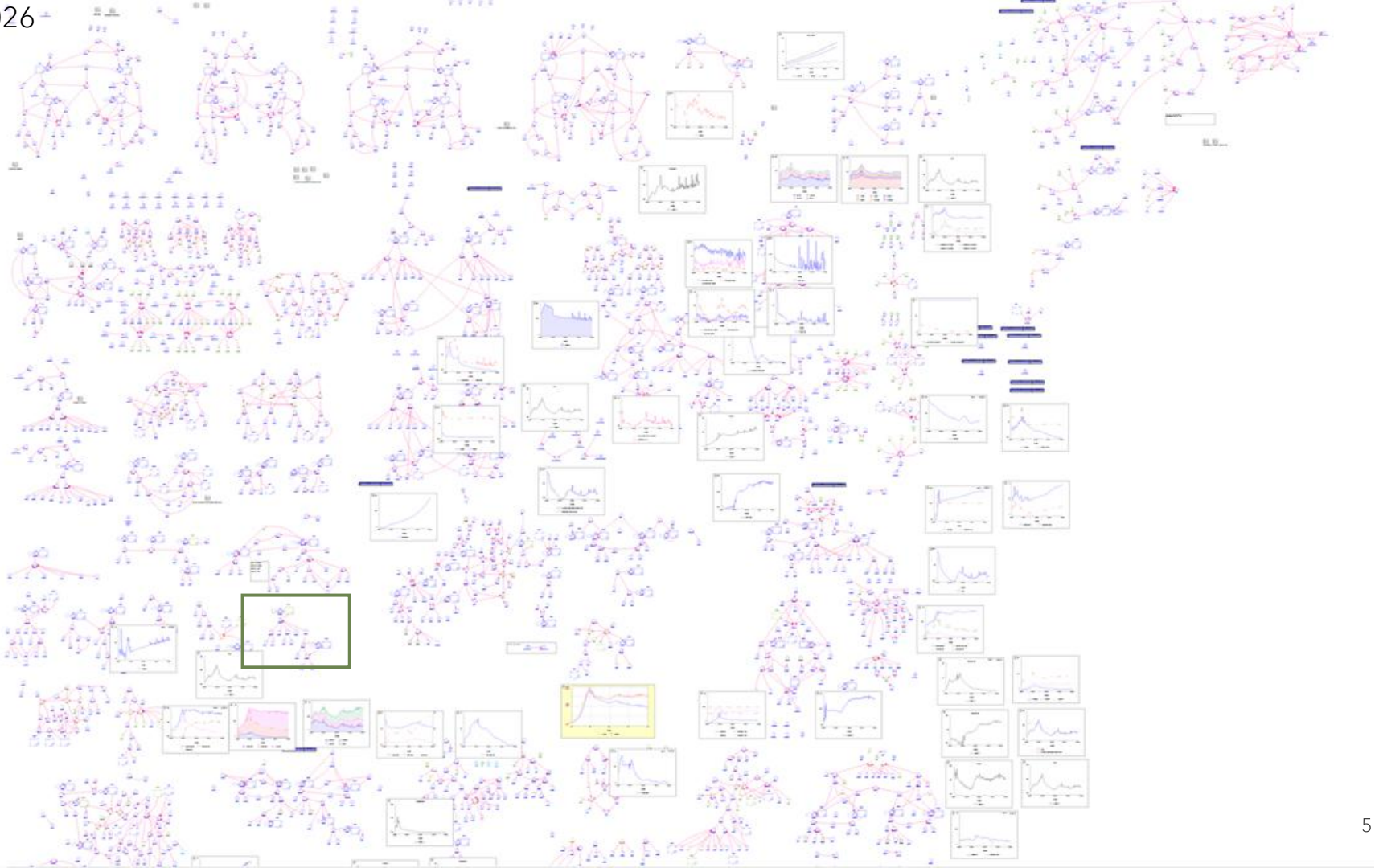
Scope: impacts of management abandonment following profit loss due to disturbances

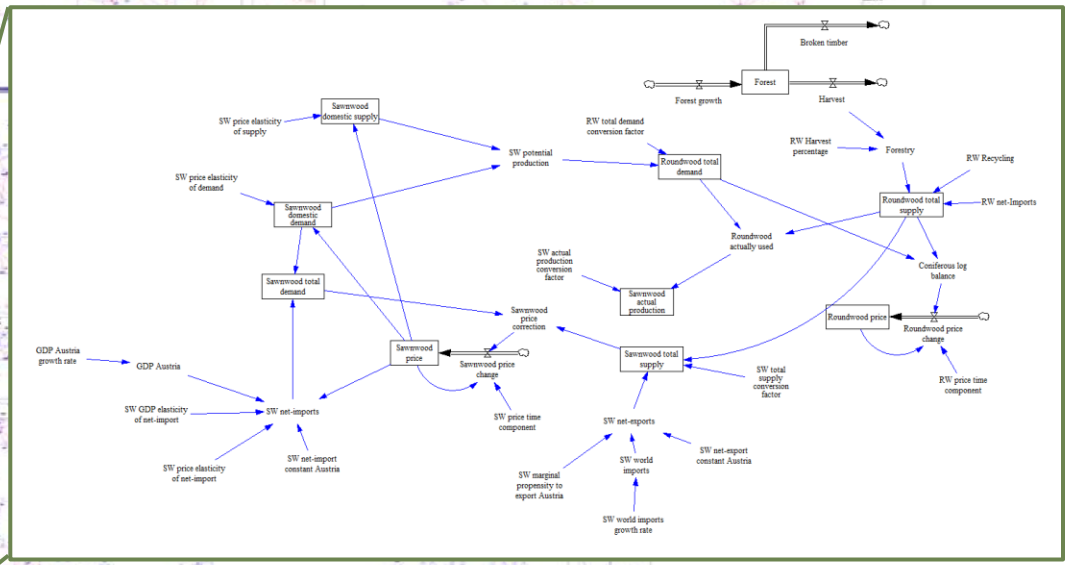
Method: FOHOW modelling

Research findings:

- Average disturbance alone is insufficient to trigger a tipping point
- Two conditions drive a tipping point: escalating forest disturbances and forest owner abandonment
- Increasing disturbance variability substantially raises the probability of a tipping point






Broken timber
Forest
Forest growth
Harvest
Sawnwood domestic supply
SW price elasticity of supply
SW potential production
RW total demand conversion factor
Roundwood total demand
RW Harvest percentage
Forestry
RW Recycling
SW price elasticity of demand
Sawnwood domestic demand
Roundwood total supply
RW net-Imports
Roundwood actually used
SW actual production conversion factor
Coniferous log balance
Sawnwood total demand
Sawnwood actual production
Sawnwood price correction
Roundwood price
Roundwood price change
GDP Austria growth rate
GDP Austria
Sawnwood price
Sawnwood price change
Sawnwood total supply
SW total supply conversion factor
RW price time component
SW GDP elasticity of net-import
SW net-imports
SW price time component
SW net-exports
SW price elasticity of net-import
SW net-import constant Austria
SW net-export constant Austria
SW marginal propensity to export Austria
SW world imports
SW world imports growth rate



Future forest value chains and biomass use, important research fields:

1. Climate change and forest disturbances (e.g., Asada et al., 2023; García- Jácome et al., 2025; Boiger et al., 2025)
2. Adaptation and forest conversion (e.g., Hoeben et al., 2023; Hoeben et al., 2025; Boiger et al., submitted)
3. Management of increasing complexity (Yavorskaya et al., submitted; Brudermann et al., submitted)
4. Orientation towards carbon management (Boiger et al.,2024; Boiger et al., 2025)

Adaptation and forest conversion

Research in this direction:

- Innovation as a resilience strategy (Hoeben et al., 2023)



Current Forestry Reports (2023) 9:301–318
https://doi.org/10.1007/s40725-023-00191-4

FOREST ENGINEERING (M WATT, SECTION EDITOR)

A Review of Potential Innovation Pathways to Enhance Resilience in Wood-Based Value Chains

Annechien Dirkje Hoeben[1] · Tobias Stern[1] · Francisco Lloret[2,3]

Accepted: 19 June 2023 / Published online: 29 July 2023
© The Author(s) 2023

Abstract

Purpose of Review Climate change poses a threat to European forests and threatens their capacity to deliver ecosystem services. Innovation is often considered critical to increasing resilience in wood-based value chains. However, the knowledge about types of innovation processes and how they enhance resilience, if at all, is largely dispersed. In this conceptual paper, we refer to examples from the forestry, bioeconomy, adaptation, and innovation literature to develop an overview of innovation pathways along the wood value chain. Thereafter, we evaluate the extent to which they enhance or compromise resilience to climate change and how they do so.

Recent Findings We differentiate between forest and value chain resilience and assume that innovation positively influences both types of resilience via three resilience drivers: diversifying the product portfolio, making operations more efficient, or making the processes more flexible. Our literature review revealed nine innovation pathways along the value chain.

Summary The pathways rarely connect forest management and the processing industry. Consequently, a mismatch was identified between the innovation pathways and resilience drivers applied to increase diversification at the beginning of the value chain (in forest management) and those applied to increase efficiency towards the end of the value chain (in the processing industry). Considering this mismatch, we stress that it is critical to reconsider the term innovation as a silver bullet and to increase the awareness of resilience drivers and innovation pathways, as well as reconsider ways to combine them optimally. We recommend engaging in open innovation activities to cooperatively draft innovation strategies across the entire wood value chain and intercept pathways by making processes more flexible.

Keywords Innovation · Value Chain Resilience · Forest Resilience · Climate Change Adaptation · Forest-Based Sector

Scope: Innovations in the forest-based sector

Method: PRISMA literature review

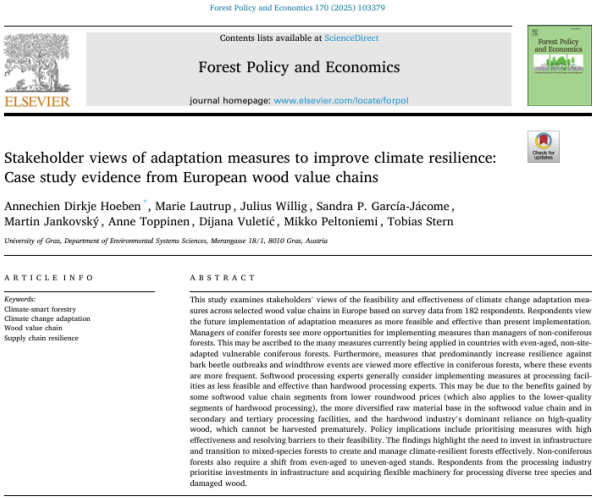
Research findings:

- Three drivers of innovation: Diversification, efficiency and flexibility
- Innovations at the beginning and the end of the value chain looks different
- Innovations do not always strengthen ecological and socio-economic resilience

Adaptation and forest conversion

Research in this direction:

- Innovation as a resilience strategy (Hoeben et al., 2023)
- Which adaptation measures to choose? (Hoeben et al., 2025)



Forest Policy and Economics 170 (2025) 103379

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Stakeholder views of adaptation measures to improve climate resilience: Case study evidence from European wood value chains

Annechien Dirkje Hoeben *, Marie Lautrup, Julius Willig, Sandra P. García-Jácome, Martin Jankovský, Anne Toppinen, Dijana Vuletić, Mikko Peltoniemi, Tobias Stern

University of Graz, Department of Environmental Systems Sciences, Merangasse 18/1, 8010 Graz, Austria

ARTICLE INFO

Keywords:
Climate-smart forestry
Climate change adaptation
Wood value chain
Supply chain resilience

ABSTRACT

This study examines stakeholders' views of the feasibility and effectiveness of climate change adaptation measures across selected wood value chains in Europe based on survey data from 182 respondents. Respondents view the future implementation of adaptation measures as more feasible and effective than present implementation. Managers of conifer forests see more opportunities for implementing measures than managers of non-coniferous forests. This may be ascribed to the many measures currently being applied in countries with even-aged, non-site-adapted vulnerable coniferous forests. Furthermore, measures that predominantly increase resilience against bark beetle outbreaks and windthrow events are viewed more effective in coniferous forests, where these events are more frequent. Softwood processing experts generally consider implementing measures at processing facilities as less feasible and effective than hardwood processing experts. This may be due to the benefits gained by some softwood value chain segments from lower roundwood prices (which also applies to the lower-quality segments of hardwood processing), the more diversified raw material base in the softwood value chain and in secondary and tertiary processing facilities, and the hardwood industry's dominant reliance on high-quality wood, which cannot be harvested prematurely. Policy implications include prioritising measures with high effectiveness and resolving barriers to their feasibility. The findings highlight the need to invest in infrastructure and transition to mixed-species forests to create and manage climate-resilient forests effectively. Non-coniferous forests also require a shift from even-aged to uneven-aged stands. Respondents from the processing industry prioritise investments in infrastructure and acquiring flexible machinery for processing diverse tree species and damaged wood.

Scope: Value chain stakeholders along the soft- and hardwood value chain in Europe

Method: Quantitative survey

Research findings:

- Adaptation measures are seen as more feasible and effective in the future
- Downstream in the value chain from sawmills to bioenergy plants, perceived feasibility and effectiveness of adaptation measures decrease



Adaptation and forest conversion

Research in this direction:

- Innovation as a resilience strategy (Hoeben et al., 2023)
- Which adaptation measures to choose? (Hoeben et al., 2025)
- Economic consequences of forest conversion (Boiger et al., submitted)

Scope: Softwood supply (based on forest conversion trajectories) and demand (based on GDP and bioeconomy market dynamics)

Method: FOHOW modelling

Research findings:

- Supply-demand gap around 2050–2070 onwards, referred to as "peak spruce"
- Shortages differ strongly by assortments: pulpwood is more constrained than logs, and fuelwood exhibits and oversupply



Peak Oil – a self-destroying Prophecy

Peak Oil ?

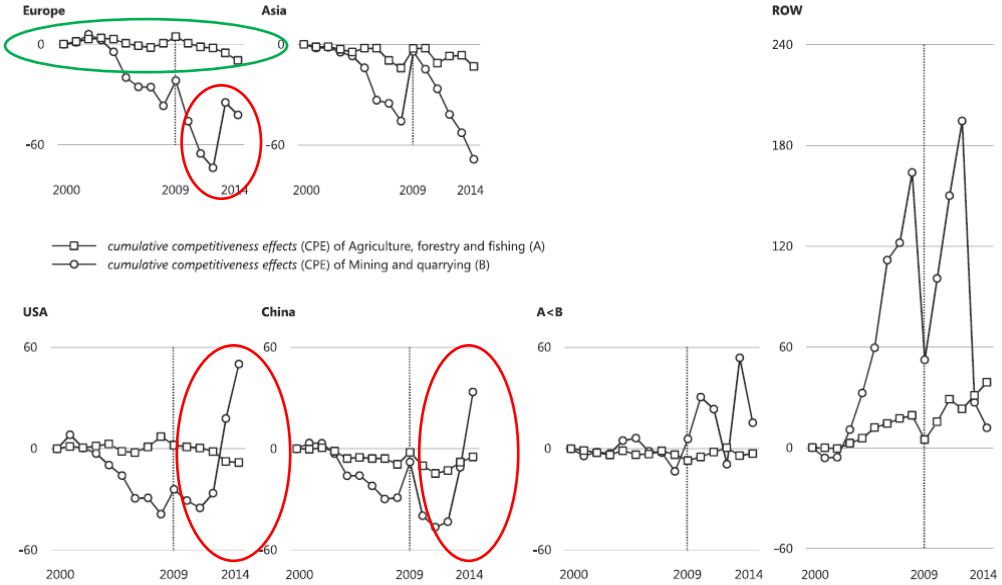
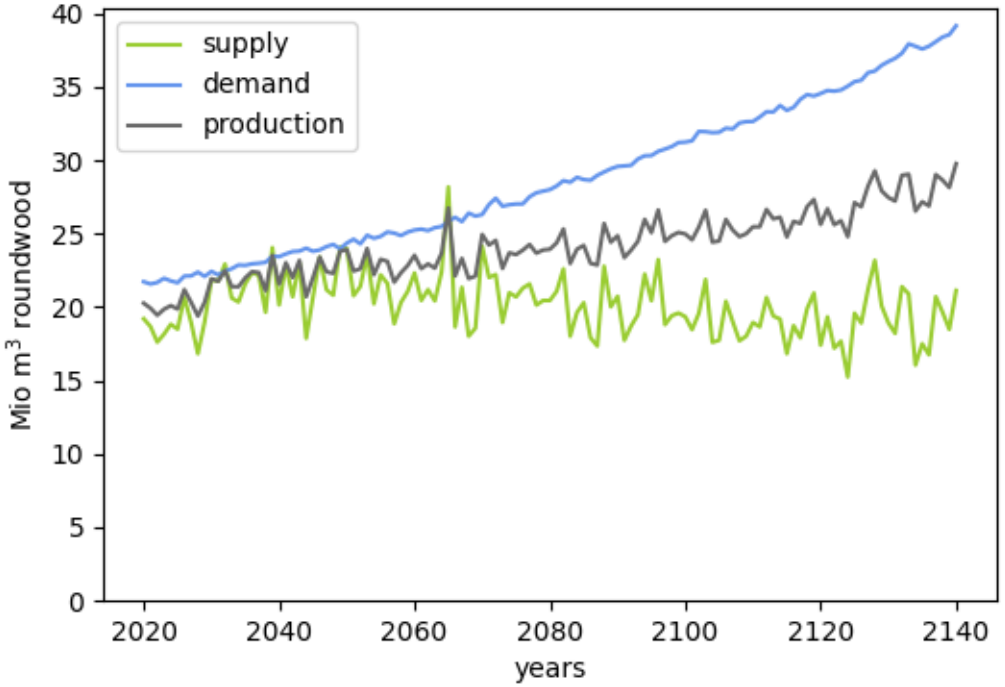


Fig. 4. Cumulative *competitiveness effects* of primary sectors (2000–2014) in 10^9 USD (nominal) by regions. Squares represent *competitiveness effects* of sector A, circles *competitiveness effects* of sector B. The sum over all regions in any year and sector equals zero. Note that effects refer to output changes between the current year and the year before. The vertical dotted line represents the year 2009.

Asada & Stern (2018). Competitive bioeconomy? Comparing bio-based and non-bio-based primary sectors of the world. Journal of Ecological Economics, 149, pp. 120-128

Peak Spruce?


supply
demand
production
Mio m³ roundwood
0
5
10
15
20
25
30
35
40
2020
2040
2060
2080
2100
2120
2140
years



Georgescu-Roegen vs. Schumpeter

"The laws of nature also apply in economics; resources are limited."

"Innovation is the true driving force behind economic development."



Future forest value chains and biomass use, important research fields:

1. Climate change and forest disturbances (e.g., Asada et al., 2023; García- Jácome et al., 2025; Boiger et al., 2025)
2. Adaptation and forest conversion (e.g., Hoeben et al., 2023; Hoeben et al., 2025; Boiger et al., submitted)
3. Management of increasing complexity (Yavorskaya et al., submitted; Brudermann et al., submitted)
4. Orientation towards carbon management (Boiger et al.,2024; Boiger et al., 2025)



Management of increasing complexity

Research in this direction:

- A behavioral gap between stated objectives and forest owner behaviour (Yavorskaya et al., submitted)

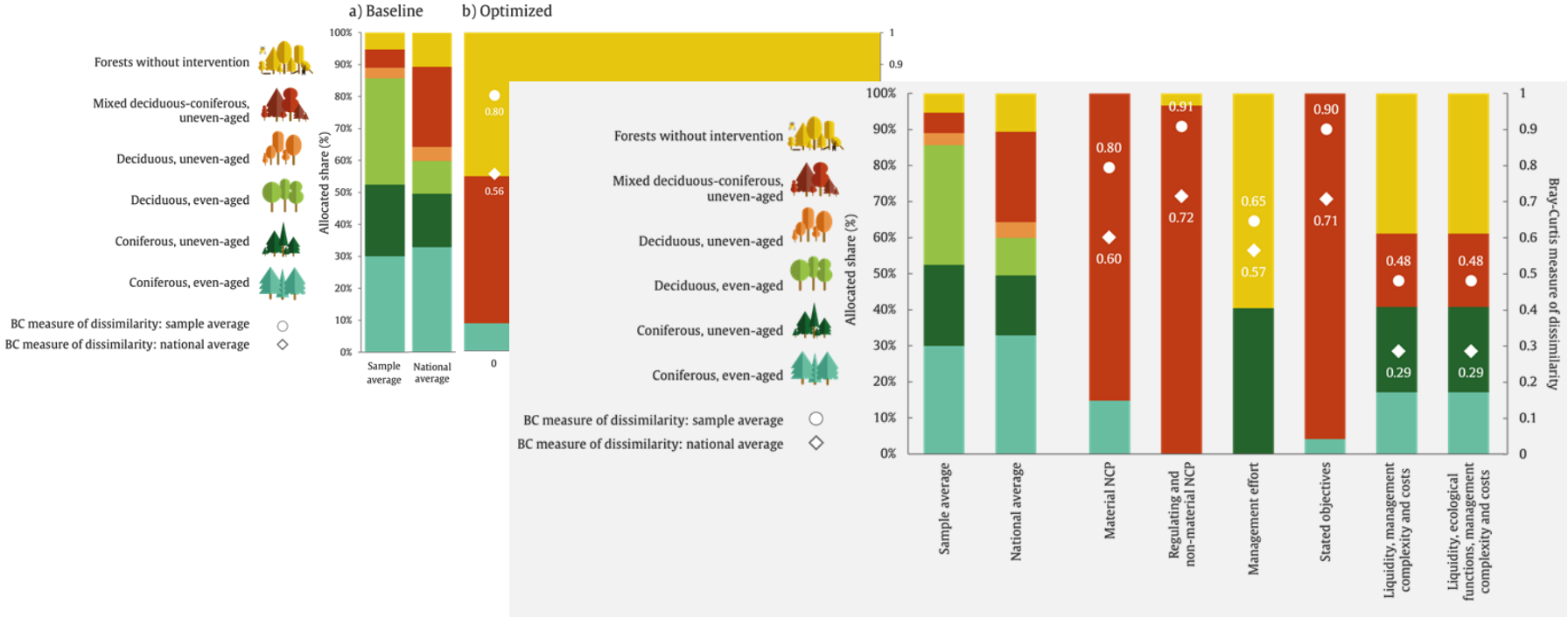
Scope: Material forest functions, non-material and regulating forest-functions and management effort

Method: Survey and Robust Optimisation Modeling

Research findings:

- SPFO view mixed forestry as a compromise to meet multiple objectives but are constrained by management complexity
- SPFO perceive material, regulating, and non-material FCP as complementary; reject the 'material needs vs. conservation' dichotomy

Management of increasing complexity





Management of increasing complexity

- Research in this direction:
  - A behavioral gap between stated objectives and forest owner behaviour (Yavorskaya et al., submitted)
  - Large stock, slow mobilisation (Brudermann et al., submitted)

Scope: The impact of peak spruce on the Styrian wood industry

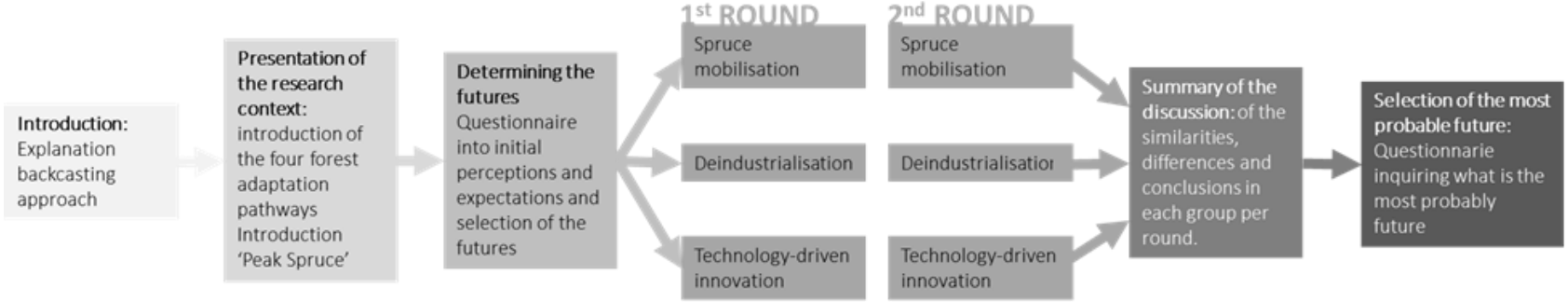
Method: Backcasting workshop

Research findings:

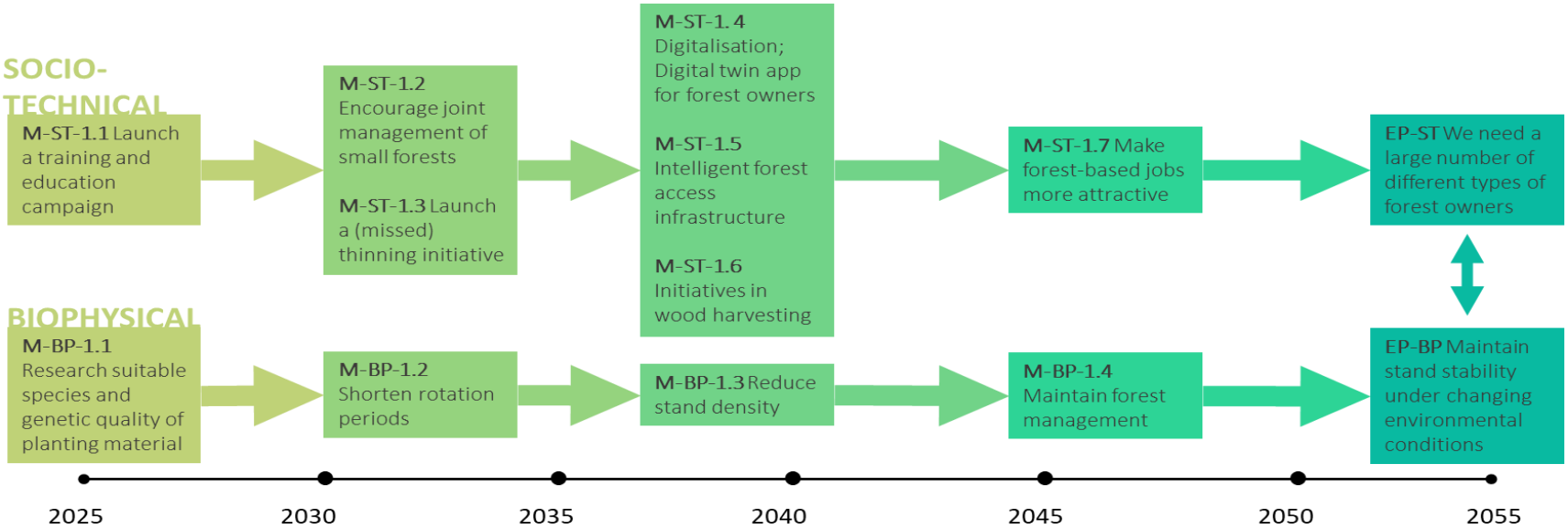
- Three futures were determined in the backcasting workshop: spruce mobilisation, deindustrialisation, and technology-driven innovation
- Key milestones across all futures: Mobilisation of small-scale forest owners, hardwood utilisation, cooperation and integration across the value chains through digitization

Backcasting – looking at not into the future

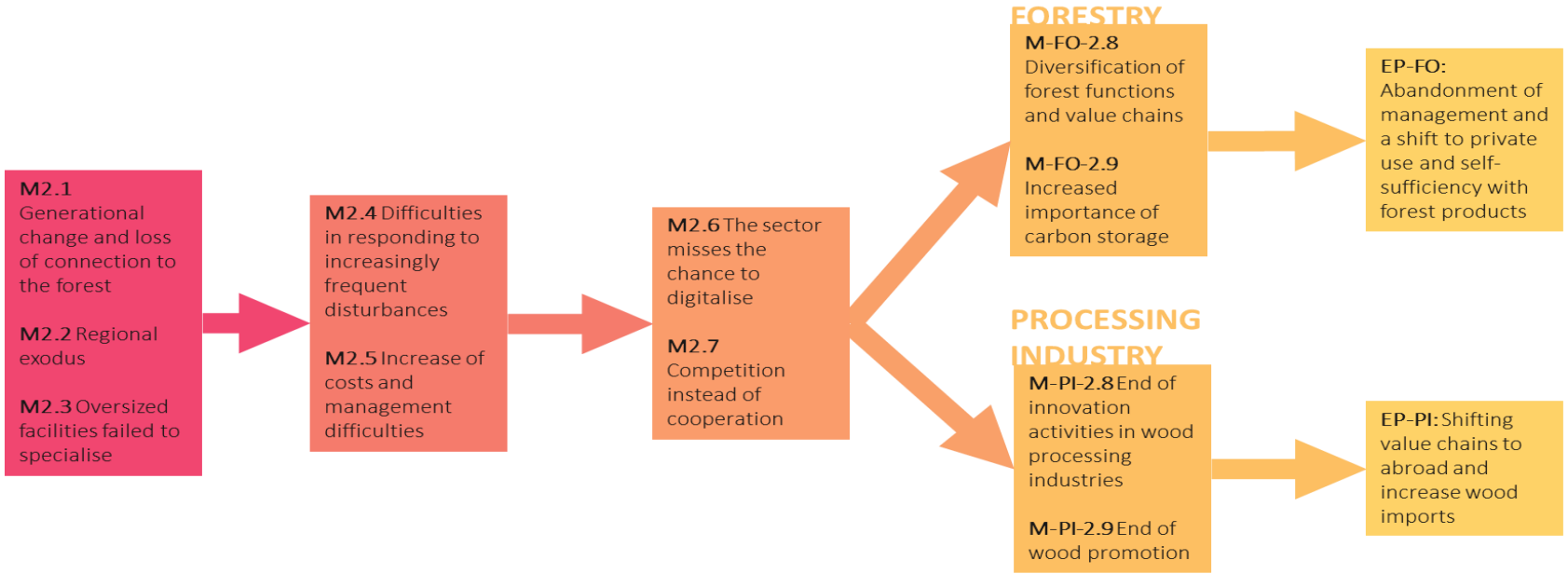




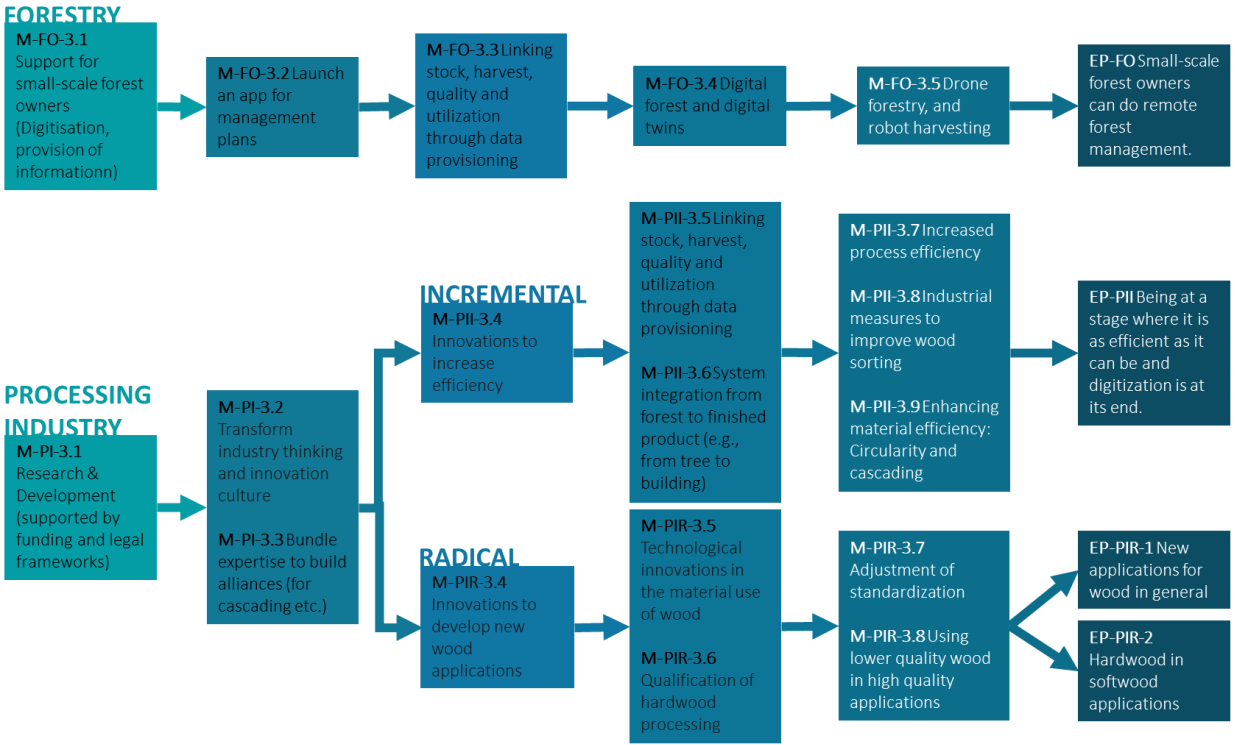
Spruce Mobilisation



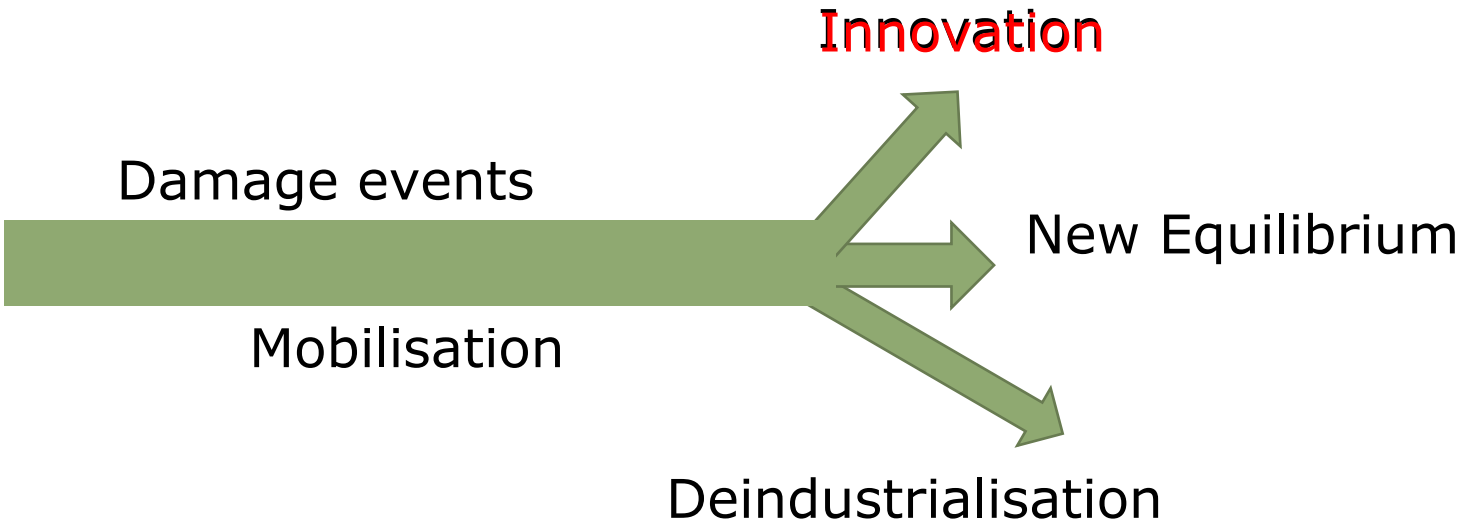
Deindustrialisation



Technology-driven Innovation



Overall Pathway





There are certainly some parallels between Peak Oil and Peak Spruce—but there are also differences, for example:

- Disasters tend to mask the problem (unlike political crises in the oil sector)
- Forest owners are less profit-driven
- Carbon sequestration through forest management



Future forest value chains and biomass use, important research fields:

1. Climate change and forest disturbances (e.g., Asada et al., 2023; García- Jácome et al., 2025; Boiger et al., 2025)
2. Adaptation and forest conversion (e.g., Hoeben et al., 2023; Hoeben et al., 2025; Boiger et al., submitted)
3. Management of increasing complexity (Yavorskaya et al., submitted; Brudermann et al., submitted)
4. Orientation towards carbon management (Boiger et al.,2024; Boiger et al., 2025)

Possible future wood use towards carbon management

- Relevance of wood for climate change mitigation
  - Carbon sequestration in forest [1]
  - Carbon storage in harvested wood products [1,2]
  - Substitution effects – saved emissions [3,4,5]



- Use of wood
  - Material use
  - Energetic use

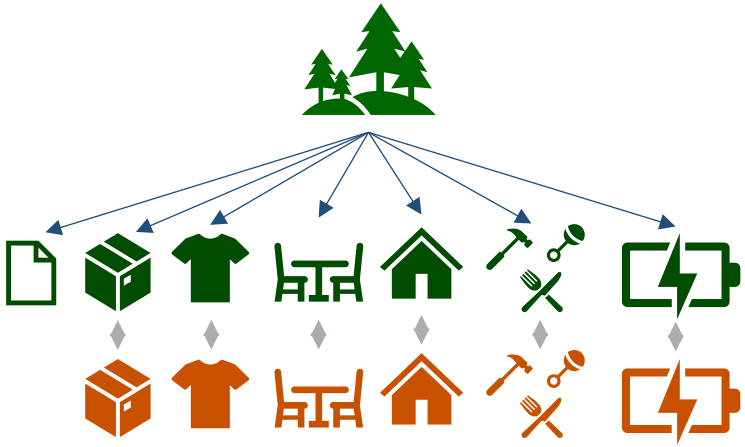


Wood as limited resource

[1] Leskinen, P., et al. (2018). Substitution effects of wood-based products in climate change mitigation. From Science to Policy, 7(November):28.
[2] Geng, A., et al. (2017). Review of carbon storage function of harvested wood products and the potential of wood substitution in greenhouse gas mitigation. Forest Policy and Economics, 85(159):192–200.
[3] Braun, M ., et al. (2016). A holistic assessment of greenhouse gas dynamics from forests to the effects of wood products use in Austria. Carbon Management, 7(5-6):271–283.
[4] Börjesson Hagberg, M., et al. (2016). Bioenergy futures in Sweden - Modeling integration scenarios for biofuel production. Energy, 109:1026–1039.
[5] Myllyviita, T., et al. (2021). Wood substitution potential in greenhouse gas emission reduction–review on current state and application of displacement factors. Forest Ecosystems, 8(1).

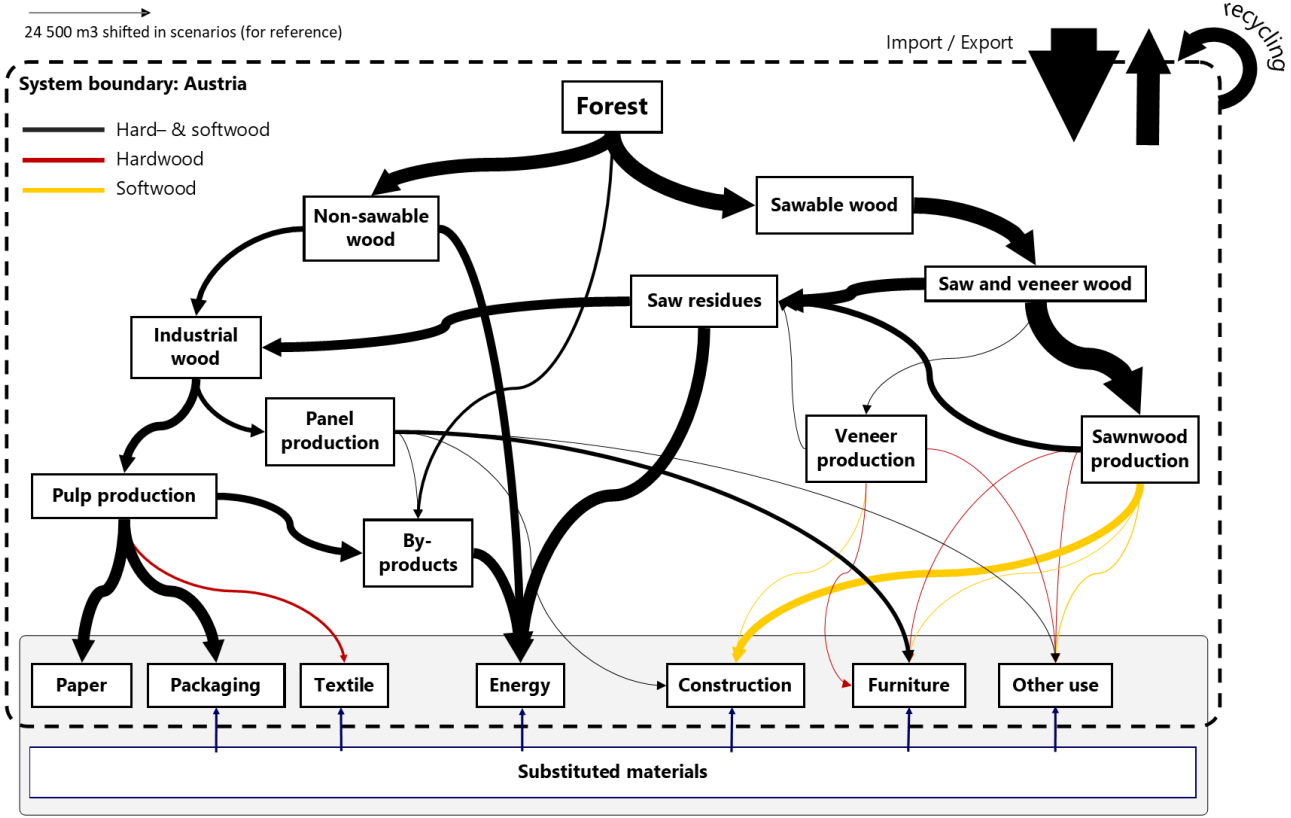
Method: System Dynamics Model

1. **Wood value chains of Austria**
   - From forest to wood-processing industries
2. **Substitution**
   - Alternative materials for production
3. **Impacts** related to wood value chains
   - GWP: fossile emissions



- Simultion of the GWP over the whole system

Method: System Dynamics Model

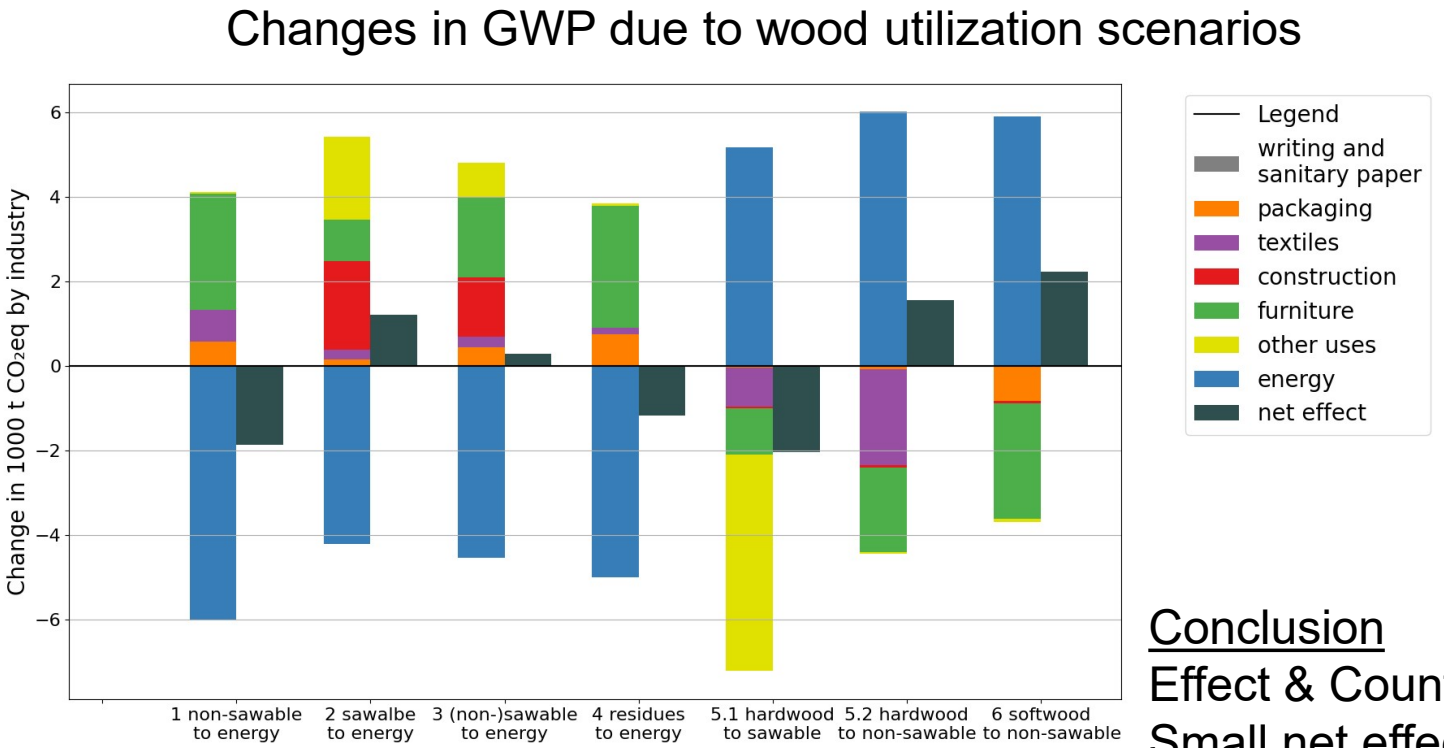


Scenarios

- **Shift of wood use**
  - Harvest constant
  - Import/Export constant
  - Shifts
    - Use of wood increased & substitute reduced
    - Effect on all industries modeled
- **Scenarios:**
  - **material vs. use for energy**

Scenario Nr.	Scenario name	Shift from to	Amount shifted	Scenario description
1	non-sawable to energy	Material to energy	10,000 tons	Roundwood from non-sawable wood (pulp and paper, panel) to energy
2	sawable to energy	Material to energy	10,000 tons	Roundwood from sawable wood to energy
3	(non-)sawable to energy	Material to energy	10,000 tons	Roundwood from non-sawable wood (50%) and sawable wood (50%) to energy
4	residues to energy	Material to energy	10,000 tons	Wood residues to energy instead of pulp&paper, panel
5.1	hardwood to sawable	Energy to material	10,000 tons	hardwood from energy to sawable wood
5.2	hardwood to non-sawable	Energy to material	10,000 tons	hardwood from energy to pulp and paper, textile and panel industry
6	softwood to non-sawable	Energy to material	10,000 tons	softwood from energy to pulp and paper and panel industry

Results



<u>Conclusion</u>

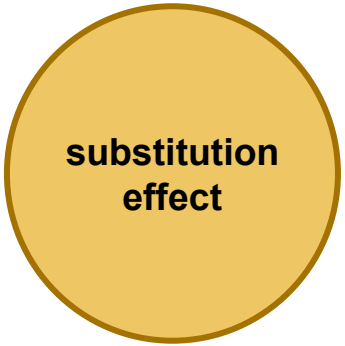
Effect & Counter-Effect

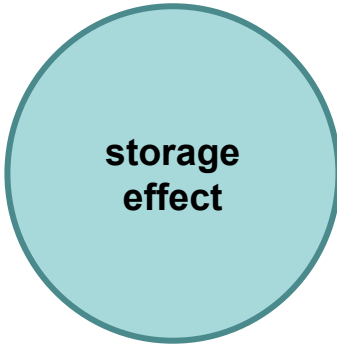
Small net effects

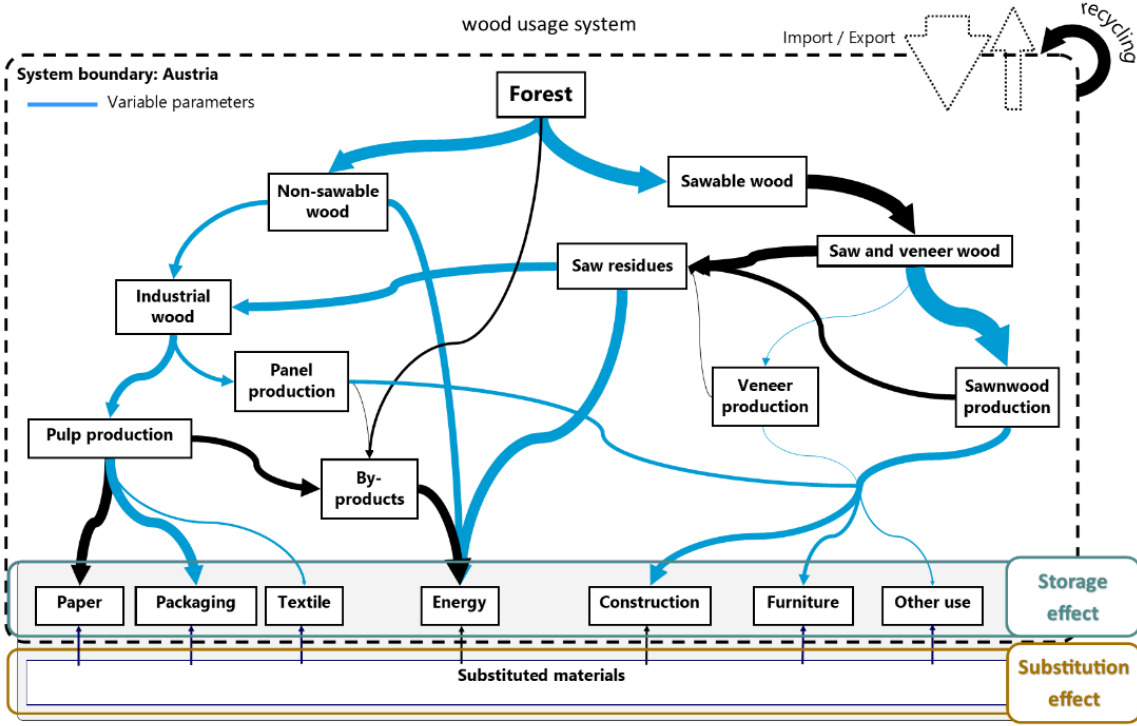
Multi-objective optimization – 2 goals

maximize

maximize



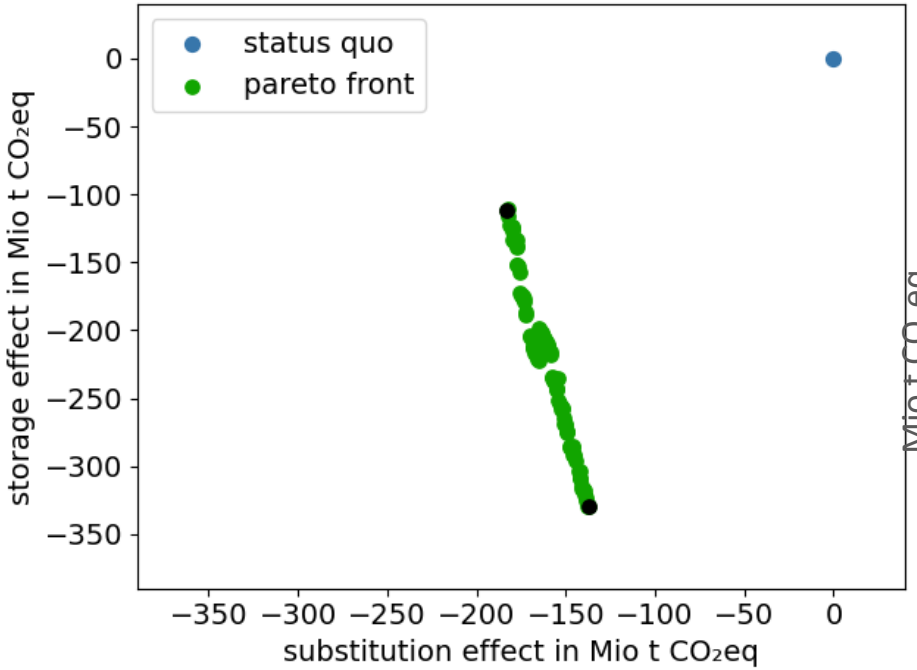


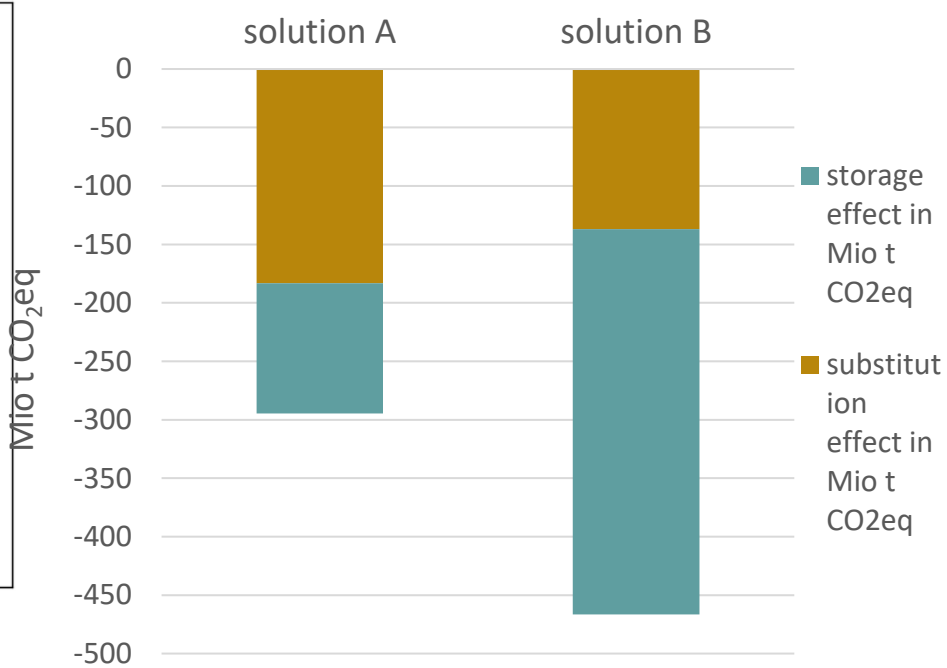


Variable parameters:

- wood distribution over value chains
- Upper/lower bounds & constraints

Maximum GHG emission reduction over 100 years





Conclusion

- The future remains unknown BUT some directions are more likely than others
- Systems Sciences Models help to identify bottlenecks and consequences of potential futures
- Future conditions are likely to foster circular use and according technologies, in particular:
  - Economic, Environmental and Social supply constrains
  - Carbon management

Engaging with the possible future is the foundation for purposefully shaping the actual future!



References

Asada, R., Hurmekoski, E., Hoeben, A. D., Patacca, M., Stern, T., & Toppinen, A. (2023). Resilient forest-based value chains? Econometric analysis of roundwood prices in five European countries in the era of natural disturbances. *Forest Policy and Economics, 153,* 102975. https://doi.org/10.1016/j.forpol.2023.102975

Asada & Stern (2018). Competitive bioeconomy? Comparing bio-based and non-bio-based primary sectors of the world. Journal of Ecological Economics, 149, pp. 120-128

Boiger et al., (2024) Shifting wood between material and energy use: Modeling the effects of substitution, J. Ind. Ecol., 28 (2024), pp. 1198-1211, 10.1111/jiec.13530

Boiger et al., (2025) Optimizing the utilization of harvested wood products for maximum greenhouse gas emission reduction in a bioeconomy: A multi-objective optimization approach, J. Environ. Manag., 373 (2025), Article 123424, 10.1016/j.jenvman.2024.123424

Boiger, T., Brudermann, A., Haeler. E., Savanovic, M., & Stern, T. (under review). *Will there be Peak Spruce?*

Brudermann, A., Boiger, T., Fank, J., Mair-Bauernfeind, C., & Stern, T. (under review). *Developing future visions for the Austrian wood value chain in light of 'Peak spruce' - A backcasting approach*

Boiger, T., Brudermann, A., Asada, R., Mohr, J., Seidl, R., Hurmekoski, E., & Stern, T. (2025). When forest disturbances hit wood value chains: Simulating tipping points in roundwood markets. *Mitigation and Adaptation Strategies for Global Change, 30*(8).

García-Jácome, S. P., Jankovský, M., Hoeben, A. D., Lindner, M., Uzquiano, S., Stern, T., ... Lloret, F. (2025). Forest value chain resilience from a local perspective in five European countries: Analysis of predictors and co-drivers. *Frontiers in Forests and Global Change, 7,* 1461932. https://doi.org/10.3389/ffgc.2025.1461932

Hoeben, A. D., Lautrup, M., Willig, J., García-Jácome, S. P., Jankovský, M., Toppinen, A., ... Stern, T. (2025). Stakeholder views of adaptation measures to improve climate resilience: Case study evidence from European wood value chains. *Forest Policy and Economics, 170,* 103379. https://doi.org/10.1016/j.forpol.2025.103379

Hoeben, A. D., Stern, T., & Lloret, F. (2023). A review of potential innovation pathways to enhance resilience in wood-based value chains. *Current Forestry Reports, 9,* 301–318.

Yavorskaya, V., Brudermann, A., Knoke, T., & Stern, T. (under review). *"It's complicated": Exploring a behavioral gap in small-scale forest management using multi-objective optimization.* Under review at *Environmental Management* (Springer).

THANK YOU!

Questions?

