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Resilient Forests for Society

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Predictors and co-drivers associated with the resilience of forest value chains: a local perspective

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Executive Summary

The health of European forests is threatened by an increasing frequency and severity of droughts, storms, pests, and other natural disturbances. Such disturbances cause deterioration of the overall vitality of the forests and their potential to deliver ecosystem services. Furthermore, short-term oversupply of wood is often followed by long-term supply shortages. In addition, the quality of wood is reduced by disturbances leading to an unfavourable value-weight-size relationship. Unfortunately, the knowledge and practical experience in coping with such value chain irregularities is scarce and scattered. This deliverable presents a mixed-method approach of quantitative and qualitative analyses of data gathered in seven case study forests around Europe, namely Bauges (FR), Galicia (ES), Finland (FI), Dublin Mountain forests (IE), Istria (HR), Kostelec nad Černými lesy (CZ), and Upper Rhine valley and foothills (DE). It aims to gain a better understanding of predictors and codrivers affecting the resilience of forest value chains on a local level. Against this backdrop, resilience is understood here as the ability of the exemplar to provide timber to their network partners and achieve an economic output delimited by sustainable forest resource management (upper resilience threshold) and ability to make a profit (lower resilience threshold). Based on case study overviews, we observed the association between predictors and co-drivers connected to the regulatory frameworks valid on the local level, timber harvesting and processing technologies available, the management of forest resources and silvicultural procedures, as well as those connected to the networks of customers, contractors, and other stakeholders over a timespan of approximately 20 years (2001-2021) and system variables. The results show that most forest enterprises are affected by natural disturbances, particularly in the continental case studies. In addition, large forest enterprises are able to absorb the effects of disturbances better than smaller enterprises. The economic output was found to be strongly related to the timber supply but was additionally affected by the market price and the impacts of disturbances on wood quality.As a result, the economic output has a greater variability over time than timber supply - large-scale disturbances caused price fluctuations, which subsequently amplified the fluctuating timber supply.

Keywords

regional forest value chain assessment, forest disturbances, timber supply, economic output.

1 Introduction

The RESONATE project aims to generate knowledge and practical decision support that fosters the resilience of both forest ecosystems and value chains. In this regard, WP3 deals with the resilience of forest value chains in Europe in their current and historical state. It addresses their resilience to immediate or short-term disturbances, as well as long-term trends, such as stressors derived from climate change through observing the stability of the outputs in terms of volumes and monetary units (T3.1; D3.2) on a national scale. On the local level (T3.2 leading to this deliverable D3.3) several resilience predictors and co-drivers were scrutinized, related to both ecosystem-specific, economic, technological, and network variables. Resilience predictors and co-drivers identified in the first two tasks of the WP will form a basis for the deliverable produced within T3.3 – a framework dedicated to achieving resilient forest value chains, which will then be evaluated by various stakeholder groups within T3.4. Within this deliverable, we used data found in D3.1 to create the unit values for the three timber quality grades, which were used to estimate the economic output of the forest enterprises (exemplars).

To develop a new approach for the operationalization of forest resilience, a broad focus on resilience assessment is needed. Also, the considerations need to be both short and long-term; besides providing decision-support for active resilience enhancement and operational guidelines for measuring and evaluating resilience, they also must balance social and environmental demands (Moser et al., 2019). According to the Operational Resilience Framework (output of the RESONATE project - D1.1) (Hurtado et al. 2022), companies in the forest-based sectors can promote selected resilience predictors that provide essential information on the stability of the supply chain. Enhancing the resilience of forests with the aforementioned predictors is, therefore, a key component of achieving a stable supply of timber and timber-derived products to the market and aligning the management of both forests and their value chains with development toward climate-adapted, sustainable, and carbon-neutral Europe.

The resulting deliverable 3.3 is the summary of our efforts to identify which predictors and co-drivers according to the Operational Resilience Framework (Hurtado et al., 2022)(D1.1) - are associated with timber supply and economic output of the exemplars on a local level. It is based on a combination of quantitative and qualitative analyses of data gathered from forest value chain exemplars in the case study regions, showcasing the differences and similarities between the patterns found in the seven case studies selected for this deliverable. In line with the Operational Resilience Framework , we describe the social-ecological system by a set of system variables and its resilience as the performance of the selected system variables

through periods when disturbances and stressors are acting (Carpenter et al. 2001), compared to a reference state. The reference state, in this case, corresponds to the maintenance in terms of stability of the timber supply and the economic output, as defined by their upper and lower resilience thresholds.

1.1 Research gap

European forests are facing major challenges such as warming temperature, extreme weather events amplified by extended periods of drought, windstorms expanding biotic threats, diseases, and over-exploitation (Lindner and Verkerk, 2021). Climate change and several socio-economic and ecological drivers increase the magnitude and impact of disturbances and extreme events. The subsequent forest degradation threatens biodiversity, timber production and other ecosystem services supplied by forests. This negatively affect forest management, and the stability and production capacity of forest value chains, constituting a major challenge to resilient social-ecological forest systems (Lindner et al., 2020).

In the event of a disturbance, forest value chains typically face a short-term oversupply of timber followed by supply shortages (Auer & Rauch, 2021). Forest value chain resilience is affected by economic and environmental limitations in wood trade, such as the inconvenient value-weight-size relation, which affects the efficiency of the logistical systems or motivation and actions of the forest owners, who might prefer short-term profits over its long-term sustainability (Hurmekoski et al., 2018) or external demand shocks. According to Hurmekoski et al. (2021), disturbances also cause a shift in the quality grade of supplied timber, which translates to lower value being extracted from the timber along the value chain. While we know that the increasing pressure on forest ecosystems and related value chains results in the deterioration of the overall vitality and ecosystem services provided by forests (Seidl et al., 2017), the knowledge and experience in handling the pressures (especially on the value chain side) is still sparse and far from satisfactory.

It is essential to act against climate change by taking adaptation measures in forest systems that foster their socio-economic and ecological resilience. Addressing the uncertainties created by climate change requires robust assessments and strategies among value chain actors. Prevention and improvement programs to fight climate change have great significance in mitigating disturbances to the forests and forest value chains (RESONATE, 2022).

The occurrence of a forest disturbance has a multitude of effects on the forest value chains. Notably, they cause fluctuations in the quantity and quality of the timber supply to the market (Fuchs et al. 2022). Both of these effects tend to lead to a short-term reduction of timber prices, which, accompanied by the higher costs of salvage logging, present considerable strain for the value chain actors. In T3.1, RESONATE researchers focused on identifying resilience

patterns on a national scale, providing knowledge on the effects of resilience predictors – factors which indicate resilience and can be managed by value chain actors – and co-drivers – factors that provide context and can be modified only over long periods of time or considerable efforts. Examples of these resilience predictors and co-drivers include disturbance-driven supply shocks, international trade, voluntary logging and the changes in quality grade ratios on the prices of assortments. However, whereas certain resilience predictors and co-drivers will affect forest value chains across scales (e.g., legislation and regulations), others can be region-specific (e.g., harvesting technologies, processing capacities, haulage capacities, tree species composition, network structure etc.). Albeit there are studies focused on the development of indicators describing climate change, disturbances, and human well-being (IIED and Garama 3C Ltd., 2014), or sustainable forest management (Victoria Department of Sustainability and Environment, 2007), an operational assessment that integrates ecological and forest value chain resilience is still missing. Considering that climate change and related forest disturbances will likely worsen in frequency and severity (IPCC, 2021), the motivation to improve the state of knowledge on the predictors and co-drivers that affect forest value chain resilience on a local level is strong.

1.2 Research objective

The presented deliverable aims to address the question of which (predictors and co-drivers) the variables are associated with the resilience of forest value chains on a local level in seven case studies around Europe, namely Bauges, (FR), Galicia (ES), Finland (FI), Ireland (IE), Istria (HR), Kostelec nad Černými lesy (CZ), and Upper Rhine valley and foothills (DE), from a local perspective. We aim to analyse the trends in (1) the stability of timber supplied by forest enterprises to their customer base and (2) the stability of the revenue streams generated by the forest enterprises in the conditions of stress caused by natural disturbances. Within this frame, we will observe the associations of variables connected to the valid regulatory frameworks (co-drivers) on the local level, and the following variables corresponding to resilience predictors: timber harvesting and processing technologies available to the exemplars, the management of forest resources and silvicultural aspects, as well as the characteristics to the networks of customers, contractors, and other stakeholders, created by the exemplars over the span of approximately 20 years (2001-2021).

2 Methodical approach

To meet the presented research objective, region-specific data was gathered by the case study representatives. Task 3.2 dealt with wood value chains. This means that we observed the ability of these value chains to withstand the timber supply shocks and other economic effects caused by the occurrence of natural disturbances. For this reason, the New Forest (UK) and Catalonia (ES) RESONATE case studies, where timber harvesting is limited, were excluded from the study. This meant that data was gathered in the remaining seven case studies – Bauges, (FR), Galicia (ES), Finland (FI), Ireland (IE), Istria (HR), Kostelec nad Černými lesy (CZ), and Upper Rhine valley and foothills (DE). Some selected case studies have small-scale wood processing industries were present (FR, DE, HR) with the use of timber confined within the region and some case studies have rather complex value chains, with diverse processing industries and access to international markets (CZ, FI, IE, ES).

2.1 Data gathering

To provide a common framework for data gathering a case study protocol was circulated (M9 of the RESONATE project). To make the results presented in D3.3 comparable, we needed to ensure that we were observing similar entities in different settings. The case studies, therefore, needed to be scaled to a similar size (“region”). A region, for the purposes of this study, was defined as a noncontinuous (but near one another) area of forests between ca 500 and 5,000 ha that is managed by a single exemplar (the forest holding). All data collected for T3.2 was related to the ‘’region’’ managed by the ‘’exemplar’’. In case secondary data were abundant on a larger scale, with similar management practices, it was possible to downscale these data to fit the said size of a region. Operational data (e.g., contracting of harvesting services, timber haulage, timber sales, logistics, etc.) were extended to include the exemplar’s network regardless of whether the actors connected to the exemplar operated inside or outside of the region.

The procedure of gathering data encompassed four steps (Figure 1). As preparation for step 1 (the secondary data investigation), a data request spreadsheet (Annex 1) was circulated, where case study representatives indicated the available data. Based on the indicated data availability, steps 2 and 3 were set in motion: data shells (empty datasets) were drafted, circulated, and populated with the data. The data shells (Annex 2) used in steps 2 and 3 were designed in line with the possibilities of the case study representatives to provide data. The filled-out datasets contained primary and secondary data complemented with case study reports, and survey outcomes (if necessary). In step 4, each case study representative delivered a filled-out dataset and a short case study report, to provide context for the dataset.

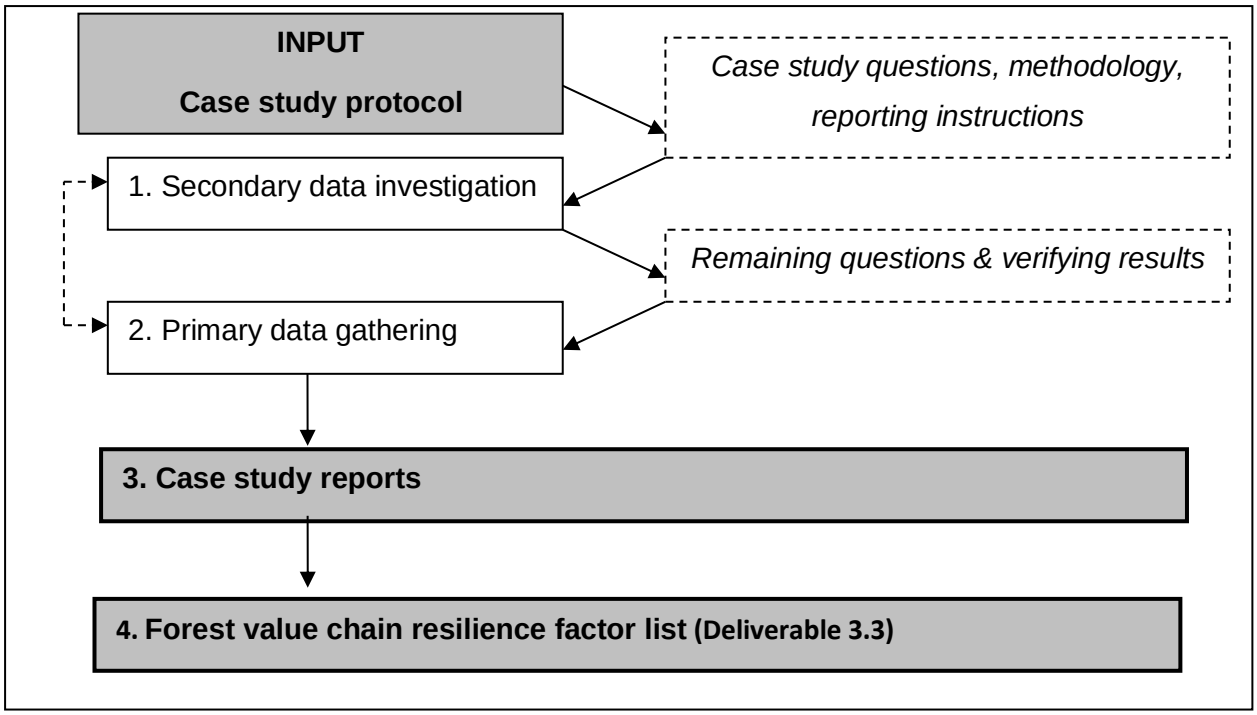

Figure 1 Workflow of the data gathering as outlined in the Case study protocol (MS9)

2.2 Data gathered by the case study representatives in the Case Study Datasets and Case Study Reports

The data included in the data shells (empty case study datasets) were related to four main groups of resilience predictors, do-drivers and system variables and restricted to a time range between 2001 and 2021. The sections were as follows (number in brackets relates to the number of issues requested to be collected):

- Regulatory framework (20),
- Forest harvesting practices (7),
- Forest management and silviculture practices (15),
- Networks of the value chain actors (13).

The data were supplemented by narrative descriptions and context provided in the relevant Case study reports.

The data requested in the data shells were based on what most case study representatives indicated as available in the data request spreadsheet. Moreover, we requested additional data from the case study representatives related to the Forest harvesting section – the volume of timber felled according to prescription (m^3 $year^{-1}$), and the volume of incidental felling (m^3 $year^{-1}$).

Overall, the case study representatives were able to supply data for most variables requested. However, the quality of the data varied greatly between case studies. In reality, the case study

representatives were able to secure mainly binary data for the regulatory framework section, and continuous data for the forest harvesting, forest management and silviculture, and the network sections.

2.3 Complementary data used

Besides data gathered directly for this deliverable, we also used data from other RESONATE tasks to assess the resilience of forest value chains on a local level. The data we used relates to the work performed within T3.1 (namely D3.1), which served as input for the estimation of the economic output of exemplars from timber sales in the particular case studies. The data we used were related to the unit values (EUR m^{-3}) for specific roundwood inputs or wood-based product outputs used in different processing types. From supplementary materials to D3.1, we extracted the data for import and export quantities and their related unit values by using the following parameters:

- Area: CZ, HR, FI, FR, DE, IE, ES
- Element: import value, import quantity, export value, export quantity
- Ud_group: Roundwood
- Ud_Items_harmonized: Industrial Roundwood (export/import) (5); Sawlogs and veneer logs (export/import) (1); Pulpwood, round and split (export/import); Wood fuel all species (3); Wood residues (export/import) (1).
- Years: 2001-2020
- Ud_value2: local currency.

Disturbance data was taken from files created by TUM for WP2 of the RESONATE project. They relate to the specific case study regions, though in certain cases, the spatial overlap between the region as defined by the MS9 for T3.2 and other RESONATE WPs was partial. From the records, we filtered out records related to damage caused by wind (including cyclonic storms, thunderstorms, and tornadoes), biotic agents (such as the *Ips typographus* bark beetle on Norway spruce – *Picea abies* L., H. Karst), and fire. We excluded the “harvest” type disturbances from the data, because, albeit these were disturbances from a forest ecosystems point of view, they did not cause economic harm to the exemplars or other value chain actors. We supplemented the data from WP2 by the additional collection of data on the volumes of incidental felling by the exemplars, namely CZ, DE, and HR. For other case studies, incidental fellings data were not possible to secure on a regional level.

2.4 Data analyses

After gathering the data, we processed them according to their presumed effects and classified them as resilience predictors, and co-drivers and analysed the performance through time of selected system variables.

2.4.1 Variables used

The system variables selected for this study were: (1) timber supply (TS) by the exemplar and (2) exemplar's economic output (EO) related to timber sales. The timber supply system variable was created as the sum of annual timber supply to other value chain actors for mechanical, chemical, and energy processing (data were gathered as part of T3.2 in the network section of the dataset). The economic output system variable was created according to equation (1).

$$EO_t = \sum Q_{it} \times p_{it} \quad (1)$$

In which the Economic output (in EUR per year (EUR year^{-1}) (*EO*) at year *t* equals the timber supplied for ith processing type (in physical units) (Q_{it}) multiplied by the unit value of timber supplied for ith processing type (EUR per physical unit) (p_{it}).

The unit value was created as the arithmetic means of the import and export unit values of Ud_items_harmonized for particular processing types weighted by the Ud_items_harmonized quantity and import and export quantity ratios. For mechanically processed timber, we used industrial roundwood (export/import) (5); sawlogs and veneer logs (export/import) (1) to create the relevant unit value, for chemical processing, we used pulpwood, round and split (export/import), and for energy processing, we used wood fuel all species (3); Wood residues (export/import) (1) to calculate the unit values.

According to Operational Resilience Framework, resilience is measured by comparing the observed performance of the system variables through time to a reference state, here delimited by upper and lower thresholds obtained from literature review. By established reference state served as a basis for comparisons of the system states after disturbances occurred. The upper threshold was based on sustainable forest resource management. For the *TS* system variable, this threshold was expressed as the mean prescribed logging volume of the time range (2001-2021) if the data was available. In cases when prescribed logging was unavailable, we set the upper threshold as the mean total timber stock divided by the typical rotation period in the country. For the *EO* system variable, it was expressed by equation (2)

$$EO_{URT} = \sum \bar{Q}_{pi} \times w_i \times p_i \quad (2)$$

Where the upper resilience threshold of the economic output (EUR; EO_{URT}) equals the sum of the mean prescribed felling volume of the time range weighted by the ratio of the timber for mechanical, chemical, and energy processing supplied by the exemplar to their customers (w_i) and the mean unit values per processing types.

The lower resilience thresholds were expressed as the ability of the exemplars to make a profit. According to the literature, the profitability of forest enterprises in the case studies was as follows: CZ – 14.05 %, HR – 4.11 %, FI – 77.46 %, FR – -1,54 %, DE – 10%, IE – 19 %. We therefore set the *TS* lower resilience threshold as X% of the minimal TS for the time range in each particular case study: CZ – 86%, HR – 96%, FI – 23%, FR – 100%, DE – 90%, IE – 81%. For the Galicia case study, we were not able to establish the reference state, due to a lack of data on prescribed logging or total timber stocks in the region. Resilience of forest value chains on a local level, was assessed by observing the trends and relationships between system variables (whether they exceeded their reference states) and several gathered resilience predictors and co-drivers. First-stage processing consisted of the classification of the gathered variables (system variables, predictors, co-drivers) according to their type into binary, categorical, and continuous data (Annex 1). Moreover, the predictors and co-drivers were categorized according to their presumed effects on the system variables, (i) effect on the short term (within 20 years), (ii) effect over the long term (longer than 20 years), and (iii) indirect effect or an effect in combination with other variables.

2.4.2 Relationships between the system variables and resilience predictors and co-drivers

The relationships between resilience predictors, co-drivers and system variables were tested by univariate regression and correlation analyses. Regression analysis is one of the statistical methods used to find whether variables are associated and a viable option for this study. In this case, the method was used to identify whether a relationship linear correlation exists between the pairs of continuous resilience predictors, co-drivers, and system variables. A statistically significant relationship points towards the association between the resilience of the regional forest value chains (as described by the development of the system variables) and the development of the particular resilience predictors and co-drivers.

3 Case study descriptions

3.1 Czech republic – Kostelec nad Černými lesy

3.1.1 Regulatory framework and legislation

In the Czech Republic, all historic management systems are allowed, with clear cut up to 1 ha in a single area or up to 2 ha in certain conditions (e.g., pine monocultures). After the final cut, the foresters must reforest the areas within two years and establish the stands after a/re-forestation within seven years. These time constraints were released to 5 and 10 years after the final cut from 2019 onwards due to the severe bark beetle outbreak in the country and the technical inability to perform the establishment in due time. Besides favouring artificial regeneration, Czech foresters are only allowed to use nursery material that originated in similar altitudinal zones and from holders of license to handle forest reproductive material. According to the Czech Forest Act (1995), foresters are mandated to introduce 20% of "meliorating and improving," mainly broadleaved tree species in the species mixture. This constituted a considerable burden at the start of the bark beetle outbreak since the forest nurseries were not prepared to satisfy the demand for saplings at first. There are no mandatory rotation periods in the country, although final cuts of mature forests cannot be performed before they reach the age of 80 years.

Any forest owner of more than 50 ha of forests must secure a forest management plan with a duration of ten years for their estates. For state and municipal forest enterprises, parts of the forest management plan are binding, e.g., the maximum total felling volume per planning period. Owners of smaller estates are allowed to follow less elaborate forest management outlines.

Considering the financial support, foresters can receive funding to manage their estates according to the principles of sustainable management. The subsidy scheme started in the year 2004 and from 2019, the subsidies were increased considerably to offset the timber

market collapse due to the short-term oversupply of timber caused by the severe bark beetle disturbance (Figure 2).

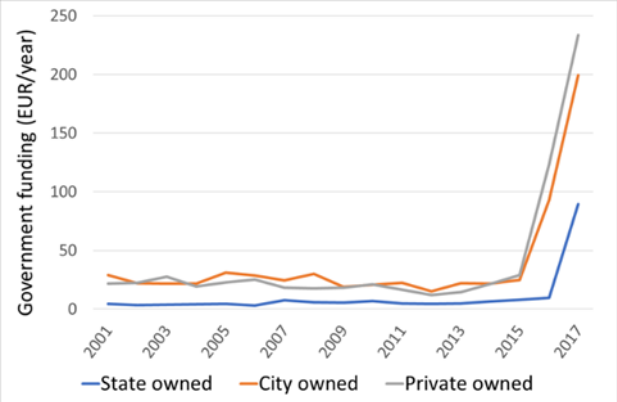

Figure 2 Funding received from the government according to the Ministry of Agriculture of the Czech Republic (2004-2021)

3.1.2 Forest management, silviculture and harvesting

The case study area is comprised of approximately 5000 ha of forest, several hectares of grassland, and various ponds used for fish production. The exemplar selected for the case study was the University Forest Enterprise of the Czech University of Life Sciences Prague. The exemplar manages forests in several districts. The main district, constituting about 77 % of all forests managed by the exemplar, contained forests formally owned by the Czech Republic. However, the forests in the main forest district were permanently set aside as "special-purpose forests" to be managed by the CZU for education, research, and other purposes.

The enterprise, while setting aside several hectares for research and education, manages most of the forests for profit. Besides timber production, the company operates a sawmill, forest and ornamental nurseries, provides hospitality services, manages game (including sales of game meat), and operates ponds for profit. Besides the production of various kinds of biomass, ecosystem services connected to recreation, culture, biodiversity protection and other ecosystem services are important in terms of management.

The forests itself are dominated by Norway spruce (mean share approximately 52% of stock volume, ranging from 45.24 % to 55.74 %) with overall low diversity (Figure 3). The total stock volume ranged from 275 to 304 m^3 ha^{-1} in the observed period, with harvestable stocks ranging from 8.47 to 10.53 m^3 ha^{-1}. The exemplar strives to convert these forests to more diverse, climate-adapted stands. However, the pace of the transformation is slow.

Forest stands are under PEFC certification since 2002 and are under clear-cut or shelterwood management systems, with a rotation period of approximately 120 years. The case study

region also contains a no-intervention beech nature reserve that occupies about 680 ha of forest land. The exemplar mostly uses artificial regeneration, with the overall declining trend of use of natural regeneration between 2001 and 2020 (Figure 4). The decline in the last years was caused by the need to reforest large areas of forests quickly due to the bark beetle disturbance.

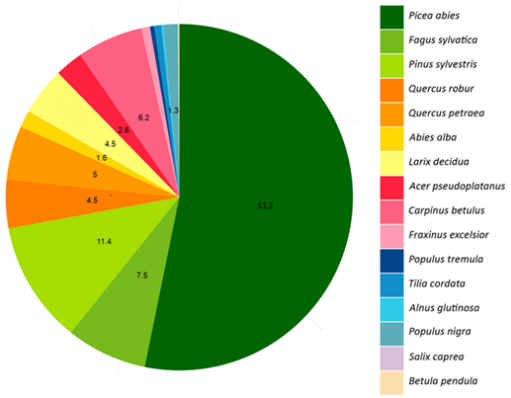

Figure 3 Tree species composition in the forests of the Czech case study

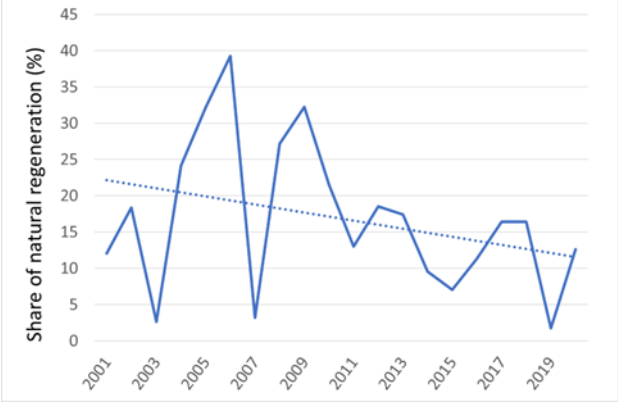

Figure 4 Share of natural regeneration used by the Czech exemplar

The annual forest harvesting volume prescribed by the forest management plan was 54,195 m^3 (ranging between 48,950 to 59,255 m^3). In reality, the volume of harvested timber was 52,574 m^3 (ranging between 42,721 (2001) and 90,421 m^3 (2020)), of which, approximately 50 % on average were incidental felling (21,216 m^3; between 2,195 (2012) and 89,796 m^3 (2020)) (Figure 5). The company harvested about 50 % of its timber using its own harvesting squads. The mean number of people employed in forest harvesting was 20, ranging from 17 (2019) to 26 (2002, 2003). The employees harvested the timber by the tree-length method (stem-only harvesting), which was then trucked to the sawmill. The company operated three to five universal skidders and four timber trucks. Overall, the universal skidder squads were able to extract 33,623 m^3 of timber per year on average (between 27,463 (2009) and 42,449 (2004) m^3). Besides the rather small portion of timber harvested by forest skidders

(approximately 3,500 m^3 per year), the company contracted cut-to-length machinery to conduct a substantial portion of the harvesting – from 2,924 (2004) to 46,259 (2020) m^3, 18,735 m^3 on average from 2004 onwards. Regarding timber trucking, the company used its own timber trucks for all timber processed in-house; timber supplied to third parties was partially trucked by contractors, though the share is unknown, and specific data could not be retrieved. shows the development of the usage of particular harvesting technologies by the company. The data gap visible for the year 2005 was due to the inability to retrieve harvesting data from that year, as the company changed its logistics management software, and the company representatives were unable to find the data exports from the year.

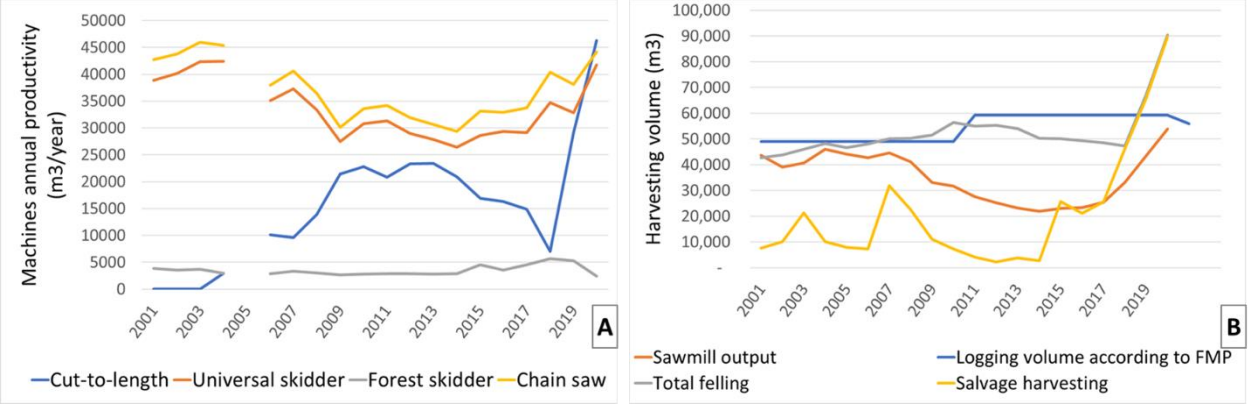

Figure 5 The volume of timber harvested by particular technologies at the CZ case study (A); the volume of harvested timber (prescribed, total, incidental) and sawmill output at the CZ case study (B)

The Czech exemplar produces and processes mainly softwood timber and first stage processed wood products. They operate a sawmill with an annual capacity to process about 50,000 m^3 of spruce timber. Other facilities at the conversion depot include a large log yard, mainly used as storage for the timber processed at the sawmill, a timber processing line, log debarker, drying units, a firewood production line, and others. The capacity of the sawmill is enough to process about 92 % of the timber, which the company would normally harvest according to forest management plan prescriptions. In reality, the sawmill utilization ranged between 44 (2014) and 108 % (2020) of its rated capacity, which accounted for roughly 69 % of the volume of harvested timber (between 44 in 2014 and 102 % in 2001) (Figure 5).

3.1.3 Value chain network

The network of the Czech exemplar related to the sale of timber consisted of several timber merchants, 2-8 large-scale and 4-6 small-scale sawmills, large-scale pulp and paper mills (both domestic and foreign), and one or two large-scale energy producers. Between 57 and 77 % of all timber supplied to the market was intended for mechanical processing (mostly supplied to the company's own sawmill). In contrast, timber of lower quality grades constituted less than half of the harvested volume (Figure 6). Notably, the company bought considerable

amounts of timber from third parties before the bark beetle disturbance manifested itself (approximately 16,288 m^3 $year^{-1}$ until 2016), to use the advantage of its processing capacities to either serve as input to its sawmill or to upgrade the timber and sell for a higher price without further processing into wood products. The volume of timber bought from third parties was subtracted from the timber supplied to the market, as it was not harvested from the forests that constitute the "region" for the purposes of this deliverable.

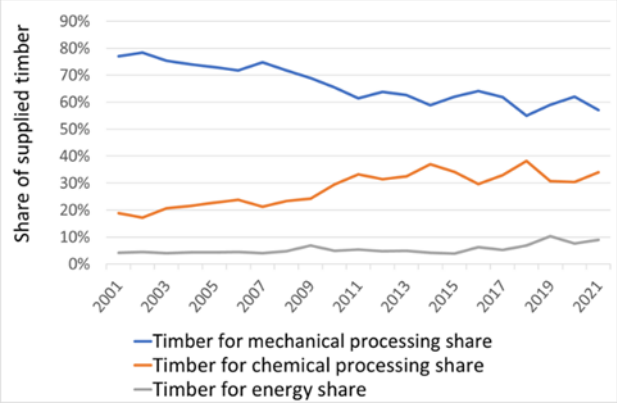

Figure 6 Shares of timber supplied for specific processing types at the CZ exemplar

Regarding other actors present in the exemplar's network, the company rents office space to a publishing company, which publishes forestry-related journals, books, and other publications and the company collaborates with other media (local). Regarding pedagogy, the exemplar provides research and educational infrastructure to CZU researchers and students, but collaborates with other education providers from Czechia, such as Forestry academy in Trutnov, Písek, Žlutice, and others for several activities. Tourism and cultural ecosystem services are important for the exemplar due to its proximity to Prague. The company maintains a network of maintained educational trails and collaborates with local tourism groups, civic society, and NGOs to promote these services. The company also provides fuelwood allotments to local people.

3.1.4 Disturbance regime

The region's most common disturbance agents were windthrows followed by bark beetle outbreaks. Historically, the disturbance size and rate did not present a substantial constraint for the management of regional forests in terms of the economic performance of the exemplar or the FVCs that start with the company. Between 2001 and 2014, the share of salvage logging due to all disturbance agents was overall 22 % per annum, with a spike to 64 % in 2007. However, in 2015, the share of salvage logging sharply increased to 51 %, around which it oscillated for three years to increase sharply again to nearly all (ca 98 %) logging carried out by the exemplar (Figure 7).

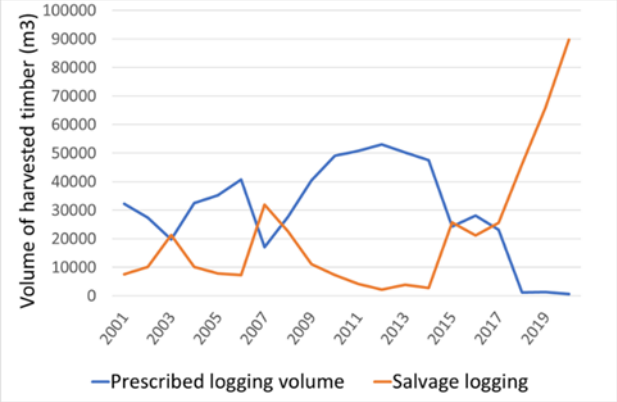

Figure 7 The share of voluntary and salvage logging performed by the CZ exemplar

The disturbance regime in the region followed the pattern visible throughout other regions of Czechia, as the large-scale bark beetle outbreaks spread from the eastern part of the country in Silesia and Moravia. Several variables likely triggered the outbreak, and its causes are still being investigated. It was fuelled by a series of hot and dry years, promoting the bark beetle swarming and decreasing natural tree defences. Figure 8 shows the bark beetle-damaged timber increase in Czechia in 2015, but notable increases started from 2017 onwards. As a result, the timber market experienced a supply shock lasting several years. Czech forest value chain actors experienced mixed effects – forest enterprises without their processing capacities had to accept the new price equilibrium. In contrast, processing facilities experienced an influx of affordable input material (Forest Economic Advisors Canada, 2020).

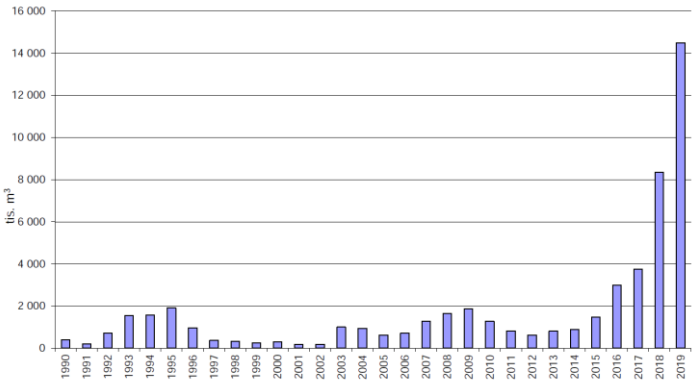

Figure 8 The volume of timber damaged by bark beetle in Czechia from the year 1990 onwards (Knizek and Liska, 2020).

That being said, the disturbances caused a shift in the quality of grades of the supplied timber typical for the disturbance agent (Lowell et al. 2010). This effect can be seen also on the regional level (Figure 6) and the increasing share of timber supplied by the exemplar to facilities that typically process lower-grade timber from 2017 onwards. Czech value chain actors without the kind of integration of resource production and processing capabilities as

observed for our exemplar could therefore experience a shortage of high-grade timber and had to resort to importing the assortments from abroad.

3.2 France – Bauges

3.2.1 Regulatory framework and legislation

The regulatory framework in France allows for the typical management systems – clear-cut, shelterwood, or selection. In the updated forest legislation of 2020, the permitted clear-cut area was reduced significantly from 10 ha to 0.5 ha. There are no mandatory regeneration/reforestation periods after final cuts. However, there are several recommendations related to the nursery materials used: the managers can use only forest reproductive materials from provenances appropriate for the “great ecological region” and “sylvoecoregion.” (Prefectural decree of the AURA region n°21-130 of 7 April 2021). Other materials can only be used only if the recommended material is not available. Specifically for mountainous forests, autochtonous species and natural regeneration are strongly recommended for regeneration/reforestation, with the exception of adapting the stands to climate change. Non-native species are only eligible for state aid if the economic, ecological or social objectives of the forest cannot be achieved by natural regeneration or planting of native species or when they contribute to strengthening the resilience of the forest stand to climate change.

From 2005 until 2020, limits for high forest regeneration were set to 50cm diameter at breast height target for spruce and fir species. For low forests (coppices) the limits were set to 40 years for beech and 50 years for oak species. Over the period 2005-2019, the communal forest of Saint-François-de-Sales has received 11,725 EUR/year (201 EUR/ha) of which:

- 10,250 EUR/year from the state for the improvement of the forest's service road,
- 1,475 EUR/year (during 2005-2019) from SYLV'ACCTES for the depressing of beech in the regeneration of coniferous trees. The total aid of 22,125 EUR was obtained in 2017.

SYLV'ACCTES is an association created in 2015, composed of public (Auvergne Rhône Alpes region, communities, public companies) and private (https://www.sylvacctes.org/) partners.

3.2.2 Forest management, silviculture and harvesting

The French case study is situated in the Natural regional park in the French Northern Pre-Alps. It consists of approximately 86 thousand ha of land, of which 55 thousand are forests. For task 3.2, the case study area selected was a communal forest of Saint-François-de-Sales.

The exemplar manages 875 ha of forests typical for the region. The forests are constituted of mainly fir and spruce (72 %), accompanied by beech on the plateaus. In addition, the slopes consist of fir and beech stands, whereas the screes and rocky outcrops are covered by stunted hardwood coppice (Figure 9). Due to the sharp gradient of conditions within the area, a diverse set of management goals is set making management challenging. The forests within the area are meant to produce timber, but recreational function is also quite important as it is visited by a rising number of tourists from nearby cities. As an indication, during winter, the trails are closed due to cross-country skiing trails. Consequently, the forest management needs to consider the safety of the visitors, e.g., by removing dangerous trees along the hiking, biking, and skiing trails. The observed period for the exemplar was reduced to span from 2005 to 2021, due to the lack of data from earlier years.

The total stock per hectare was 214 m^3 throughout the observed period, while harvestable stock (expressed as the volume of prescribed felling divided by the area to be covered by harvesting operations) ranged between 45 and 75 m^3 ha^{-1}. The exemplar used selection management system throughout the observed period and preferred harvesting softwood timber.

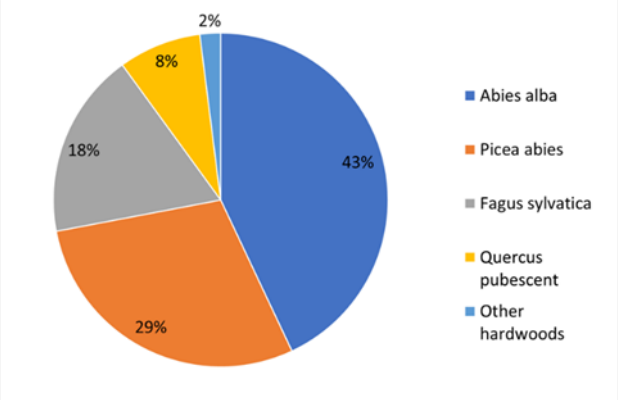

Figure 9 Tree species composition in the forests of the French case study

The company wants to convert the forests to be more diverse and climate-adapted. The exemplar promotes uneven-aged, mixed stands and biodiversity measures (e.g., keeping veteran trees. To tackle drought, they plant drought resistant species in disturbed areas. On the other hand, the communal forests use almost exclusively natural regeneration, and all of the forests are PEFC certified.

Data on performed forest harvesting in the exemplar's forests was available only between 2005 and 2018. Logging prescriptions were available for the period between 2005 and 2021. Prescribed logging ranged between 2,472 and 4,885 m^3 $year^{-1}$ (average 3,734 m^3 $year^{-1}$), while logging actually performed ranged between 1,040 and 9,073 m^3 $year^{-1}$ (average 3,862 m^3 year

(Figure 10). Little information is available on how the operations were performed. Due to the terrain configuration, chainsaw loggers and skidders were deployed for harvesting, the reported annual productivity of the chainsaw loggers was 6,600 m^3 $year^{-1}$ and the skidder annual productivity was 11,000 m^3 $year^{-1}$. The loggers were contractors and approximately ten of them worked in the exemplar's forests throughout the observed period. The number of machines that worked in forest harvesting within the Bauges case study was unknown, nor was the type of the machines used.

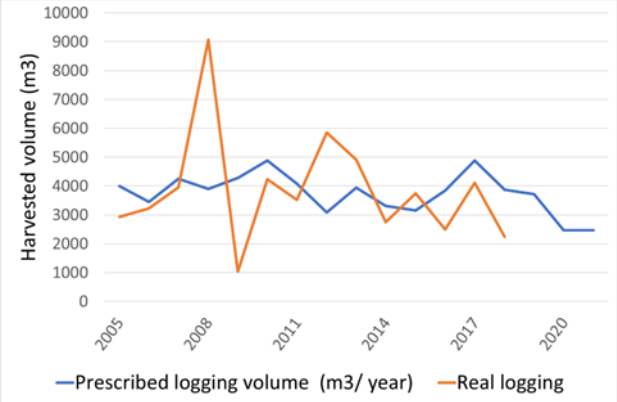

Figure 10 The volume of harvested timber (prescribed – blue line), total – orange line) at the FR case study

3.2.3 Value chain network

The value chain within the French case study was relatively small-scale, though according to the case study representative, the greater Bauges case study envelops about a hundred companies involved in the secondary transformation of wood (carpenters, joiners, cabinet makers, violin makers, sculptors). The exemplar markets their timber directly to two sawmills, and a single energy plant in the area, they do not sell the timber to merchants. The energy plant was introduced into the network in the year 2020. Other than that, the exemplar also provides timber allotments to members of the community. About 85 % of the timber was supplied to the sawmills, and the remainder was supplied as energy wood to energy producers (or community members) (Figure 11).

Due to the importance of tourism in the case study area, the exemplar has connections to tourist associations, organisations that manage cross-country ski resorts, NGOs, government bodies, as well as research organisations or extension services.

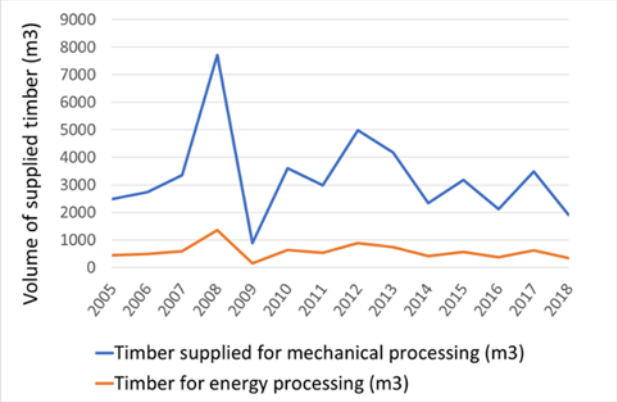

Figure 11 Timber supply development of the French exemplar over the observed period

3.2.4 Disturbance regime

The disturbances in the French case study were primarily due to windstorms and subsequent bark beetle outbreaks. The biotic disturbances also occurred in the conditions of the hot and dry climate, following the windstorm in 1999 and later from 2018 until the end of the observed period. The terrain configuration made it difficult to perform salvage logging, thus promoting the bark beetle outbreaks. It is important to note that the disturbance data available from D2.2 included the whole case study area of the Bauges massif (i.e., approximately 52,000 ha of forests), while the value chain data were restricted to a smaller area of forests managed by the exemplar selected. Therefore, the overlap between the disturbance data and the data gathered for T3.2 was only partial and could result in poor alignment. This can be seen in the years 2008-2010 and in 2018, where the overall disturbance data shows either greater or smaller increases in disturbance than timber supply data would suggest.

3.3 Germany – Upper Rhine valley

3.3.1 Regulatory framework and legislation

According to gathered data, the regulatory framework in Germany resembles that of the Czech Republic, although less strict and centralized. All historic management systems are allowed, with clear cut up to 1 ha in a single area, pending approval from regional forest offices. After the final cut, the foresters must reforest the areas within three years though there are no mandatory periods for establishing the stands after a/reforestation. No restrictions on the use of nursery material are set. Similarly, there are no mandatory rotation periods in the country, although final cuts of high forests cannot be performed before they reach maturity, which depends on the concrete species (e.g., conifers typically need to reach the age of 50 years and broadleaves 70 years to allow for a clear cut). Forest owners typically develop a forest management plan, which is binding when accepted. Legally, any changes to the management are subject to the approval of the regional forest office.

Considering the financial support foresters are awarded for the management of their estates, the schemes are very intricate, sources include state-provided, federal or EU-level funding. They target multiple measures, such as management and guidance support for forest owners, practices promoting sustainable forestry, nature protection, disturbance compensations, maintenance of forest roads, certification premiums, etc. However, the administrative load for the beneficiaries is quite high, so many forest owners do not opt for them.

3.3.2 Forest management, silviculture and harvesting

The case study area covers approximately 1,425 ha of forests in the low-elevation areas along the Rhine. The exemplar chosen was the community forests of Friesenheim. Friesenheim forests overall represent the typical ownership structure for the state of Baden-Württemberg, where approximately 60 % of forests are community-owned, 30 % are state-owned, and 10 % are private forests. Of the 1,425 ha o forests, 455 ha are under protection. Forest stands were certified by the PEFC and are under shelterwood management system. The company mostly uses artificial regeneration, however, about one third of all regeneration was natural. Besides timber production, other services, such as biodiversity or recreation are also important, notably in areas with a denser population. While the exemplar strives for climate adaptation, the applied measures are mostly undertaken on a trial-and-error basis.

The forests managed by the exemplar mainly consisted of beech (mean share approximately 37 % of stock volume, ranging from 35 % to 38 %), followed by fir (14-15 %), and Norway spruce (13-15 %) (Figure 12). While coniferous species had been mixed in large shares for timber production in the past, their dominance has shrunk due to dieback under repeated disturbances through storms, drought events and bark beetles. The total stock volume was 304 m^3 ha^{-1} in the observed period, with harvestable stocks of 40 m^3 ha^{-1}. The exemplar prefers cutting softwood tree species, little demand was perceived for hardwoods, except for high-grade oak timber, which was demanded for casket production.

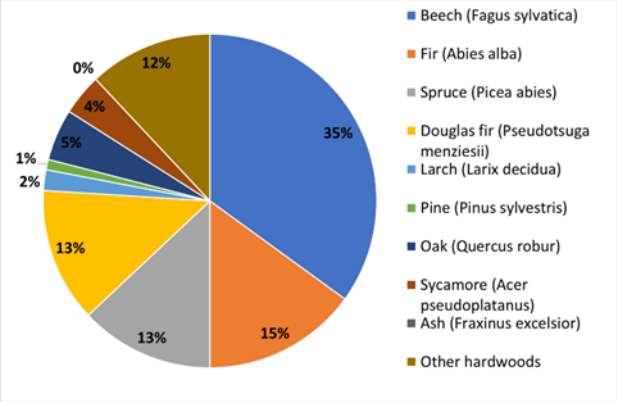

Figure 12 Tree species composition in the forests of the German exemplar

The exemplar prefers to harvest softwood timber. However, due to several disturbance events and subsequent spruce and other coniferous species decline, the availability of softwood for harvesting has become “a challenge”. The company rents three skidders (both converted farm tractors and dedicated forest skidders) for its six full-time and 12 seasonal employees. It contracts an external contractor who operates a skidder, a harvester, and a forwarder to carry out the harvesting operations. Most of the logging was carried out by motor-manual felling and skidder extraction, while the remainder was harvested by cut-to-length machines (Figure 13).

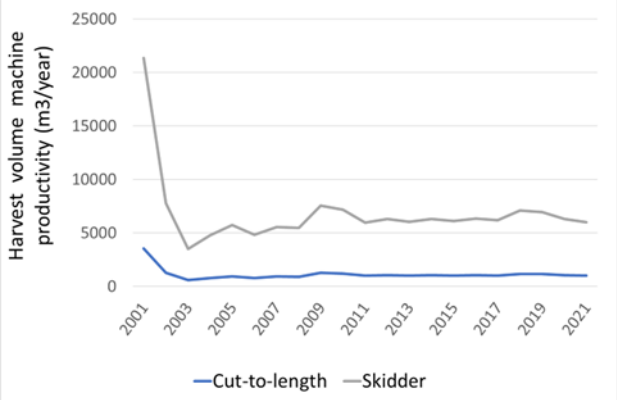

Figure 13 Technologies used for forest harvesting by the German exemplar

The mean annual forest harvesting volume prescribed by the forest management plan was 7,310 m^3 (ranging between 6,500 and 8,500 m^3). In reality, the mean volume of harvested timber was 9,130 m^3 $year^{-1}$ (ranging between 4,690 (2003) and 28,447 m^3 (2001)), of which, approximately 50 % on average were incidental felling (4,580 m^3; between 805 (2013) and 28,162 m^3 (2001)) (Figure 14).

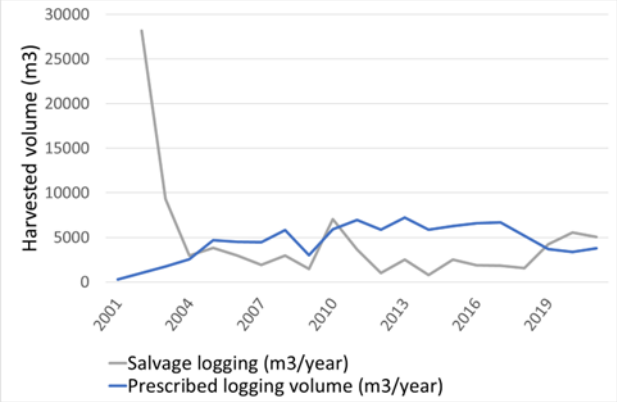

Figure 14 The development of salvage and voluntary logging throughout the observed period performed by the German exemplar

3.3.3 Value chain network

The network of the German exemplar related to the sale of timber consisted of several timber merchants, 15 mid-scale sawmills, three large-scale pulp and paper mills, and 11 small-scale energy producers in the region. Approximately 40 % of the exemplar's timber was supplied for mechanical processing, almost 50 % were supplied to energy producers, and the remainder were supplied to the pulp and paper mills. The amounts supplied can be seen in Figure 15.

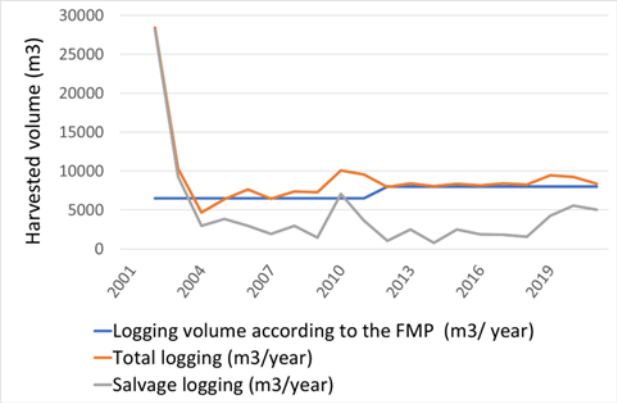

Figure 15 Shares of timber supplied for specific processing types at the German exemplar

Regarding other actors present in the exemplar's network, the company has relations with other forest enterprises, and interacts with the government indirectly, via legislation. Other than that, no other stakeholder groups were reported in the exemplar's network. As reported by the case study representative, the exemplar tries to involve local and regional stakeholders by informing them about planned management interventions and discussing long-term strategies on how to use the forest. There are also declarations of intent with other forest owners in the region mainly regarding disaster management, for example in relation to wildfires.

3.3.4 Disturbance regime

The region's most common disturbance agents were windthrows followed by bark beetle outbreaks. Two notable windstorms occurred within the observed period – Lothar (start of the period) and Kyrill (2007). Following the Lothar windstorm, salvage logging accounted for practically all harvesting operations conducted in 2001. In 2002, 90 % of all logging was still incidental. The second large-scale disturbance event occurred in 2009 (Kyrill windstorm) – 70 % of all logging was incidental (Figure 16). In 2018, the disturbance severity increased again due to drought and hot weather and the subsequent biotic pest outbreaks and persisted until the end of the observed period.

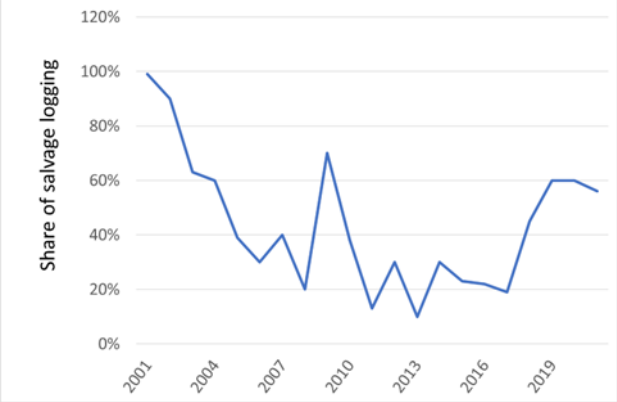

Figure 16 The share of salvage logging on total logging performed by the German exemplar

3.4 Finland – Kainuu

3.4.1 Regulatory framework and legislation

Finland has a well-regulated, production-oriented forestry. From 2014, all well-known management systems are allowed (clear-cut, shelterwood, selection or high-grade systems), whereas before only clear-cut and shelterwood systems (based on age limits and dimensions) were allowed. The rotation periods are not strictly mandated, but the forest managers are provided with guidance on the optimal age and cost-effectiveness of harvesting operations. After the final cut, the forest owners must reforest the areas within ten to 25 years. Before the novelisation of the Finnish Forest Act (2014), reforestation had to be concluded three years after a clear-cut. Legally, there are no restrictions on using material for regeneration, however the recommendation is to use Finnish nursery material. The Forest Act (2014) also allowed for the use of more tree species for reforestation if they are suitable for the biotope. The newly available species include Pinus sylvestris, Picea abies, Betula pendula, Populus tremula, Larix sibirica, Acer platanoides, Alnus glutinosa, Quercus robur, Ulmus laevis, Ulmus glabar, Tilia cordata, Fraxinus excelsior, and Populus x wettsteinii.

Forest management plans are mandatory for common forests and become binding unless a disturbance occurs. In other forests, developing a forest management plan is not required. However, foresters need to notify authorities regarding management measures at least ten days before the action being carried out.

Funding for forest management is available for securing wood production, management and restoration of forests, and supporting biodiversity improvement measures and nature conservation. Forest owners can receive subsidies for several activities, such as tending operations, maintenance of peatland ditch networks, forest road construction, fertilisation, and environmental improvement measures. The development of funding from the year 2014 until 2021 can be seen in Figure 17.

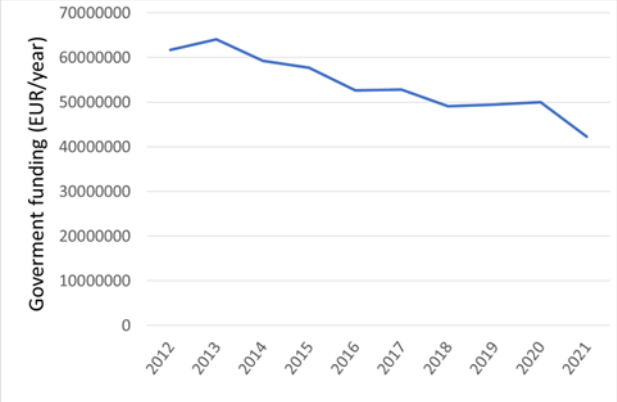

Figure 17 Funding received from the state by all forest owners in Finland as reported by the case study representative

3.4.2 Forest management, silviculture and harvesting

The case study is specific in that it is partially based on data from all of Finland (in areas that in the rest of the case studies are region-specific) and the data from an exemplar which operates in the northern Kainuu region of Finland. The case study area therefore covers an area far greater than the rest of the case studies analysed and the data needed to be scaled down to the approximate size of 5000 ha of forest. Kainuu region is located about 600 km from Helsinki and the forests found in the region are northern boreal forests. The exemplar selected was a state-owned forest company, which produced environmental services for a diverse set of customers. Aside from productive forests (total area of forests approximately 700 thousand ha), the exemplar also managed forests under protection (around 16 %).

The forests managed by the exemplar are dominated by 81% coniferous species, mainly pines (mean share approximately 59% of stock volume) (Figure 18). The total stock volume ranged from 57,962293 to 60,166,196 m^3 (83.29 m^3 ha^{-1}) in the observed period, with harvestable stocks ranging from 50,810,544 to 56,649,010 m^3 (78.42 m^3 ha^{-1}). The exemplar preferred cutting softwood tree species.

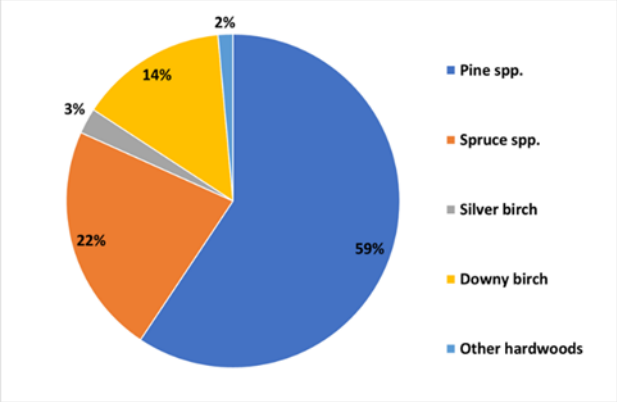

Figure 18 Tree species composition in the forests of the Finnish case study

All exemplar's forests were certified by the PEFC throughout the observed period. The case study region also contains forests under a protection regime – circa 16% of the area (155 thousand ha). The dominant management system was the clear-cut system, followed by the shelterwood system and from 2016, the selection system also began to be in use (Figure 19).

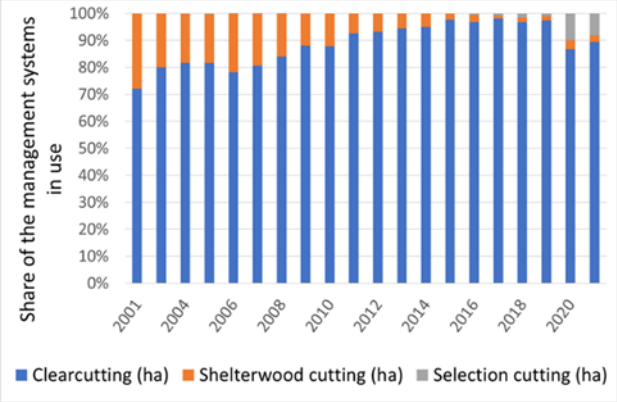

Figure 19 The share of management systems used by the Finnish exemplar

The company mostly used artificial regeneration, with a decreasing trend over the period when data were available (2015-2021) (Figure 20).

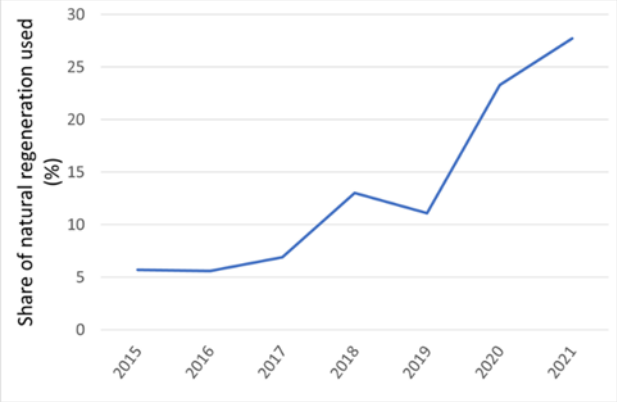

Figure 20 Share of natural regeneration used by the Finnish exemplar

Very little data were provided in the case study dataset regarding the forest harvesting, technologies used by the exemplar and their productivity. However, the exemplar is a large enterprise that is well-integrated to the national industries, so data available for the country are likely to be representative for the exemplar as well. The amount of timber harvested in the year 2021 by the exemplar was 1.25 million m^3 over bark and the area of forests where harvesting operations took place that year was 16,209 ha. The data on the area of harvests were available throughout the observed period (9,885 to 19,221 ha $year^{-1}$) and considering a stable harvesting rate, the volume of harvested timber ranged from 764,6845 to 1,486,968 m^3 $year^{-1}$ (average: 1,176,794 m^3 $year^{-1}$). Scaled to 5,000 ha, this represented between 69 and 134 ha $year^{-1}$ of the harvested area and between 5,336 and 10,375 m^3 $year^{-1}$ of harvested timber (Figure 21). Considering the fact that in the whole of Finland, the annual harvests amount to about 64 million m^3 of timber, the exemplar's share in this figure is about 1.8 %.

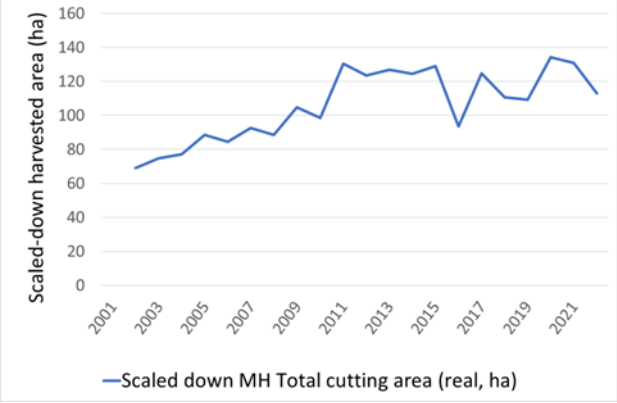

Figure 21 The area of harvests at the Finnish case study

Finland is the pioneer of using fully mechanized harvesting technologies and the cut-to-length harvesting method. In the year 2000, the share of mechanized harvesting overall was 94.5 %, while the remainder was harvested using motor-manual technologies. In the extraction phase of the timber production process, Örn (2003) reports that almost all timber is forwarded to the

roadside landings and the use of skidders accounts for only a few percent. The exemplar does not own any machines to perform harvesting operations and contracts 15 companies to carry out the harvesting. The exemplar representative estimated that about 100 workers conduct the harvesting in their forests. They report that over the observed period, the number of companies contracted by the exemplar had a decreasing trend due to the increasing productivity of the machines used.

3.4.3 Value chain network

The value chain network of the Finnish exemplar relates to the sale of timber consisted of timber merchants, 8 mid- and large-scale sawmills, 17-22 large-scale pulp and paper mills, and 9 mid- and large-scale energy producers. While the pulpwood was transported to longer distances, most sawn- and energy wood was processed locally. Since the data on timber supply was scarce, we used LUKE datasets on roundwood removals (LUKE, 2022) devise annual ratios between timber used for mechanical, chemical, and energy processing. In the Kainuu region between 2001 and 2021, 35 % of timber was used for mechanical processing, 59 % for chemical, and 6 % for energy processing (Figure 22).

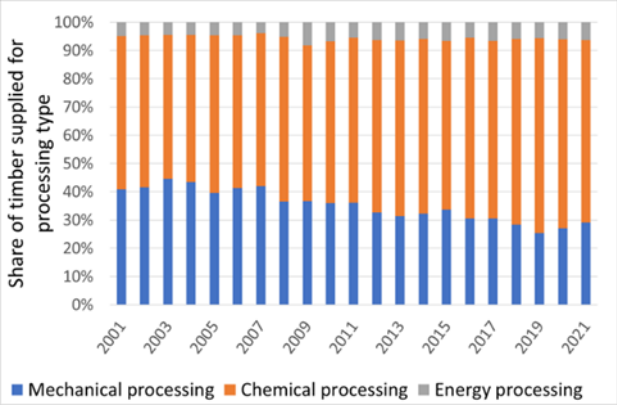

Figure 22 Shares of timber supplied for specific processing types at the Finnish exemplar

As a large-scale company, the exemplar was connected practically with all stakeholder groups mentioned in the data shell – other forest enterprises, government, extension services, NGOs, industrial partners, media, citizen groups, and research and development partners. The usage of land- and water areas managed by the exemplar are planned according to the government strategies and laws. Working with local and national stakeholders has become more robust and open. Among the more important stakeholder groups are Nature organisations, NGOs and government and municipal agencies and over time, the exemplar reported a decline in conflicts. In addition to this, the exemplar takes into account the general societal obligations in its actions concerning strategy, ownership policy alignments, diversity-, recreation-, reindeer- and Sami areas target definition with the help of support from information systems, dimensioning of operations, planning of actions and involving and including the stakeholders.

Considering research and development, the company has been active in this from the beginning of the 21st century. At first, the focus was on machinery development, while recently the focus shifted towards remote sensing, laser scanning and geographic information system mapping.

3.4.4 Disturbance regime

Finland was historically subject to disturbances caused by windstorms and snow-induced damage. Biotic agents include elks or moles, some fungal infestation and, to a limited extent, insects. Despite the potentially large spatial scale, the intensity of the disturbances tended to be limited, with only 4 % of the forests being disturbed sufficiently to substantially reduce the quality grades or quantity of the timber that could be extracted. Figure 23 shows that at the beginning of the observed period, a large-scale disturbance even occurred. This was attributed to the windstorm Janika. In the following years, the disturbances were relatively small-scale, caused by fire. A second sharp increase occurred in 2010, and the third one in 2012, both caused primarily by windstorms. However, considering the amount of timber removed from Finnish forests, the extent of these events was relatively low, roughly between eight and 11 per cent of the annual harvesting volumes. The storms caused secondary bark beetle outbreaks, which had, though not insignificant, limited effects (relative to the scale of Finnish forestry). The mean annual amount of timber damaged by the disturbance agent was 156 thousand m^3, ranging from approximately 2,000 to 633,000 m^3 $year^{-1}$.

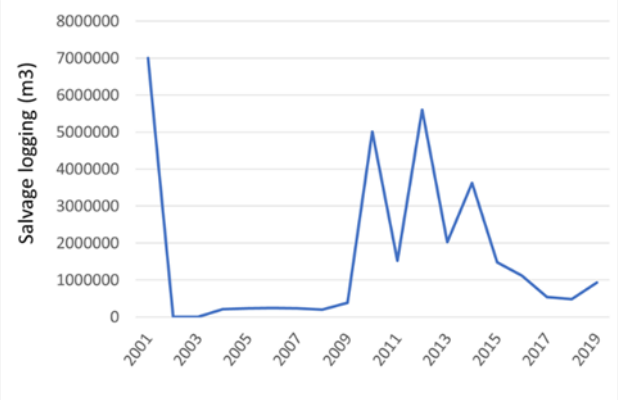

Figure 23 The volume of salvage logging in Finland according to DFDE dataset

3.5 Ireland – Dublin mountains

3.5.1 Regulatory framework and legislation

In Ireland, the regulatory framework is based on both national and international regulations. The original Irish Forest Act (1946) was replaced several times, the last iteration was published in 2014 (Irish Forest Act, 2014). Forestry in Ireland is relatively “new”, with most of the forests aged 30 years or less. All historic management systems are allowed, with clear cut up to 25

ha in a single area. After the final cut, the foresters must reforest the areas within two years, though there is no regulation on establishing the stands after a/re-forestation within a certain period of time. Irish foresters are bound to use only nursery material from holders of license to handle forest reproductive material and are incentivized to use domestic seed from registered seed stands. DAFM (2015a) contains detailed information on what type (origins/provenances per tree species) are eligible for grant aid in a/reforestation. Further requirements are specified in DAFM (2015b) for grant-aided native woodland establishment. Foresters are also incentivized to plant a minimum of 10 % of broadleaved species or 10 % of "diverse conifers" – species other than Sitka spruce and lodgepole pine – to be granted aid (DAFM 2015c).

There are no mandatory rotation periods in the country, nor is any forest owner obliged to write a forest management plan for their estates. When written, the forest management plan is valid for ten years. For state and municipal forest enterprises, parts of the forest management plan are binding, e.g., the maximum total felling volume per planning period. Owners of smaller estates are allowed to follow less extensive and elaborate forest management outlines.

Considering the financial support, Coillte and other agencies that own forests in the region of the Dublin Mountain Makeover project were awarded funding of approximately 250,000 € year^{-1} to rebuild the regional forests from the clearcut system to the continuous cover forestry system. The scheme started in the year 2009 and continued until the end of the observed period (Figure 24).

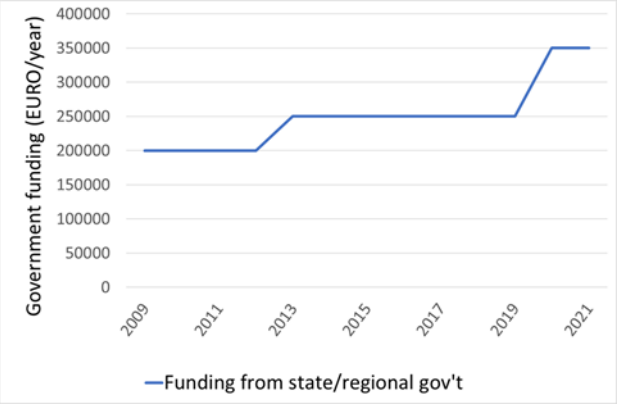

Figure 24 Funding received by the exemplars and other actors through the Dublin Mountain Makeover project

3.5.2 Forest management, silviculture and harvesting

The case study area contained approximately 900 ha of forests. The region selected for the deliverable is converted from a production-oriented, clear cutting and replanting cycle towards a continuous cover forestry model. The exemplar selected for the case study was the Coillte state forestry company. The exemplar manages forests all around Ireland. Within the case

study region, it manages about 50 % of the forests, the remainder being managed by private owners. The regional forests were planted originally in the 1940s and late 1960s.

The region is managed by a non-profit branch of Coillte – Coillte Nature. While the enterprise as a whole manages most of the forests for profit, Coillte Nature is responsible for forests that have other management goals. Besides the production of various kinds of biomass, ecosystem services connected to recreation, culture, biodiversity protection and other ecosystem services are important in terms of management.

Tree species composition data are only available from 2013 until 2021. The forests managed by the exemplar are rather monospecific – dominated by Sitka spruce (mean share approximately 59% of stock volume) with overall low diversity. About 10 % of tree species in the mix are broadleaved, others are coniferous (Figure 25). The aim is to achieve a 25 % share of broadleaved species in the mix by 2040. The total stock volume ranged from 108 to 278 m^3 ha^{-1} from 2014 to 2021, with harvestable stocks according to Irish management practices ranging from 75 to 159 m^3 ha^{-1}. The exemplar prefers cutting softwood tree species.

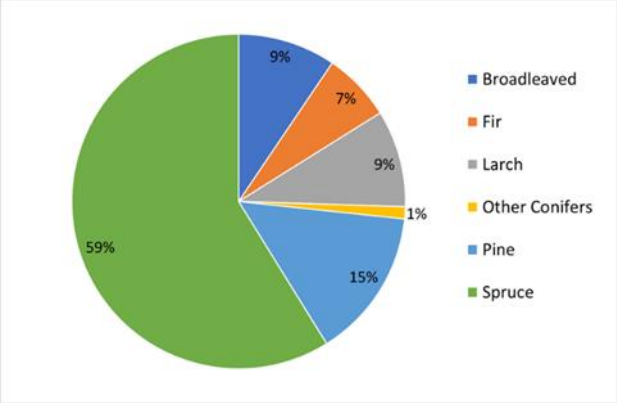

Figure 25 Tree species composition in the forests of the Irish case study

The company strives to convert these forests to more diverse stands that provide cultural and biodiversity services. Forest stands were certified by both the FSC and PEFC systems throughout the observed period (2001 to 2021) in the year 2002. The clear-cut management system continuously decreased from the initial 90 % representation in 2001 to 35 % in 2021 (Figure 26). The case study region also contains a reserve that occupies 10 % of forest land and an additional 15.65 ha of forests are under protection.

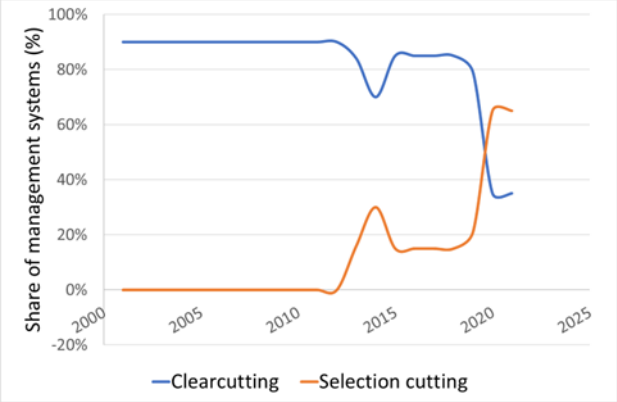

Figure 26 Share of management systems used by the Irish exemplar

The exemplar produces mainly softwood timber, which it markets on a national scale. The amount of timber harvested from the region ranged between 54 m^3 in 2008 and 10,142 m^3 in the year 2004, with an average harvested volume of 4,707 m^3 (Figure 27). The regional forests were harvested exclusively by cut-to-length machines, namely harvesters and forwarders. In the year 2021, woodchippers were used in the regional forests. No data were provided for the number of machines that worked in the region. Two data points were provided for the annual production of timber by harvesters – 22,000 m^3 $year^{-1}$ in the year 2005 and 44,000 m^3 $year^{-1}$ in the year 2021. Both numbers relate to the machines being used in clear-cuts.

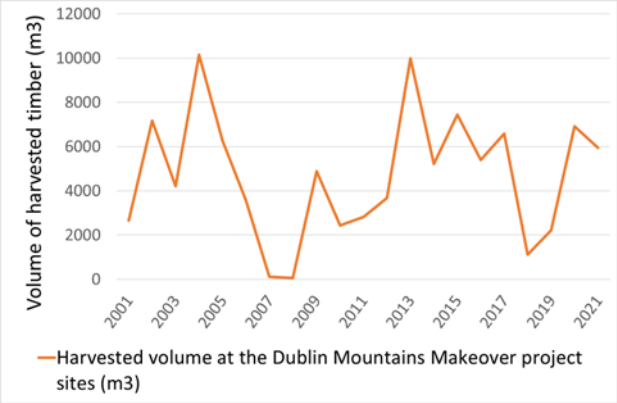

Figure 27 The volume of harvested timber at the Irish case study

The company harvested most of its timber using contractors. Throughout the observed period, two to three people who worked in forest harvesting were employed by the exemplar. The number of contractors used to carry out the harvesting operations was available only from 2017 onwards (four). The exemplar employed between 12 and 16 people overall from the year 2015 until the end of the observed period; earlier data on employment were not available.

3.5.3 Value chain network

The network of the Irish exemplar consists of eight sawmills (two small-, five medium-, and one large-scale), two panel mills for lower-grade timber (pulpwood), and one large-scale

energy producer introduced into the network in 2010. Approximately 70 % of timber harvested by the exemplar from the region were sawlogs, 29.3 % were pulp logs, and a constant 60 m^3 per year were supplied to the energy producer (Figure 28, Figure 29). The mean distance to the customers from the exemplar (headquarters to headquarters) was 140 km throughout the observed period.

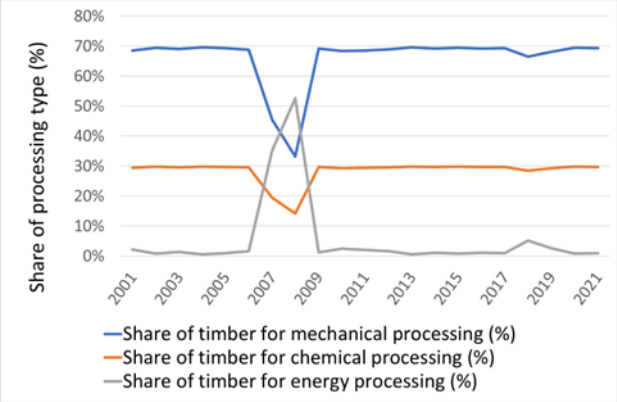

Figure 28 Share of timber supplied for mechanical, chemical, and energy processing

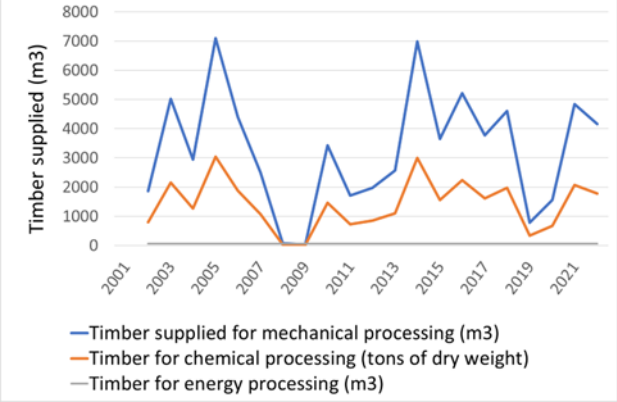

Figure 29 Timber supplied for specific processing types by the Irish exemplar

As a large state enterprise, Coillte has a wide array of actors it connects with. The company is connected to non-governmental organizations, other industry partners, media, citizen groups, tourist associations and other stakeholder groups. Regarding research and education, it collaborates with national and international institutions on projects that are externally funded or commercially important to the company. The Dublin Mountains Partnership, with Coillte as a partner, was launched in 2008. The project involves interaction between society, landowners, and the forest industry with the aim of improving the recreational experience for Dublin Mountains users. Several direct partners are involved – Coillte, South Dublin County Council, Dun Laoghaire Rathdown County Council, Dublin City Council, National Parks and Wildlife Service and the Dublin Mountains Initiative, since 2018 Fáilte Ireland has sat on the DMP Board.

3.5.4 Disturbance regime

Disturbance data was not available for the particular region. Because of this, we used disturbance data generated via the RESONATE project, which served for the creation of D2.2, Disturbance Hot-spot maps. The most common disturbance agent in Ireland was windthrow. In the years 2006-2011 and then 2018-2020, fire also was a minor disturbance agent. Typically, the average size of the windthrows was approximately 2,100 ha year^{-1}. The disturbance size ranged from 572 ha (2017) to 4,471 ha (2002). To compare, the mean size of fire-induced disturbances was less than 14 hectares. Irish forestry is historically affected mainly by windthrow disturbances. Data gathered within the RESONATE project (Irish case study factsheet) provided a limited range of data from the Coillte state forest enterprise related to salvage logged timber that was supplied to the market, considering the period observed within this study, data from 2001 to 2015 apply (Figure 30).

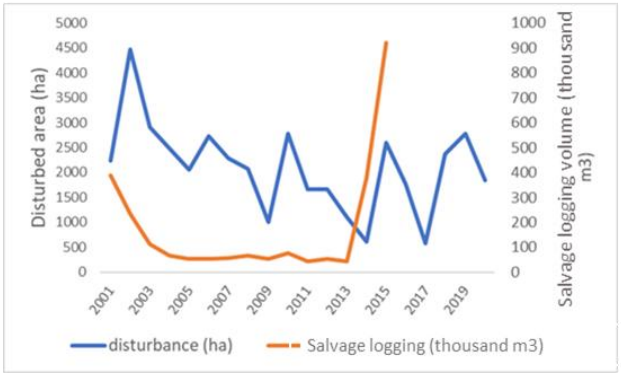

Figure 30 The area of Irish forests disturbed by wind and fire and the amount of salvage logging due to disturbances in Ireland

The disturbance regime in Ireland was relatively stable, with the exception of peaking wind-induced disturbance at the start of the observed period (which showed both in disturbed area and volume of salvage logging), breakages were periodic and relatively small-scale. However, the country's largest disturbance came in 2014 – storm Darwin. The effects of the storm can be seen in the sharp increase of salvage logging in the country, reaching 3.79 million m^3 in 2014 and further 9.20 million m^3 in 2015. According to McInerney (2014), the storm affected approximately 8,320 ha of forests (+/- 632 ha) and threw about 2 million m^3 of timber (+/- 159 thousand m^3).

3.6 Spain – Galícia

3.6.1 Regulatory framework and legislation

In Spain, the obligation to draft a Forest Management Plan was adopted in 2012. Its recommendations, however, are not binding for the actual forest management in Galicia. According to the dataset, all mentioned management systems are allowed, including the clear-

cut system. The clear-cut area in a single harvest is not limited. No regulations are present related to the mandatory rotation period. Neither did the provincial or national government limit the lower age final cuts for high or low forests. After the regeneration cut, the clear-cut areas need to be reforested within two years. The production and marketing of reproductive forest materials (seeds, plants and plant parts) is regulated by Spanish Royal Decree 289/2003, on the marketing of reproductive forest materials, which transposes into the legal system Spanish Council Directive 1999/105/EC. Based on Directive 1999/105/EC, several Regulations, Decisions and Recommendations have been established that develop technical aspects of said regulations (go to the EU legislation section). For species not regulated by the R.D. 289/2003, Law 30/2006, on seeds and nursery plants and phylogenetic resources, is applicable, which establishes as requirements the labelling of reproductive materials and their accompaniment of the corresponding supplier document. It also establishes that to market seeds or nursery plants. Professionals must be previously registered, developed in Royal Decree 1891/2008, which regulates the registration procedure for producers in the National Registry of Seed and Nursery Plant Producers.

There is no document that mandates that specific species must be mixed-in when establishing a forest and no general restrictions on using tree species apart those included in the Spanish Catalogue of Invasive Alien Species. Despite there being no general recommendation or limitation to the compositions of forest stands, there are some limitations to certain species in specific cases included in the Galician Forest law and other sectoral regulations. For example, agricultural land may not be forested (unless some limited cases of broadleaves), also Pine, Eucalyptus or Acacia may not exist in the buffer zone of 50 m from any building in the forest area, etc.

Galicia is an autonomous region of Spain that produces more than 9 million m^3 of timber annually. This constitutes more than 50 % of Spanish roundwood production, with the Galician forestry sector currently providing 12 % of industrial employment in the region. One of the main characteristics of the Galician Forest Sector is the high degree of private forest ownership in small, scattered holdings. According to Ambrosio et al. (2003), private forests comprise approximately 97 % of Galician forestlands, with about two-thirds of those in holdings of less than 2 ha (often in several non-continuous parcels, 80 % of them smaller than 0,5 ha). Approximately 30 % of private forests are owned by communities, as private collective ownership.

Forest financing in Galicia comes in different forms either from public or private funds. Regarding public financing, the main source is the funds from the Galician Ministry of Rural Affairs (Consellería do Medio Rural), which also includes the European co-financing

instruments as those related with CAP. Despite these public funding schemes, most of the forestry activities are self-funded by the owners of the land.

3.6.2 Forest management, silviculture and harvesting

In this case, the forest management unit area was 250 ha on average. The fragmented ownership pattern of family forestry, though having contributed greatly to livelihood in rural areas, now face severe challenges in profitability, changes in traditional practices to adapt to climate change, etc. Broadleaved and Eucalyptus sp. (59 %) are dominant in the area, followed by Pinus sp. (34%).

The case study area spans over 2 million ha, thus we scaled the data to 5,000 ha to fit the spatial range established in M9 of the RESONATE project.

Broadleaved species dominated in the region (Figure 31). Eucalyptus and other broadleaved species made up for 59 % of the mix. These were followed by pine sp. (34 %), of which, *Pinus pinaster* (25 %) was the most abundant. Other softwoods made for 7 %. The share of natural regeneration was 40 % between 2001 and 2015. From 2016 until 2021 its share decreased to 20 %. The most used management system was clear-cut, at 85 %, followed by shelterwood system with a proportion of 10 % and the selection system with 5 %.

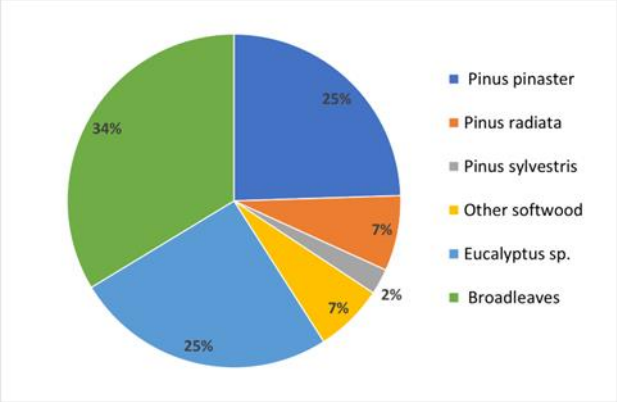

Figure 31 Tree species composition in the forests of the Galicia exemplar

In 2022 there are 361.612 ha PEFC (43.237 forest management units) and 90.961 ha FSC which considering both systems accounts for 23 % of Galician forests. Figure 32 shows the incremental increase of the share of certified forests. The share of protected areas was 19 % throughout the observed period, which was 374 thousand ha overall or 934.9 ha when scaled down to 5,000 ha.

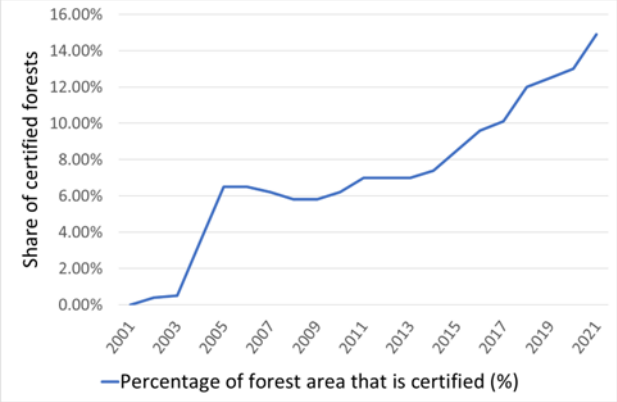

Figure 32 Percentage of forest area that is certified in 5000ha of Galician forests

According to the Smart Specialization Strategy of Galicia RIS-3-Galicia 2014-2020, one of the outstanding spatial and social singularities of Galicia with respect to the national and European context is the abundance of forest resources associated with economic sectors that have strong socio-economic roots in the territory. Two of its challenges are strictly linked to Forestry: 1. New model of Management of natural and cultural resources based on innovation Modernization of traditional Galician sectors through the introduction of innovations that affect the improvement of efficiency and performance in the use of endogenous resources and their reorientation towards alternative uses with greater added value in energy activities; aquaculture; pharmacological; cosmetics; food; and cultural. 2. New industrial model based on competitiveness and knowledge.

The first revision of the forest plan of Galicia approved in 2021 includes a specific axis for “statistics, training and forestry research” a sub-axis for “forestry research, development and innovation” and a program promoting forestry research, development and innovation.

The prescribed logging in Galicia increased from 5,190,000 m^3 (2001) to 10,022,184 m^3 (2021). Harvesting operations were performed by contractors and the number of people working in forest harvesting grew from 1,225 people (2001) to 4,726 (2021). The mean annual productivity of harvesters increased from 20,000 m^3 to 40,000 m^3 over the observed period, while the productivity of forwarders increased twofold, from 15,000 m^3 to 30,000 m^3. Skidder productivity was the same throughout the period at 24,000 m^3. Besides the increased productivity, the growing harvesting volumes were also extracted from forests by more machines. The number of harvesters doubled from 50 to 100, while the number of forwarders grew by one hundred machines, from 150 to 250 machines. Processors were also used in Galicia (the only case study where this type of machines operated) and their number ranged from 20 to 75. From 2007, feller-bunchers were also used (also the only occurrence of this machinery type. Traditional technologies, connected primarily with the stem-only or full tree harvesting methods (Figure 33). The number of skidders increased by two, to five units in 2021.

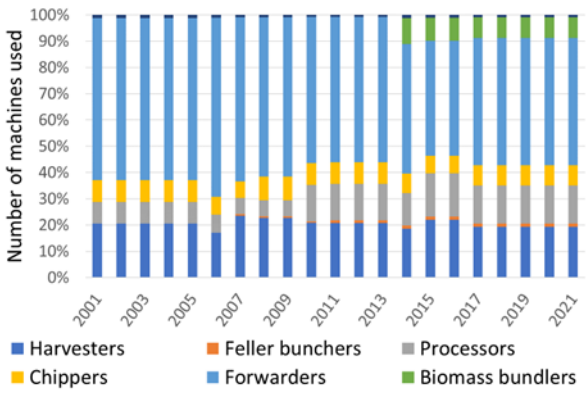

Figure 33 Number of machines used in Galicia between 2001and 2021

To be able to compare the supply chain data with other case studies, we present them in their scaled-down form. The logging prescription ranged from approximately 13,000 m^3 to 25,000 m^3 (Figure 34), the number of workers in harvesting was 12 on average, increasing four times throughout the observed period (Figure 35).

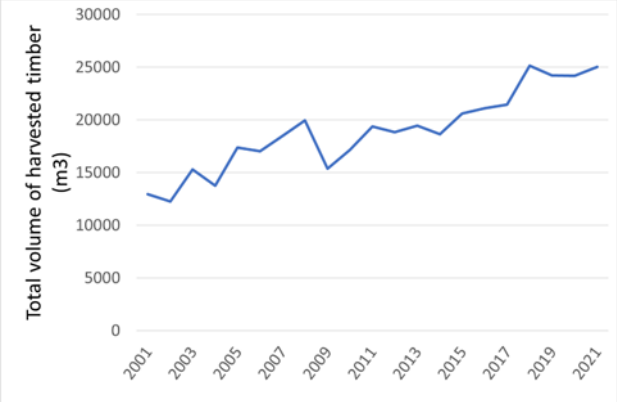

Figure 34 Total volume of harvested timber in Galicia between 2001 and 2021 (scaled to 5,000 ha)

This was caused by the increasing logging volumes and the fact that CTL technologies were used in the region from the beginning. Scaled down, the number of machines used in harvesting was two harvesters and one forwarder. The road network density was 25m ha^{-1}.

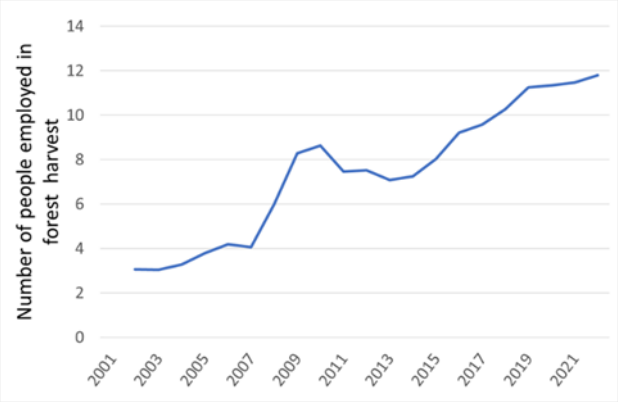

Figure 35 Number of people employed in forest harvesting in Galicia between 2001and 2021 (scaled to 5,000 ha)

3.6.3 Value chain network

The supply chain in Galicia is composed of numerous small-scale sawmills (between 489 (2001) and 300 (2021) or 1.22 to 0.75 scaled down). Pulp was processed in one large-scale pulp and paper mill, while energy was produced by three to four small- or large-scale companies. The volume of timber supplied to sawmills was 4.8 million m^3 $year^{-1}$ on average (18,071 m^3 $year^{-1}$ scaled-down), ranging from 2.89 to 6.16 million m^3 $year^{-1}$ (12,959 to 21,493 m^3 $year^{-1}$ scaled-down). The pulpwood supplied was 3 million m^3 $year^{-1}$ on average (3,562 m^3 $year^{-1}$ scaled-down), ranging from 1.3 to 1.6 million m^3 $year^{-1}$ (3,246 to 4,032 m^3 $year^{-1}$). Annually, the timber supplied for energy was 1.1 million m^3 $year^{-1}$ on average (2,794 m^3 $year^{-1}$ scaled-down), ranging from 1 to 1.3 million m^3 $year^{-1}$ (2,497 to 3,121 m^3 $year^{-1}$ scaled-down) (Figure 36).

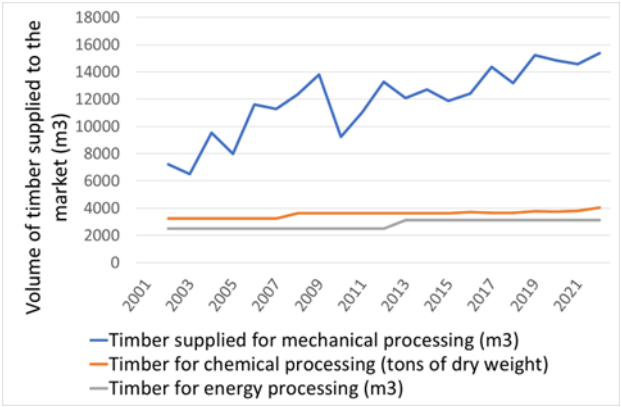

Figure 36 Volume of timber supplied to the market in Galicia between 2001 and 2021 (scaled down to 5,000 ha)

3.6.4 Disturbance regime

The greatest area disturbed in Galicia was in the year 2006, when approximately 43,000 ha were disturbed, while the smallest area of disturbances was reported in 2016 – approximately

11,700 ha (Figure 37). Considering the total forest area, the disturbances were rather small, affecting about 2.15 % of the area of forests.

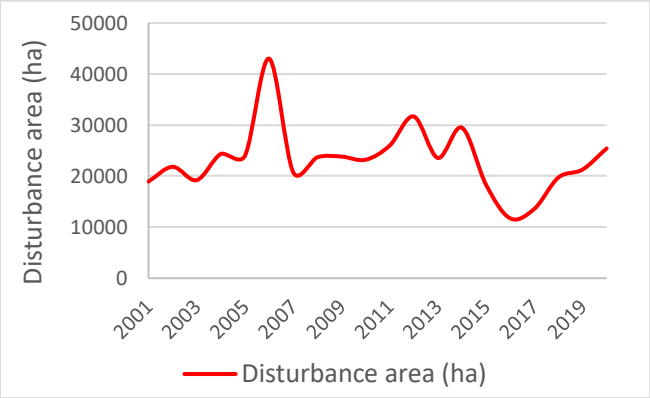

Figure 37 Area of disturbed forests in Galicia between the years 2001-2020

3.7 Croatia – Forest District Buzet

3.7.1 Regulatory framework and legislation

According to the gathered data, the regulatory framework resembles that of Czechia and Germany. Until 2004, the forest management plan was binding for the state-owned forests, but not for the “small-scale” (up to 300 ha) privately owned forests. After 2004, elaboration of a forest management plan was made mandatory. The works on making/elaborating management plans are financed by the state from the 'Green Tax' fund, except for the large-scale owners, who finance its elaboration on their own.

Only shelterwood and selection management systems are allowed. Clear-cutting is not allowed, except for transforming coppices to high forests, when the conversion was not possible through measures of the shelterwood system (valid from 2001 to 2005). In 2006, it became easier to transform degraded forests to high forests if natural regeneration was not possible. For example, when regenerating by dominant tree species seedlings in low-density stands, Black Alder, Willow and Poplar forest stands, *Robinia pseudoacacia* stands could be clear-cut and regenerated by root sprouts.

Regeneration of stands after final felling was set to two years, the stands were to be established within three years after regeneration. The nursery material used is governed by the Act on the forest reproductive material - NN 75/09, 61/11, 56/13 i 14/14. The restrictions on the species used is stated in the Rulebook on foreign species which may be placed on the market and invasive foreign species (2013) and the Act on the Prevention of the Introduction and Spread of Alien and Invasive Alien Species and their management - NN 15/18, 14/19 since 2018. The lower age limit for high forest final cut is differentiated according to species

(FM RuleBook 2018) and it depends on the prescribed rotation period of the forest stand main tree species.

State and regional funding from 2001 to 2005 was enabled by the so-called 'Green Tax'. Since 2006, the national government provided funding to private forest owners/managers if they ask for eligible forest management and silviculture operations in their forests - the Fund is collected by paying major economic beneficiaries tax for NWFS (Green Tax); and from 2019 Funds from Rural Development Fund were also available for State- and Private-owned forests.

3.7.2 Forest management, silviculture and harvesting

Croatian Forests Ltd. (Hrvatske šume d.o.o.) is a state company that manages public and most private forests in the Republic of Croatia. It is divided into 17 forest districts. Forest District Buzet manages the forest on the territory of Croatian case study – Istria + two islands outside Istrian Region. It is divided into nine forest management offices and two production units – sawmill and nursery. In Istria, FD Buzet manages 51,624 ha of public forests (42.8%) and 69,016 ha of private forests (57.2% of total of 120,640 ha). From the total amount of forests 63% are productive forests, 28% are protective forests and 9% are special purpose forests. Production unit Nursery Frančeskija grows seedlings for reforestation (beech, oak and pine), various horticultural plants and fruits (fig) for wholesalers. Production unit Sawmill Lanišće produces wooden planks, construction beams and other construction materials and firewood in the total amount of 6,000 m^3/year. The sawmill was bought in year 2020 after the closure of a private sawmill. Because the area of the exemplar exceeded the requested scale, the data gathered was scaled down to 5,000 ha.

The species composition in the exemplar's forests was diverse (Figure 38). Broadleaved species dominated, with 77 % representation. Beech and oaks represented 32.8 % and 28.01 %. Coniferous species were represented mainly by *Pinus nigra* (11.74 %) and *Pinus halepensis* (8.46 %).

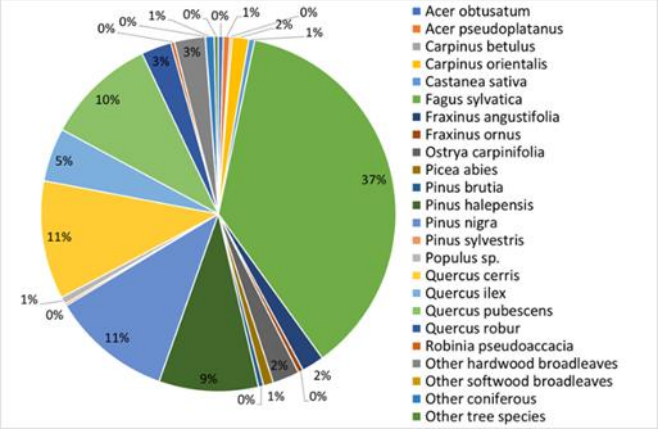

Figure 38 Tree species composition in Forest District Buzet Istria - Croatia

Forest area under protection increased from 9.03 % in 2001 to 39.18 % (2010) and then to 93.56 % (2021). The soil protection function was the most abundant – 40,492 ha (2021). Forests intended for protection of nature (reserves, nature parks, significant landscapes, park forests, forests for sports and recreation) constituted 12,782 ha (2021). All forests in Forest District Buzet were certified. Shelterwood and selection management systems were most used in the forest district (Figure 39). All regeneration was natural throughout the observed period.

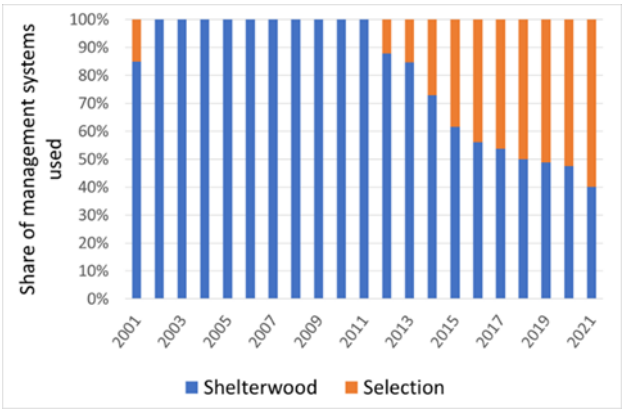

Figure 39 Share of forest management systems in Forest District Buzet Istria - Croatia

Hardwoods were harvested in the forest district more than softwood species, dominated by beech. Figure 40 shows the development of annual prescribed logging over the period, with an increase from 41,999 to 54 308 m^3. Interestingly, teal annual logging volumes was lower than prescriptions. Salvage logging operations were rather low and though there was some increase, it was not substantial.

In total, FD Buzet employed 161 persons (in 2021), of which 95 persons were directly or indirectly working in forest harvesting. Skidders were used to carry out harvesting operations primarily, which points towards the preference of the stem-only or full tree harvesting methods. The mean annual productivity of the skidders was 26,440 m^3. Until 2019, animal logging was also used in the forest district, and since 2016, CTL technologies were also regularly deployed,

however, in a limited extent (900 m^3 – 4000 m^3 annually). The share of particular technologies is shown in Figure 40.

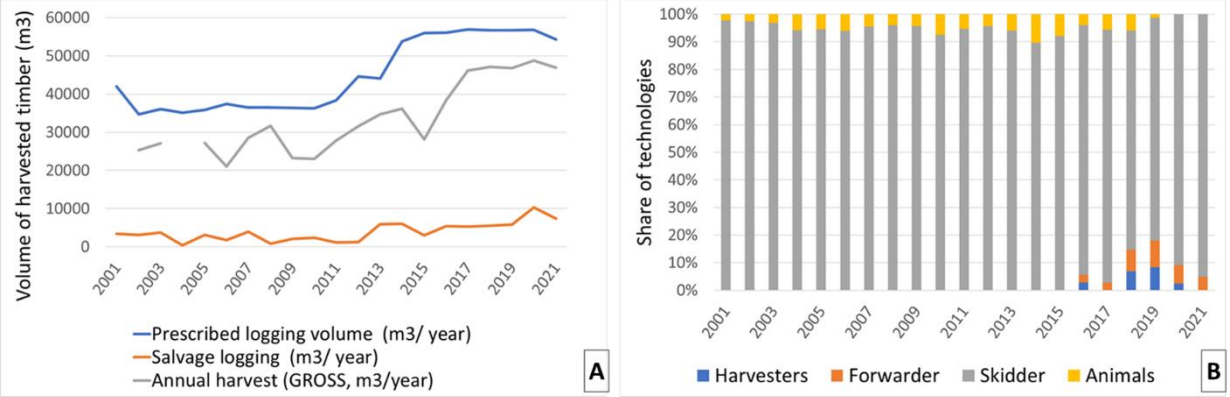

Figure 40 Share of harvesting machines used in Forest District Buzet Istria – Croatia (A); share technologies in harvesting (B).

3.7.3 Value chain network

The network of the exemplar was rather limited. The timber supply data shows that timber was supplied mainly for energy processing (approximately 45 %), followed by timber supplied for mechanical processing (39 %) and about 16 % was supplied for pulp and paper production. The number of connections and the size of sawmills, pulp and paper mills or energy producers could not be retrieved by the case study representative. From 2020, the forest district began operating their own mid-sized sawmill. Sawmill Lanišće produced wooden planks, construction beams and other construction materials and firewood in the total amount of 6,000 m^3/year. No timber was supplied to pulp and paper mills or energy producers.

3.7.4 Disturbance regime

The Istria region is under heavy pressure from climate change. Historically, no severe past disturbances were recorded. However, the whole area suffers from long and severe drought periods. The forest fires are a persistent threat, but the fire protection system was successful in monitoring and fighting fires in their very beginning, thus the extent of the disturbance was rather small. Second threat comes from the lack of management in private forests, which are generally very small in size and the owners are mainly old and with little interest in forest management.

4 Results

4.1 The resilience of the timber supply and economic output of the Czech exemplar

The first system variable describes the ability of the exemplar to provide a stable supply of timber to the processing facilities (including their own sawmill) further in the value chain under the stress of natural disturbances and volatile market conditions. In the Czech regulatory

framework, the exemplar must perform salvage logging after a disturbance (Forest Act 1995) and reforest within two years. In a severe disturbance, the exemplar's storage capacities would get saturated. The exemplar would therefore need to supply the timber to the market to avoid quality decrease and fines from the authorities for non-compliance.

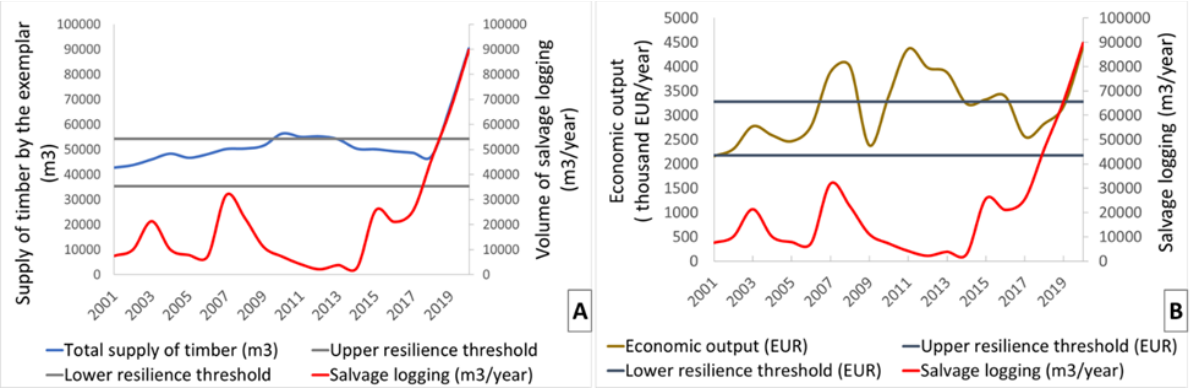

Figure 41 Timber supplied to the market by the Czech exemplar over the observed period (A); Economic output of the exemplar in the observed period (B).

On Figure 41, it can be seen that the less extensive disturbances in 2003 and 2007/08, which were local, did not result in a substantial increase in the total amount of timber harvested and subsequently supplied by the company to the market. The year 2015 noted the changing trend and the large-scale bark beetle disturbance reaching the exemplar. From this year on, salvage logging constituted approximately 50 % of the total harvests and in 2018, its share increased further, to 98-99 % of all logging. In 2019, the volume of harvested timber exceeded the upper resilience threshold (see page 12), thus making the management unsustainable over the long term. The resilience thresholds were set to 35,360 m^3 $year^{-1}$ (lower threshold) and 54,195 m^3 $year^{-1}$ (upper resilience threshold).

The Economic output system variable relates to the estimated stability of the revenue stream of the exemplar for the sale of timber. This system variable relates to the ability of the exemplar to salvage value from the timber streams under the conditions of disturbance. Besides the stability of the timber supply, disturbances can cause a shift in the quality of produced assortments, increasing the amount of timber sold for lower unit prices. Another effect, caused by the supply shock, is the lowering of prices. Since price data were not collected in this study, we used a proxy unit value based on import/export data, as described in the methodology section (page 11) of the deliverable.

Figure 41 also shows the development of the economic output system variable over the observed period. The resilience thresholds for the variable were set to 2,175,758 EUR $year^{-1}$ (lower threshold) and 3,275,800 EUR $year^{-1}$ (upper threshold). In the observed period, we can see three periods when the economic output exceeded the upper resilience threshold – in the

year 2008-2009, when the exemplar processed excess timber from disturbance that occurred. Considering that the timber supply was within its reference state, we do not regard this as a breach of the reference state in terms of sustainable forest management. However, during the second and third periods when the upper threshold was exceeded, the exemplar also exceeded the upper resilience threshold for timber supply stability, thus exceeding the amount of timber that could be sustainably sourced from the region's forests.

The correlation between timber supply and economic output reported a strong positive correlation with total logging (*Table 1* and Table 2). Based on the data, we expected this kind of relation for both system variables, the more is logged the more is supplied and is also reflected in the output. Logging prescription and voluntary logging showed a moderate positive correlation with both system variables. Despite the relatively low amount of funding received by the state, the relationship was statistically significant, with a moderately strong positive correlation. In terms of tree species composition, the share of coniferous species showed a moderate positive correlation with the economic output. Interestingly, the share of coniferous species had no relationship with timber supply. Regarding technologies used, a strong positive correlation was observed between the timber supply system variable and the annual production by the cut-to-length machines, while its relationship with economic output was moderately strong. The shift towards using fully mechanized, more productive, harvesting technologies caused a decline of the number of people working in harvesting operations and the correlation of the number of people employed in harvesting with timber supply was strong and negative. Looking at the network of the value chain actors connected to the exemplar, the number of connections to processing facilities had no significant relationship with either of the system variables.

Table 1 Results of the correlation analyses between timber supply system variable and resilience predictors and co-drivers available in the dataset retrieved from the Czech exemplar. Significant relationships highlighted by bold typeface.

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year	**0.53**	**0.01**
Logging volume according to FMP	**P**	m3/year	**0.43**	**0.05**
Prescribed logging volume	**P**	m3/year	0.03	0.90
Total logging	**P**	m3/year	**0.75**	**0.00**
Salvage logging	**P**	m3/year	-0.12	0.62
People employed in forest harvesting	**P**	number	**-0.75**	**0.00**
Total people employed by the exemplar	**P**	number	**-0.74**	**0.00**
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year	**0.75**	**0.00**
Volume of timber skidded from forests by Universal skidders	**P**	m3/year	-0.35	0.12

Volume of timber skidded from the forests by forest skidders	**P**	m3/year	**-0.45**	**0.04**
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year	-0.35	0.12
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year	-0.25	0.28
Road network density	**C**	m/ha	0.04	0.86
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%	-0.18	0.44
Share of coniferous species in the tree species composition	**C**	%	0.25	0.27
Use of clear-cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Share of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	**0.43**	**0.05**
Total timber stocks	**C**	m3/ha	0.25	0.27
Sawmills in exemplar's network	**P**	number	0.20	0.39

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

Table 2 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the Czech exemplar. Significant relationships highlighted by bold typeface.

Predictor/ co-driver	**Type of variable**	**Unit**		
			R	p
Funding from state	**C**	€/year	**0.63**	**0.00**
Logging volume according to FMP	**P**	m3/year	0.42	0.06
Prescribed logging volume	**P**	m3/year	0.21	0.36
Total logging	**P**	m3/year	**0.77**	**0.00**
Salvage logging	**P**	m3/year	0.16	0.49
People employed in forest harvesting	**P**	number	**-0.57**	**0.01**
Total people employed by the exemplar	**P**	number	**-0.44**	**0.05**
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by cut-to-length machinery	**P**	m3/year	**0.65**	**0.00**
Volume of timber skidded from forests by Universal skidders	**P**	m3/year	0.09	0.68
Volume of timber skidded from the forests by forest skidders	**P**	m3/year	-0.08	0.73
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year	0.06	0.78
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year	-0.01	0.95
Road network density	**C**	m/ha	0.15	0.51
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%	-0.05	0.84
Share of coniferous species in the tree species composition	**C**	%	**0.53**	**0.01**
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		

Harvestable timber stocks	**C**	m3/ha	0.42	0.06
Total timber stocks	**C**	m3/ha	**0.53**	**0.01**
Sawmills in exemplar's network	**P**	number	0.35	0.12

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

4.2 The resilience of the timber supply and economic output of the French exemplar

The timber supply of the exemplar had high variability, which would point towards their need to process timber damaged by a forest disturbance. Unfortunately, the data on salvage logging performed by the exemplar were not available, and the disturbance data relates to the whole Bauges case study area. Therefore, we cannot fully verify whether the exemplar really performed salvage logging after disturbances, or it was logging as planned. On the other hand, the volume and area of logging prescriptions are available (Figure 42), and we can see that the prescriptions did not align with the harvesting data in the periods mentioned. This, then, hints at salvage logging being performed by the exemplar. Considering that the disturbance data for the Bauges case study shows increased disturbance area during these periods, we can infer that the disturbances also affected the forests managed by the exemplar, although their sites overlapped with the location of the exemplar's forests to a varying degree.

The variability of the timber supply over time points towards the exemplar's limited ability to suppress the supply of timber to the market in conditions of ongoing disturbances. To comply with the need to stay within the long-term harvesting "quota," they reduced the harvesting volume in the following year (or tried to in the case of the period between 2015 and 2019). If, however, a disturbance was still ongoing, they continued to perform salvage logging. Because we had data on logging prescriptions, we based the resilience thresholds on this variable. The resilience thresholds were set to 3,741 m^3 $year^{-1}$ (upper threshold) and 654 m^3 $year^{-1}$ (lower resilience threshold). Over the observed period, the exemplar exceeded the upper threshold by 121 m^3 $year^{-1}$, suggesting that the disturbances caused the exemplar to manage their forests in a way that was not fully sustainable over the observed period.

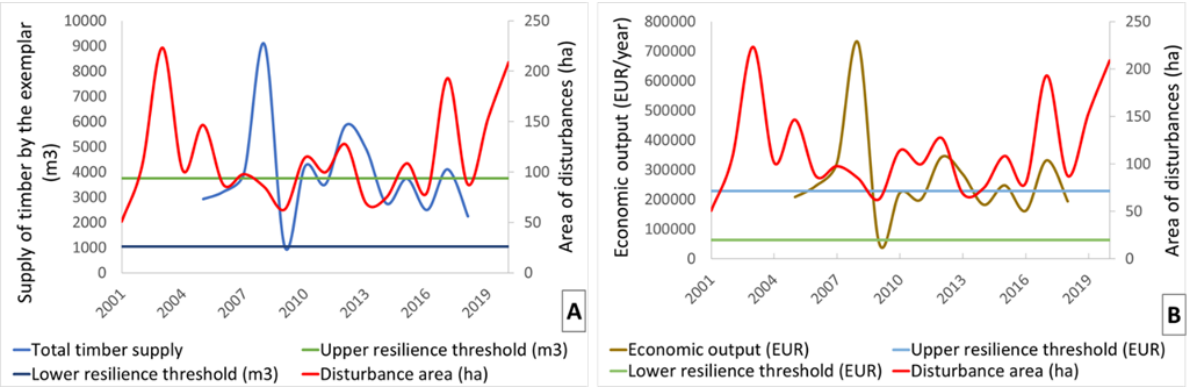

Figure 42 Timber supplied to the market by the French exemplar over the observed period (A); economic output of the exemplar in the observed period (B).

The development of the economic output is very similar to the development of the timber supply over time. However, the economic output also considers the effect disturbances have on the market, and thus can provide insight into the economic stability of the exemplar. The resilience thresholds for the system variable were set to 227,835 EUR year^{-1} (upper threshold) and 39,814 EUR year^{-1} (lower threshold). From Figure 42, it can also be seen that disturbances indeed amplified the market conditions even on a local scale, this is notable in the period between 2008 and 2009 in the graph, where during the second year mentioned, the unit value of timber caused the exemplar to reach the lower resilience threshold. In the subsequent years, the unit value of timber again amplified the effects of the timber supply development (e.g., the years 2015-2019).

Over the researched period (2005-2018), the timber supply and economic output in Bauges fluctuated, especially in 2008 and 2009 driven by larger European storm events. In this period, the actual logging largely exceeded the prescribed logging which temporarily increased the economic output. Our apprehension of a market driven by disturbances could be supported by the fact that only one co-driver has a strong positive correlation with the timber supply: the total timber stocks (m3/ha) (Table 3 and *Table 4*). Regarding the correlation between the predictors and co-drivers and the economic output, the results are slightly different but hint at similar inferences: The co-drivers harvestable timber stock and total timber stock have a moderate positive correlation, whereas prescribed logging, area to be covered, and volume harvested are not correlated to the economic output.

Table 3 The table below illustrates the correlation analysis made in the French case study between system variables, timber supply and indicators. Significant correlations are highlighted.

Predictor/ co-driver	**Type of variable**	**Unit**		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	**0.58**	**0.00**

Total logging	**P**	m3/year	**0.49**	**0.01**
Salvage logging	**P**	m3/year		
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	**0.58**	**0.00**
Total timber stocks	**C**	m3/ha	**0.79**	**0.00**
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation.

Table 4 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the French exemplar. Significant relationships highlighted by bold typeface.

Predictor/ co-driver	**Type of variable**	**Unit**		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	0.25	0.13
Total logging	**P**	m3/year	0.24	0.14
Salvage logging	**P**	m3/year		
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		

Road network density	**C**	m/ha		
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	**0.47**	**0.00**
Total timber stocks	**C**	m3/ha	**0.44**	**0.02**
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation.

4.3 The resilience of the timber supply and economic output of the German exemplar

The timber supply stability refers to the exemplar's ability to offset the effects of natural disturbances in terms of supply shocks these tend to generate. The exemplar must be economically stable and possess sufficient capacities to accommodate the accumulated timber. In the case of the German exemplar, we can see that disturbances caused them to bounce above the reference state for the majority of the observed period (Figure 43). The resilience thresholds were set to 3,788 m^3 $year^{-1}$ (lower threshold) and 7,310 m^3 $year^{-1}$ (upper resilience threshold).

Disturbances frequently cause economic harm to forest enterprises not only because the market can get into a state of supply shock that decreases the prices but also because the disturbances (windthrows are notable, e.g., for breakage) cause a decline of timber quality grades. This shows the performance of the economic output system variable over the observed period. The resilience thresholds for the variable were set to 250,287 EUR $year^{-1}$ (lower threshold) and 483,015 EUR $year^{-1}$ (upper threshold). On Figure 43, it be can seen that the excess in timber supply resulted in increased economic output. However, from the economic perspective, the lower resilience band is more important, since it relates to the ability of the exemplar to generate profit. We can see one instance of this happening – the year 2003, when the exemplar reduced logging to compensate for the excessive logging in the prior years, caused by the Lothar windstorm.

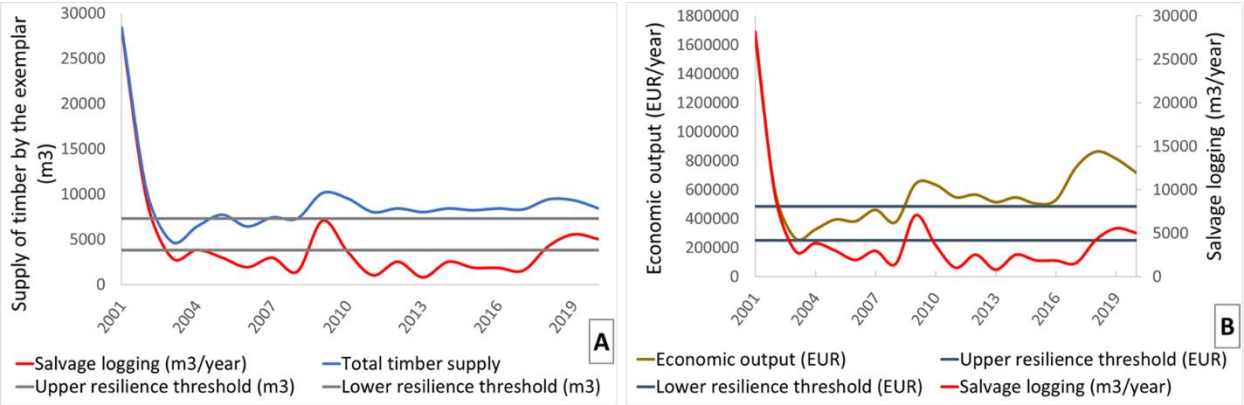

Figure 43 Timber supplied to the market by the German exemplar over the observed period (A); economic output of the exemplar in the observed period (B).

In the Upper Rhine exemplar, the timber supply and economic output fluctuated greatly in 2001, 2002, and 2009, when large European storms occurred. In this respect, total and salvage logging was correlated with the timber supply, with some peaks during the occurrence of disturbances (Table 5 and Table 6). The annual production by technologies used in forest harvesting, i.e. harvesters, forwarders, and forest skidders, are all strongly correlated with the timber supply. However, voluntary logging volume shows a moderate positive correlation with the economic output of the exemplar. This is possibly reflected as maintaining or increasing profit. The indicators total and salvage logging showed no correlation with the economic output. If we consider that the volume of salvage logging has a positive correlation with timber supply, the lack of relationship between the economic output system variable and this resilience predictor is likely caused by the effects of timber prices throughout the observed period. However, a lack of data on the exemplar's network, such as and the number of sawmills, pulp and paper mill or energy plant connections, or other network predictors and co-drivers hinders a more complex view of the situation.

Table 5 The table below illustrates the correlation analysis made in the German case study between system variables, timber supply and indicators. Significant correlations are highlighted.

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year	0.18	0.33
Prescribed logging volume	**P**	m3/year	-0.16	0.33
Total logging	**P**	m3/year	**0.98**	**0.00**
Salvage logging	**P**	m3/year	**0.48**	**0.00**
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year	**0.92**	**0.00**
Volume of timber forwarded by forwarders	**P**	m3/year	**0.92**	**0.00**
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year	**0.91**	**0.00**

Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%	-0.24	0.20
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha		
Total timber stocks	**C**	m3/ha		
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

Table 6 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the German exemplar. Significant relationships highlighted by bold typeface.

Predictor/ co-driver	**Type of variable**	**Unit**		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year	**0.50**	**0.01**
Prescribed logging volume	**P**	m3/year	**0.31**	**0.05**
Total logging	**P**	m3/year	0.19	0.23
Salvage logging	**P**	m3/year	-0.14	0.37
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year	0.26	0.10
Volume of timber forwarded by forwarders	**P**	m3/year	0.26	0.10
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year	0.26	0.10
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha	**-0.60**	**0.00**

Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha		
Total timber stocks	**C**	m3/ha		
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

4.4 The resilience of the timber supply and economic output of the Finnish exemplar

In Figure 44, we can see that the wind disturbance from the start of the observed period had little effect on the amount of timber supplied to the market by the Finnish exemplar. On the other hand, the two subsequent major disturbance events in 2010 and 2012 align with the increase in the amount of timber supplied to the market by the exemplar. Although we need to keep in mind that the exemplar provided only indirect data on the amount of timber harvested throughout the observed period (the area of harvests and several harvesting datapoints), and the disturbance data relate to the whole of Finland. Because the exemplar did not supply data on prescribed logging, we used harvestable timber stocks to construct the resilience thresholds – the upper resilience threshold (6,941 m^3 $year^{-1}$) was constructed to reflect a sustained total timber stock (83.29 m^3 ha^{-1}). The lower resilience threshold (3,955 m^3 $year^{-1}$) was constructed as the minimum timber supply when operations were still viable (23 % of the upper resilience threshold). It is also important to keep in mind that these data are scaled to 5,000 ha, as the exemplar manages substantially larger area of forests.

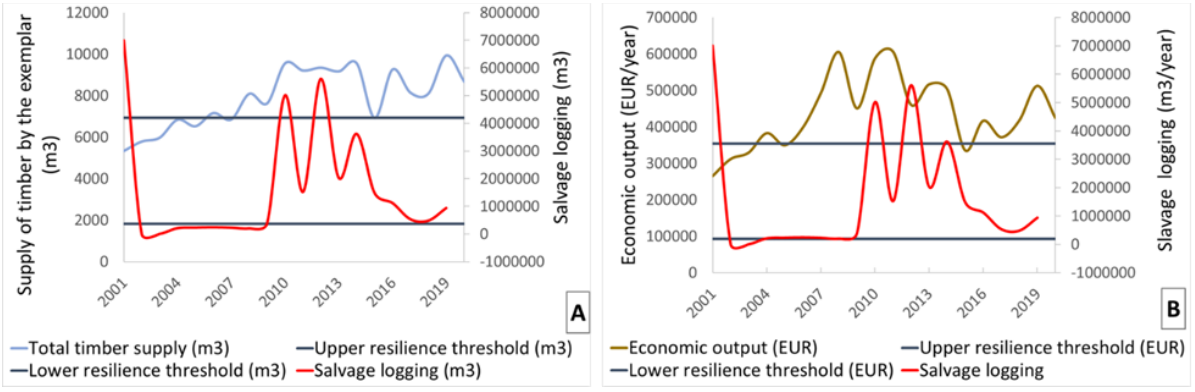

Figure 44 Timber supplied to the market by the Finnish exemplar over the observed period (A); economic output of the Finnish exemplar in the observed period (B).

The resilience thresholds for the economic output system variable were set to 354,403 EUR $year^{-1}$ (upper threshold) and 201,926 EUR $year^{-1}$ (lower threshold). In the observed period, we can see that the economic output did not fully align with the domestic disturbance events and there was a visible lag (Figure 44). The shifts in the unit values (price proxies) were considerable during the second and third disturbance events and amplified the effects of

fluctuating timber supply between 2009-2015. Over the researched period (2002-2021), in Kainuu, the timber supply and economic output fluctuated, and overall increased by approximately 25%. Similar to Bauges, the salvage logging after disturbance events, between 2009 and 2013 exceeded the upper resilience threshold. This coincided with the time of large windthrow events in the case study region.

The results of the statistical analysis of the timber supply (Table 7 and Table 8) show that the share of coniferous species in the mix are strongly correlated with the total timber supply and economic output. This is not surprising as coniferous species comprise a considerable share of economic income in the Finnish forest value chain. In addition, the use of shelterwood management system is strongly negatively correlated with the timber supply. This could point to the changing regulatory framework and legislation. The Finnish forest Act was updated in 2014 and allowed more tree species to be included in reforestation. In addition, before 2014 only clear-cut and shelterwood systems were allowed. It is also interesting that the timber supply is moderately positively correlated to the amount of funding by the state, even though the funding was slowly reduced over the period 2014-2021. The exemplar's system variables development shows that they were outside the reference state as we set it and that there were periods, when the disturbance peaks and system variables aligned. On the other hand, increased use of shelterwood system, reforestation with more species and funding for climate-smart forestry are measures that could limit such development over time.

Table 7 The table below illustrates the correlation analysis made in the Finnish case study between system variables, timber supply and indicators. Significant correlations are highlighted.

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year	**0.59**	**0.00**
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	0.36	0.11
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year		
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number		

Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%	0.30	0.18
Share of coniferous species in the tree species composition	**C**	%	**0.80**	**0.00**
Use of clear cut management system	**P**	ha	0.28	0.23
Use of shelterwood system	**P**	ha	**-0.74**	**0.00**
Use of selection system	**P**	ha	0.23	0.31
Harvestable timber stocks	**C**	m3/ha		
Total timber stocks	**C**	m3/ha		
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

Table 8 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the Finish exemplar. Significant relationships highlighted by bold typeface.

Predictor/ co-driver	**Type of variable**	**Unit**		
			R	p
Funding from state	**C**	€/year	0.12	0.62
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	-0.11	0.62
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year		
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%	-0.24	0.29
Share of coniferous species in the tree species composition	**C**	%	**0.46**	**0.04**
Use of clear cut management system	**P**	ha	0.30	0.18
Use of shelterwood system	**P**	ha	-0.18	0.44
Use of selection system	**P**	ha	-0.09	0.70
Harvestable timber stocks	**C**	m3/ha		
Total timber stocks	**C**	m3/ha		

Sawmills in exemplar's network	P	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

4.5 The resilience of the timber supply and economic output of the Irish exemplar

Under normal circumstances, the timber supply from the exemplar to the market should be stable and not exceed either of the resilience thresholds. The ability of the exemplar to stabilize the amount of timber they market describes, among other things, their ability to manage forests so that they are resilient to disturbances, thus mitigating the supply shocks resulting from said disturbances. In this, the Irish case study was specific because the Dublin Mountain Makeover project aimed to rebuild the spruce-dominated production forests into forests managed for increased biodiversity and recreational value. This shows also in Figure 45, where the amount of timber erratically increased and decreased over the years, only aligning with the disturbance data partially after the storm Darwin. The erratic trend rather reflects the silvicultural interventions when Sitka spruce and other conifers were removed from the forests to be replaced with broadleaved species intended for the new management goals by Coillte and the Dublin Mountain Partnership.

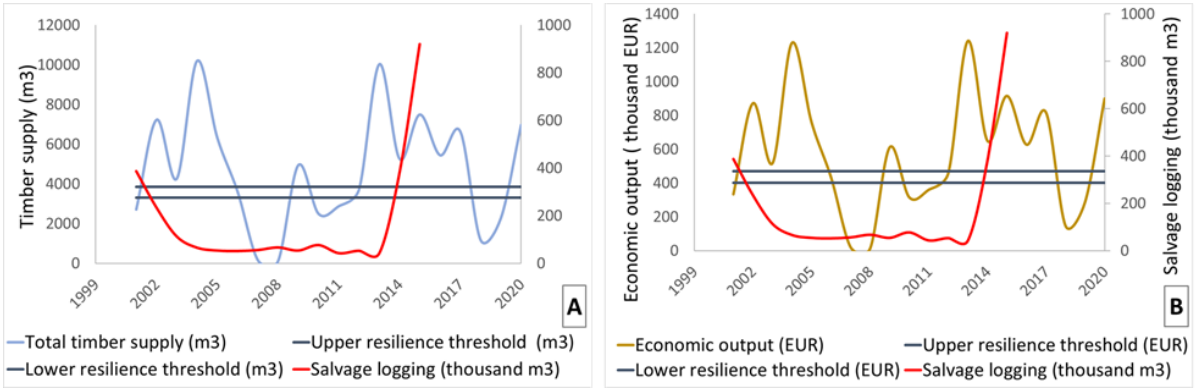

Figure 45 Timber supplied to the market by the Irish exemplar over the observed period (A); Economic output of the exemplar in the observed period (B)

Figure 45 shows the development of the economic output system variable over the observed period. The resilience thresholds for the variable were set to 402,422 EUR year^{-1} (lower threshold) and 522,805 EUR year^{-1} (upper threshold). For the Irish case study, the timber supply and economic output system variables had very similar developments. This was caused by the fact that the disturbances did not affect the exemplar noticeably, thus the exemplar maintained stable shares of the timber quality grades throughout the observed period. Similarly, the unit values of timber were also quite stable, ranging from 115 (2008) to 129 (2020) EUR m^{-3} throughout the period, with an average of 122 EUR m^{-3}.

Over the researched period, the timber supply and the economic output in the Irish case study – the Dublin mountains – fluctuated with a large peak in 2014 following a large windthrow event (Storm Darwin). As a result, the salvage logging exceeded the timber supply and led to a comparatively small increase in the economic output. Counterintuitively, in the Dublin mountains it seems that in times of comparatively little disturbance (e.g., 2008/2009), the share of timber provided for mechanical and chemical processing decreases. This could point to a time lag in the market followed by a disturbance (e.g., in 2003 and 2005). In contrast, the share of timber provided to mechanical and chemical processing was comparatively low in 2019 following a decrease in disturbances in 2017.

If we try to explain the above observations with the results of the statistical analysis (Table 9and Table 10), we find that salvage logging is not correlated with the timber supply or economic output. In fact, the prescribed logging data, as provided by the case study representative, fit the timber supply data perfectly. This would mean that the forest value chain in the Dublin case study is not adversely affected by disturbances. We could speculate that the observed time lag following a forest disturbance is a coincidence or that over time supply shocks are balanced out. Merely, the prescribed logging volume is correlated with the timber supply and economic output. This can be ascribed to the regulatory framework: For state and municipal forest enterprises, such as the exemplar in our case study (the Coillte state forestry company) parts of the forest management plan are binding, e.g., the maximum total felling volume per planning period.

Table 9 The table below illustrates the correlation analysis made in the Irish case study between system variables, timber supply and indicator. Significant correlations are highlighted.

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year	0.20	0.39
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	**1.00**	**0.00**
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year	0.18	0.44
People employed in forest harvesting	**P**	number	0.09	0.68
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha	0.20	0.38
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		

number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	0.15	0.52
Total timber stocks	**C**	m3/ha	0.17	0.46
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

Table 10 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the Irish exemplar. Significant relationships highlighted by bold typeface

Predictor/ co-driver	**Type of variable**	**Unit**		
			R	p
Funding from state	**C**	€/year	0.03	0.90
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	**0.84**	**0.00**
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year	0.34	0.13
People employed in forest harvesting	**P**	number		
Total people employed by the exemplar	**P**	number	-0.03	0.89
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year	0.18	0.44
Road network density	**C**	m/ha	-0.11	0.63
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	0.04	0.85
Total timber stocks	**C**	m3/ha	0.04	0.86
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

4.6 The resilience of the timber supply and economic output of the Galician exemplar

The timber supply increased by 50 % over the observed period (Figure 46). Because of the small disturbed areas, we assume the increase in timber supply was primarily caused by the

situation on the market (i.e., greater demand for timber) rather than disturbance occurrence. On the other hand, though the effect lags (potentially an attribute of the most common disturbance agent in Galicia – fire), increased timber supply can be seen in years that followed the disturbances – 2007 and 2008 or 2016 until the end of the observed period.

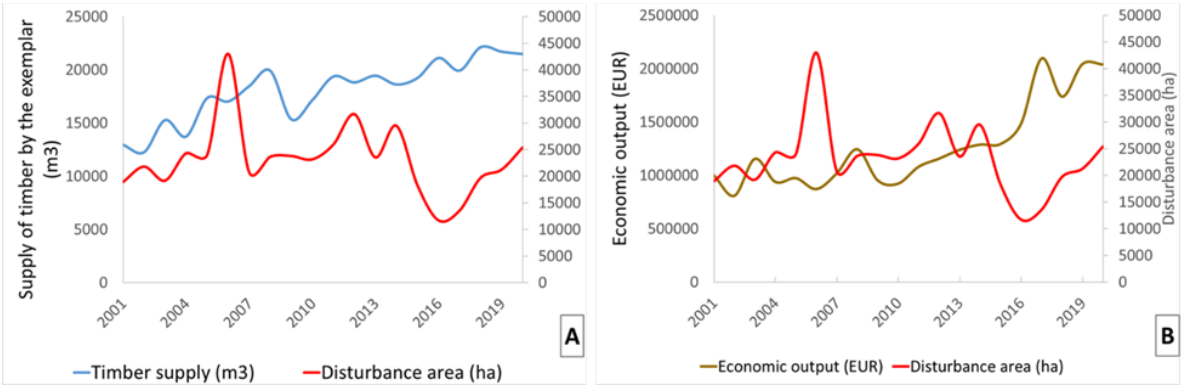

Figure 46 Volume of timber supplied to the market in Galicia between 2001and 2021 and disturbances in Galicia between 2001and 2021 (A); Economic output and disturbances in Galicia between 2001and 2021 (B).

The economic output also increased over the observed period in Galicia, though the effects of the price proxy are visible. The increased supply of timber during the first disturbance event was offset by the decreasing unit values, so the economic output stagnated in the beginning of the observed period (Figure 46). During the second and third disturbance increases (2012, 2014) the unit values of timber caused the economic output to increase more than the timber supply (which was relatively stable). Similar development can be seen in the last period of disturbance culmination (2016 onwards).

Over the researched period, the timber supply in Galicia increased by approximately 50%, whereas the economic output almost doubled. The timber supply and economic output are strongly correlated with the prescribed logging volume (Table 11 and Table 12). This is unsurprising, as over the period 2001-2021, the prescribed logging roughly doubled, and forest owners followed this recommendation. As a result of the increased harvesting operations, the number of employees in forest harvesting almost quadrupled, whereas the number of machines approximately doubled. This points to an increase in productivity, which can also be seen in the table below as machines and people employed in harvesting operations all are moderately positively correlated with the timber supply. Interestingly, the number of sawmills in the exemplars network has a negative correlation with the timber supply and the economic output although the timber supplied to the sawmills has steadily grown over the researched period. This can be ascribed to the many small-scale sawmills in Galicia either increasing their productivity or market consolidation, rather than the forest owners increasing

their network of sawmills. It can also be ascribed to the increased prices over the researched timeframe (as the economic output grew stronger than the timber supply) and the potential financial struggles of some of the sawmills.

Table 11 The table below illustrates the correlation analysis made in the Spanish case study between system variables, timber supply and indicators. Significant correlations are highlighted.

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	**0.78**	**0.00**
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year		
People employed in forest harvesting	**P**	number	**0.58**	**0.00**
Total people employed by the exemplar	**P**	number		
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number	**0.61**	**0.00**
Number of feller bunchers used	**P**	number	**0.60**	**0.00**
number of processors used	**P**	number	**0.55**	**0.00**
Number of chippers used	**P**	number	**0.57**	**0.00**
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha		
Total timber stocks	**C**	m3/ha		
Sawmills in exemplar's network	**P**	number	**-0.48**	**0.00**

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

Table 12 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the Spanish exemplar. Significant relationships highlighted by bold typeface

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year		

Prescribed logging volume	**P**	m3/year	**0.58**	**0.00**
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year		
People employed in forest harvesting	**P**	number	**0.49**	**0.00**
Total people employed by the exemplar	**P**	number	-0.09	0.59
Volume of timber harvested by harvesters	**P**	m3/year		
Volume of timber forwarded by forwarders	**P**	m3/year		
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year		
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year		
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha		
Number of harvesters used	**P**	number	**0.57**	**0.00**
Number of feller bunchers used	**P**	number	**0.61**	**0.00**
number of processors used	**P**	number	**0.54**	**0.00**
Number of chippers used	**P**	number	**0.53**	**0.00**
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%		
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha		
Total timber stocks	**C**	m3/ha		
Sawmills in exemplar's network	**P**	number	**-0.43**	**0.01**

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

4.7 The resilience of the timber supply and economic output of the Croatian exemplar

Croatia has a regulatory framework that resembles those of Czech Republic or Germany in certain key aspects. One of these aspects is that forest enterprises usually develop meticulous forest management plans, which, for large enterprises in case of Croatia, are obligatory to follow. This means, that when no substantial forest disturbance is present, the forest enterprise tends to follow the logging prescriptions in terms of annual logging volumes. From Figure 47, we can see that for most of the observed period, the timber supply well below the upper resilience threshold. The disturbances in the regional forests, represented by the volume of salvage logging performed by the exemplar, caused shifts in the timber supply, however, only after the year 2017, when the amount of salvage logging was sustained on elevated levels, the timber supply exceeded the upper resilience threshold and became unsustainable if maintained for prolonged periods of time.

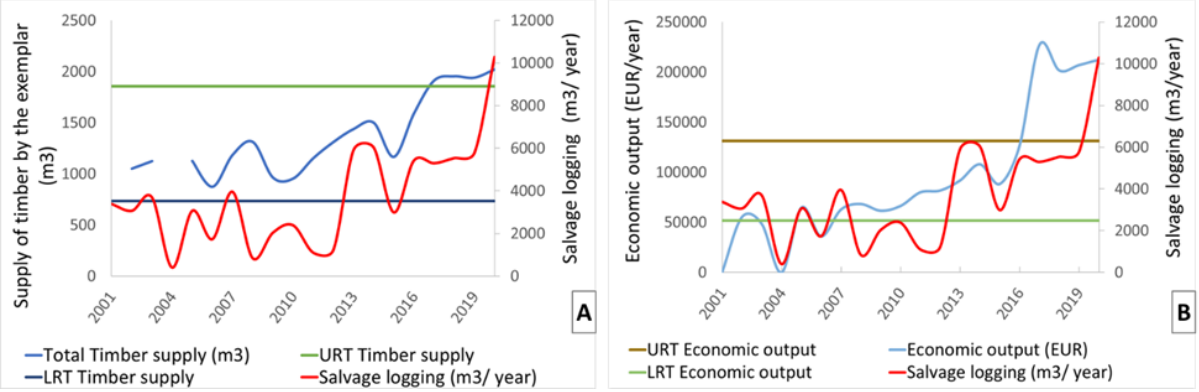

Figure 47 Volume of timber supplied to the market by the Croatian exemplar between 2001 and 2021 and disturbances in the region between 2001 and 2021 (A); Economic output of the Croatian exemplar and disturbances in the region between 2001and 2021 (B).

On the right side of Figure 47, we can see the development of the economic output, with the amplifications the market dynamics caused for the exemplar. Sadly, the data for the years 2001 and 2004 are missing, so we see the complete trend over the observed period, but in the first part, until the year 2007, the exemplar operated outside of the reference state, which could have caused some economic issues, if sustained over longer periods of time. Then, after 2017, the economic output followed the trend in increased timber supply, and again we can see the effects of unit values on the economic output, which amplified the effects of increased timber supply. This points to a relatively stable market, with high unit values over the period between 2017 and 2020, the inference being that the disturbances observed at the exemplar's forests were rather small-scale and regional, with limited effects on the market level.

Interestingly, the statistical analysis showed that practically all observed resilience predictors and co-drivers correlated with the timber supply and economic output system variables (Table 13 and Table 14 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the Croatian exemplar. Significant relationships highlighted by bold typeface). The only exceptions being the volume of timber extracted by animals and the share of coniferous species in the tree species composition (for both system variables). A strong relationship was observed between prescribed logging volume and both system variables, whereas the relationships between salvage logging and the system variables were moderately strong. From the point of view of forest harvesting operations, the relationships were similar to those observed in Czech Republic – the number of people employed in forest harvesting had a negative relationship with the system variables, whereas the relationships between the volume of timber harvested by CTL machines had a positive relationship (in Czech Republic, the machines were not distinguished into harvester and forwarders, but the resilience predictors have a similar

meaning). Interestingly, in the case of the Croatian exemplar, the road network density had a strong positive relationship with both system variables. This points towards the exemplar's ability to invest into the road network and maintain the roads for timber haulage and other uses. Lastly, in the case of Croatian exemplar, both total and harvestable timber stocks correlated with the system variables, and had positive relationships, so the disturbances which occurred in the region likely had no adverse effects on the sustainability of timber production and resource management in the region.

Table 13 Results of the correlation analyses between timber supply system variable and resilience predictors and co-drivers available in the dataset retrieved from the Croatian exemplar. Significant relationships highlighted by bold typeface

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	**0.80**	**0.00**
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year	**0.72**	**0.00**
People employed in forest harvesting	**P**	number	**-0.81**	**0.00**
Total people employed by the exemplar	**P**	number	**-0.77**	**0.00**
Volume of timber harvested by harvesters	**P**	m3/year	**0.61**	**0.00**
Volume of timber forwarded by forwarders	**P**	m3/year	**0.79**	**0.00**
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year	**0.83**	**0.00**
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year	0.03	0.91
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha	**0.87**	**0.00**
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%	-0.27	0.24
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	**0.75**	**0.00**
Total timber stocks	**C**	m3/ha	**0.84**	**0.00**
Sawmills in exemplar's network	**P**	number		

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

Table 14 Results of the correlation analyses between economic output system variable and resilience predictors and co-drivers available in the dataset retrieved from the Croatian exemplar. Significant relationships highlighted by bold typeface

Predictor/ co-driver	Type of variable	Unit		
			R	p
Funding from state	**C**	€/year		
Logging volume according to the forest management plan	**P**	m3/year		
Prescribed logging volume	**P**	m3/year	**0.74**	**0.00**
Total logging	**P**	m3/year		
Salvage logging	**P**	m3/year	**0.44**	**0.05**
People employed in forest harvesting	**P**	number	**-0.68**	**0.00**
Total people employed by the exemplar	**P**	number	**-0.69**	**0.00**
Volume of timber harvested by harvesters	**P**	m3/year	**0.60**	**0.00**
Volume of timber forwarded by forwarders	**P**	m3/year	**0.55**	**0.01**
Volume of timber harvested by the cut-to-length machinery	**P**	m3/year		
Volume of timber skidded from forests by Universal skidders	**P**	m3/year		
Volume of timber skidded from the forests by forest skidders	**p**	m3/year	**0.57**	**0.01**
Volume of timber processed by motor-manual logging (chainsaw)	**P**	m3/year		
Volume of timber extracted by animals	**P**	m3/year	0.38	0.09
Exemplar's sawmill output	**P**	m3/year		
Road network density	**C**	m/ha	**0.72**	**0.00**
Number of harvesters used	**P**	number		
Number of feller bunchers used	**P**	number		
number of processors used	**P**	number		
Number of chippers used	**P**	number		
Share of the use of natural regeneration	**P**	%		
Share of coniferous species in the tree species composition	**C**	%	-0.18	0.44
Use of clear cut management system	**P**	ha		
Use of shelterwood system	**P**	ha		
Use of selection system	**P**	ha		
Harvestable timber stocks	**C**	m3/ha	**0.70**	**0.00**

*C - resilience co-driver; P - resilience predictor; blank spaces denote that the correlation analysis could not be performed either due to a lack of data or due to insufficient variability within the datasets; volume of timber skidded from forests by cut-to-length machinery - harvesters and forwarders working in tandem without separation

5 Discussion

The regional perspective on the resilience of forest value chains is an under- researched topic. Most research is focused either on the resilience of forest systems or global value chains, looking at the national or international perspective (Fuchs et al. 2022, Loeffler and Anderson, 2018, Schwarzbauer, 2007, Seidl et al. 2017, Zhai and Kuusela, 2020). Albeit many issues? are relevant on all levels, certain variables can be efficiently researched mainly in collaboration with companies in the market. Within this deliverable, we observed the fairly high stability of timber supply and economic output of forest enterprises or regions via the comparative case

study approach, perhaps with the exception of the Galician case study. We found that most exemplars were affected by the natural disturbances which occurred at their local level or on a larger scale, shifting the national or international market conditions.

All but the Irish exemplars experienced the effects of disturbances on the amount of timber they supplied to the market (the Irish case study was the exception partially, due to the specificities caused by changing management goals). Large-scale disturbances, which affected the European timber market had effects both on exemplars, which were directly affected (e.g., Germany in the case of the Lothar or Kyrill windstorms, Czech Republic in the case of Kyrill), while others perceived these effects by experiencing price shifts caused by the supply shocks in other countries (e.g., Galicia in case of Kyrill).

The data points towards the better ability of large exemplars (Czechia, Galicia, Croatia, Finland) to absorb the effects of disturbances compared to smaller exemplars (e.g., Germany, France). This could be explained by the greater processing and storage capacities of the large exemplars, and their ability to dampen the voluntary logging and offset the effects of greater salvage logging. These latter mentioned predictors showed correlation with the amount of timber supplied to the market. In the case of the Czech exemplar, the fact that they could process the timber into first-stage wood products (the year 2008, Kyrill windstorm) proved to be another mitigating factor. However, even for the larger exemplars, the ability to absorb the effects of disturbances is not unlimited. Even exemplars with extensive processing and storage capacities at their disposal proved to exceed the resilience thresholds when the extent of the disturbance was too great (e.g., Czechia from 2017 onwards, Finland during the years 2011-2015, Galicia from 2017 onwards, and Croatia from 2017 onwards).

On the other hand, smaller exemplars, such as the case studies from Germany or France, had limited capacities to “flatten the curve” and stabilise the amounts of timber they placed on the market when disturbances occurred. In the event of a disturbance, the German and French exemplars immediately started processing the damaged timber and offloading it to the market. Figure 42 shows that the German exemplar did this after Lothar, Kyrill, and the drought and bark beetle disturbances at the end of the observed period. Figure 42 shows similar effects for the French exemplar, with the disturbance data and logging volumes aligning closely from 2010 until 2018 (the last year logging data for the French case study is available).

Overall, the timber supply increased in Czechia, Finland, Galicia, and France. Timber stocks also increased in most case studies over the observed period (Czechia being the exception) and positively correlate with the timber supply (e.g., in Germany or France). We found that financial support received from the state was positively correlated with the timber supply. however, the causal relationship was likely switched – the increased timber supply caused the

increased support from the states. Especially in the case of Czechia, this was due to the state intervening when the extensive bark beetle disturbance endangered the ability of forest owners to regenerate their forests after salvage logging took place.

Another interesting resilience predictor was the number of employees in harvesting. Two types of relationships between this predictor and the system variables can be observed – a negative (Czechia, Croatia) or a positive (Galicia). This can be explained in connection to the machinery, technologies, and harvesting methods used by the exemplars. In Czechia, the most productive machines, harvesters and forwarders, which are used with the cut-to-length harvesting method, were introduced in 2003 and their share on harvesting operations grew over time, partially necessitated by processing damaged timber. The fully mechanized technology was more productive than conventional motor-manual felling and skidding technologies, which resulted in the decrease in the number of workers in harvesting while increasing the amount of harvested (and supplied) timber. In Galicia, cut-to-length harvesting was used as the primary harvesting method throughout the observed period, so to be able to harvest more, the Galician forest owners needed to employ more of these machines and more workers. This then resulted in the positive correlation between the system variables and the number of workers employed in harvesting. Innovation, expressed as the number of highly productive machines deployed, therefore, seems to partially play a role in the stability of the timber supply.

Of course, innovations play a role along the value chains over time, not just in their initial stage. When innovative usage of timber shifts from the protected experimental niches into wider landscape use, policies must be set accordingly (Späth and Rohracher 2012) to consider if there are possibilities of governing the change of the technological regime in the desired field, or just to support the innovation (Berkhout, 2005). According to Smith (2003), policymakers should prioritise the support of the constantly emerging niches of new technologies. Another aspect to consider is the prevention of technology „lock-ins“ (Arthur, 1989) – a resistance to competing alternatives due to the technology’s attractiveness and common use (Zeppini et al., 2014). The differences in policy support of innovation uptake could partially explain (along with the availability of capital, for which we did not gather data) the difference in harvester usage between the Czech, Finnish, and Galician case studies).

In the case of the Finnish and German case studies, the share of coniferous tree species in the mix was also a significant resilience co-driver of the analysed system variables. While in Finland the share had a positive correlation with both timber supply and economic output, whereas in the German case, it had a negative correlation with the economic output (and had an insignificant relationship with timber supply). The relationships likely reflect the suitability

of coniferous species in the Central-European region. At the start of the observed period, the aftermath of the storm Lothar (and later Kyrill) decreased the share of conifers in the mix in Germany, while timber supply remained relatively stable throughout the observed period. On the other hand, in Finland, the timber supply increased over time and the share of conifers in the mix also increased. This is in line with the mixed results of studies from around the world that deal with the effects of climate change on the overall availability of timber, and tree growth. In certain areas, we can expect increased growth, whereas in others, tree growth will be stunted by the effects of climate change (Ciais et al., 2008; Nabuurs et al., 2002; Sitch et al., 2008; Aakala and Kuuluvainen, 2011). The variables that cause this include water availability, seasonal temperature shifts, soil productivity decrease, vegetation period prolonging, and more (Boonstra et al., 2008; Peñuelas et al., 2011; Huang et al., 2013; Luo and Chen, 2015).

Besides the timber supply, we also analysed the resilience of the economic output in the case study exemplars. The upper threshold of the reference state for economic output, from a long-term perspective, is connected to the timber supply, which certainly has a sustainability threshold. Although the economic output was closely correlated to the timber supply and show similar correlation structure there are some key distinctions between the two. Firstly, the economic output is also related to the unit value (price proxy) and secondly, it is related to the potentially changing assortment structure due to salvage logging caused by the disturbances. As mentioned in D3.2 of the RESONATE project, the price shifts can go both ways. Initially, supply shocks can decrease the prices, because with most types of disturbances, there is a sudden abundance of input material on the market. Along these lines, the changes in quality grades of the timber supplied to the market caused by the disturbances also tend to associate with lower the revenue streams, because the timber logged is damaged and suitable only for processing with smaller added value. In the long run, extensive disturbances can cause price spikes. Prestemon and Holmes (2008) state that the prices after the Hugo hurricane revealed a 30% price spike due to salvage and a long-run enhancement effect, leading to prices 10% to 30% higher than they would have been had Hugo not occurred. After the initial phase, when salvage logging takes place, the foresters tend to apply management changes to moderate the effects of price fluctuations. Jöbstl (2011) reports that the development of price relations for dimensional assortments and logging cost relations tends to reduce the optimum rotation length, while a decreasing timber price level increases the optimum rotation period. However, the changes in the relations are usually small enough not to justify the change in the rotation period.

For the observed exemplars, we found that the economic output had greater variability over time than the timber supply. Large-scale disturbances caused price fluctuations (sometimes captured by proxy variables, which then may amplify the effects of fluctuating timber supply.

This can be seen in the data of practically all case studies, though the data lags caused misalignment between the occurrence of disturbances and economic output variability (e.g., the period between 2008 and 2016 in Finland, 2017-2020 in Galicia). In other cases, the alignment between the disturbance and economic output data was very strong – Czechia 2007-2008 (Kyrill, Emma) or 2017-2020 (bark beetle disturbance), Germany 2001 (Lothar), 2009 (Kyrill, Paula, Emma), 2017-2020 (drought and bark beetle disturbance), France 2010-2018 (multiple events), or Ireland 2014 (Darwin).

Likely, it was because of these lags and amplifications that we observed fewer correlated variables for the economic output system variable, though if they were observed, similar variables were correlated to the economic output as were to the timber supply. For Czechia, funding from the state, the number of workers in forest harvesting, and the use of the CTL harvesting method were correlated with economic output. However, variables such as the share of coniferous tree species in the mix or the total timber stocks were both correlated only with the economic output system variable. In the case of Galicia, the overlap between the two system variables was complete, whereas in Germany, logging according to prescription, and total logging volume, as well as the share of coniferous species in the mix. In France, the only difference between the correlations was that logging prescription was not correlated with the economic output.

The international or national level predictors and co-drivers of resilience also play a role in the local scale (e.g., financial support from the state). Therefore, the increasing economic output over the observed period could have also been caused by the fact that timber prices tend to increase in general and the price differences are decreasing. For example, the demand for firewood rises as the use of fossil fuels for heating purposes declines to meet the political actions designed to reduce greenhouse gas emissions (Röser et al. 2008). This change affects the lower grade wood assortments (Buongiorno et al., 2011a; Hillring, 2006; Raunikar et al., 2010). In countries, which are pioneers in de-fossilisation of the economies, like Germany, there is a significant rise in demand for pulpwood and generally low-quality assortments, which can be used for heating, as well as for energy purposes (NTFP) (Albrecht et al., 2012). This is an ongoing trend, thus the correlation between price of energy and the price of fuelwood grows stronger (Bauer, 2006; Knoll and Rupp, 2007; Schulte, 2007; Wittkopf, 2005; Olsson et al., 2011). Buongiorno et al., (2011b) as well as Raunikar et al., (2010) predicted merging the prices of fuelwood and other timber by 2025, with a rise of the price up to 2060 and the fuelwood use increase of 60% in Europe. This convergence would lead to an increase of the cost of the roundwood up to 30% by 2030, causing the subsequent rise of the sawn timber and panels by 15%, while the price of paper would rise by about 3 %. As a result of the higher price, the demand would be lower, and as such, the global value-added in the wood industry

would fall by 1% (Buongiorno et al., 2011c). This, of course, may also lead to a rise in local pulpwood prices, as shown by some authors (Schwarzbauer and Stern, 2010; Trømborg and Solberg, 2010). Gejdoš et al. (2020) studied the effects of selected parameters on the price of sawn wood and found that coniferous sawlogs price was significantly affected negatively by the amount of salvage logging and positively by the GDP.

6 Embedding the findings in RESONATE and concluding remarks

Between case studies, the data that could be gathered by the representatives differed largely Even when the data were gathered, the observed period was too short to provide a sufficient number of variations, like the legislation updates, which were few or the density of road networks, which also changed only after a longer period in most case studies where the data were provided. Thus, the study should be taken as the first step in finding the drivers of forest value chain resilience on a local level and generalising our findings should be done with caution. Another aspect of this study is that the value chains were studied not in their entirety, but rather we aimed at the interface between forest management and the first-stage processing of timber, all while applying static analytical methods. This enabled us to focus on a manifold of variables that affect this interface but could not provide a complex view of the local forest value chains.

An interesting outcome was that the relationships between the system variables and many potential resilience predictors (e.g., with the share of coniferous species in the tree species composition or the number of workers in forest harvesting) were not uniform across the case studies, even in the directions of the correlations. This points to the complexity of the forest systems, and to the fact that the assessments need to consider local context, such as the standing of the exemplar in the region, their ability to raise capital for innovation and their ability to implement these innovations, to expand the networks of their customers or whether the species used in the regional forests were inside their natural habitat.

Despite the limitations, it was found that the stability of the economic output is strongly correlated with timber supply but is additionally affected by the market price and the quality change of timber after a disturbance. From this point of view, the exemplars are affected by both region-specific disturbances, which can potentially alter their timber supply, and also larger-level variables alter their costs and revenues, potentially amplifying the fluctuations in timber supply.

This work sets the basis for further analyses of the interlinkages between the regional, national and international outlook on the resilience of forest value chains. What is needed now, exceeding the scope of this RESONATE task in terms of the local perspective on the resilience

of forest value chains, is to focus on observing further stages in the value chains, optimally in their entirety.

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8 Annexes

Annex I: Data request spreadsheet

Annex II: Data shell template

Annex III: Scatterplots of system variables and resilience predictors in case studies