Climate-Smart Forestry in Russia and potential climate change mitigation benefits

Russian forests and climate change

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5.

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5.1 Introduction

In response to climate change, Climate-Smart Forestry (CSF) has been introduced as a holistic approach to guide forest management (Nabuurs et al., 2017; Bowditch et al., 2020), with the aim to connect mitigation with adaptation measures, enhance the resilience of forest resources and ecosystem services, and meet the needs of a growing population. CSF builds on the concepts of sustainable forest management, with a strong focus on climate and ecosystem services, and has three mutually reinforcing components (Verkerk et al., 2020) that are employed in a mix of spatially diverse forest management strategies:

- Increasing carbon storage in forests and wood products, in conjunction with other ecosystem services;
- Enhancing the health and resilience through adaptive forest management; and
- Using wood resources sustainably to substitute non-renewable, carbon-intensive materials.

In this chapter, we applied the CSF approach to provide insights in the climate change mitigation potential (and other impacts) of alternative CSF implementation strategies across Russia. Due to the significantly varying regional circumstances we aimed to illustrate this through three case studies.

5.2

Approach and general scenario assumptions

5.2.1 Case studies

To understand how and to what degree CSF can provide climate benefits across Russia, we elaborated a portfolio of measures for three case study regions (Figure 19). The conditions and trends for each of these regions is described in detail in Chapters 5.3–5.5.

5.2.2 CSF strategies

To explore the climate change mitigation impacts of CSF, we adopted a scenario approach to assess what could happen if certain management measures were implemented with regard to increasing the mitigation potential (or decreasing disturbance losses), while paying attention to adaptation aspects and, where possible, increasing the

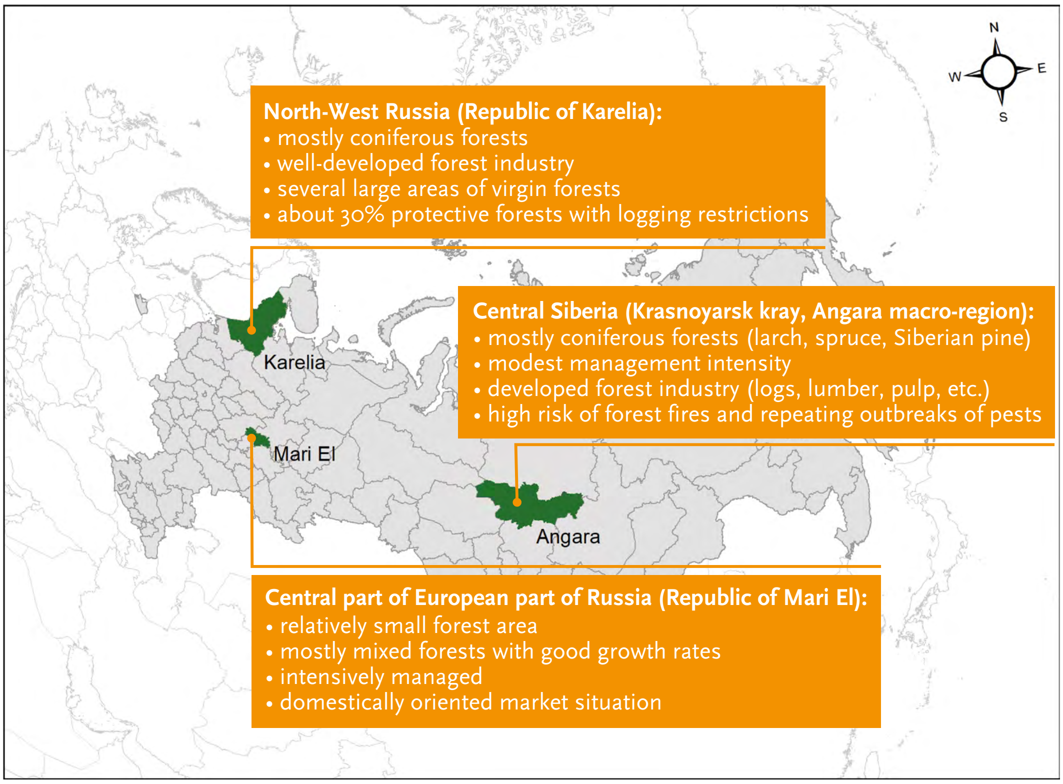

Figure 19. Overview of the three case study regions covered.

Table 3. Overview of potential CSF options for each of the three case study regions, identified during an expert workshop in June 2019.

Topic	Republic of Karelia	Republic of Mari El	Angara macro-district (Krasnoyarsk kray)
Expanding forest area	-	Afforestation on abandoned agricultural lands	-
Forest regeneration	Better selection of site-adapted species		
	Regenerate forests with improved breeding materials		
Thinning and cutting regimes	Increase share of thinnings in total harvests		
	Careful selection of cutting regimes to avoid paludification	-	-
Dealing with natural disturbances	Reduce emissions from forest fires and insect outbreaks by preventive activities	Reduce emissions from forest fires and insect outbreaks	Reduce emissions from forest fires and insect outbreaks
	Improved infrastructure to support effective restoration, fire suppression and fire prevention	Increase share of broadleaved species to reduce fire risk	Improved infrastructure for fire suppression and fire prevention
Wood use	Increased use of wood and felling residue (textiles, chemicals)	Increased use of wood (construction, furniture)	Increase share of wood in construction (high rise construction in urban area)
Planning	Better spatial planning (logistics, harvesting, protection)		

production of renewable resources. The analysis distinguished between short- to medium-term mitigation measures and long-term potentials for the next 50 years. The options considered are listed in Table 3.

In a next step, the options were refined to focus on measures that could provide climate benefits. The final set of CSF options for each case study is described in Chapters 5.3–5.5.

5.2.3 Assessing mitigation impacts

The magnitude of the climate benefits of CSF measures was estimated over a period of 50 years by comparing carbon storage under a CSF scenario with a baseline scenario in which current (i.e. the past 10 years) management practices and wood use are continued, and without any additional measures taken to mitigate or adapt to climate change.

We included in the analyses the carbon balances of forest biomass (above and below ground), harvested wood products (HWP), and material substitution. We excluded impacts of soils as effects were considered too uncertain (e.g. soil models typically focus on mineral soils and do not cover the carbon dynamics in organic soils (peatlands) very well). We have also excluded the bioenergy component as in these three regions there is hardly a commercial (e.g. pellet) type of bioenergy.

Table 4. Datasets used in EFISCEN in the three case studies.

Data	Republic of Karelia	Republic of Mari El	Angara macro-district
Forest area and growing stock by species and age class	• Forest Plan of the Republic of Karelia for years 2019–2028 • Gromtsev et al. 2019	• Forest Plan of the Republic of Mari El for 2019–2028 – Yoshkar-Ola, 2018 • Strategy for the socio-economic development of the Mari El Republic for the period until 2030. – Yoshkar-Ola. –2018.	• State report about environmental condition and protection in the Krasnoyarsk kray in 2017. • Forest Plan of the Krasnoyarsk kray 2018 • Strategy for the Development of the Forestry Complex of the Krasnoyarsk kray until 2030 • Forestry regulations of local division of forestry by 2018 (for all forestry units in Angara macro-district)
Annual increment (net or gross)*	• Kazimirov et al., 1990; 1991	• Shvidenko et al., 2008	• Shvidenko et al., 2008
Annual mortality	• Zagreev et al., 1992 • Krankina and Harmon, 1995	• Forest Plan of the Republic of Mari El for 2019–2028 – Yoshkar-Ola, 2018	• Zagreev et al., 1992 • Krankina and Harmon, 1995 • (3%/5yr of the Growing stock)
Management parameters	• Regional rotation lengths (data provided by expert)	• Regional rotation lengths (data provided by expert)	• Regional rotation lengths (data provided by expert)
Basic wood densities	• Species-specific wood density (t dry matter/m³ fresh) (IPCC, 2003)		
Age-dependent, species-specific biomass distribution functions	• Schepaschenko et al., 2018		

*Note that concepts on annual increment differ between Russian and western European forestry (Pisarenko et al., 2000). For our simulations we used net annual increment, which can be defined as the average annual volume of gross increment less that of natural losses over a reference period on all trees measured to a minimum diameter of 0 cm at breast height (UNECE-FAO, 2000).

The development of the biomass carbon pool has been estimated with the European Forest Information SCENario Model (EFISCEN) model version 4.2 (Sallnäs, 1990; European Forest Institute, 2016; Verkerk et al., 2017). EFISCEN is a large-scale forest model that projects forest resource development. The model uses national forest inventory data as the main source of input. Based on this information, the model can project the development of forest resources, as affected by growth and management actions (e.g. tree species selection, thinning, final fellings) and changes in forest area. The data used in EFISCEN are described in Table 4. The total simulation period was 50 years.

Carbon balances for HWP were only estimated for wood harvested over and above the baseline scenario. Carbon balances for HWP from wood harvested in the baseline scenario could not be calculated due to a lack of detailed information on historical wood use in each case study. To estimate future emissions from HWP, we followed the Tier 2 approach in the 2013 IPCC KP Supplement (IPCC, 2014). Default half-life times of

35, 25 and 2 years are assumed to estimate the decay of sawnwood, wood-based panels and paper and paperboard, respectively (IPCC, 2014). Half-life times for textile fibres are not covered by these recommendations and we assumed a half-life time of 3 years. To estimate the substitution effect of increased production of wood-based textile (case study for Republic of Karelia), we used information on life cycle emissions to produce lyocell fibres. Shen et al. (2010) report substitution values 2.75 and 4.05 t CO_2/t fibre when lyocell substitutes petroleum-based fibres. Based on this we used an average substitution factor of 3.40 t CO_2/t fibre. A displacement factor of 2.4 t CO_2 eq/t wood product was assumed for structural construction in the case studies for Republic of Mari El and Angara macro-district (Leskinen et al., 2018).

5.3

Case study: Republic of Karelia

5.3.1 Trends and issues

Description of forest resources

Karelia is located in the taiga zone in north-western European Russia. The region extends 672 km from north to south and 424 km from west to east (at the latitude of Kem). Its total area amounts to 180 500 km^2. A line passing from Medvezhjegorsk city area to Porosozero divides the territory into two vegetation zones, namely, the north taiga subzone and the middle taiga subzone. The larger part of the territory lies in the northern taiga subzone. Summer is short and cool, while winter is long but usually free of extremely cold temperatures. Cloudy weather is common with both high relative air humidity and precipitation (400–650 mm/year). The mean annual air temperature is about 1 °C, varying from 0.5 °C in northern Karelia to 2.2 °C in southern Karelia. The lowest air temperatures occur in February and the highest in July. The growing season is almost one month shorter in northern Karelia than in the south and growing conditions of woody plants gradually deteriorate on moving from south to north.

The forest area of the Republic of Karelia covers 9.5 mill. ha. The total timber stock is 102.3 mill. m^3, of which 87% is softwood (pine (*Pinus sylvestris*) and spruce (*Picea abies*)) and 13% deciduous (birch (*Betula pendula* and *B. pubescens*), aspen (*Populus tremula*), alder (*Alnus incana*)). The average growing stock is 107 m^3/ha and the total annual increment of timber stock is 14.8 mill. m^3. The forest cover is 54%. Pine covers 64%, spruce 24%, birch 11%, aspen 0.7% and grey alder 0.2% of the forested area. Siberian larch (*Larix sibirica*) naturally grows only in National park Vodlozerskii near the border with Arkhangelsk oblast.

Karelian forests typically have relatively more young and old growth coniferous forests than forests in the middle age classes, as can be seen in the age structure graph for coniferous forests (Figure 21). In the 1950s, intensive clear felling became the most used forest management method, leading to a lot of young forest now. Prior to this, selective logging was the most common practice. The large share in area of forests older than 100 years in the region is due to the prevalence of protective forests, low productive forests that are unattractive for wood harvesting due to difficult access. The high fraction of deciduous forests in the middle age-class is due to the lack of effective restoration of coniferous forests in the 1990s, which caused Scots pine and Norway spruce to give way to deciduous species (generally birch). The small peak in mature forest area of deciduous forests older than 60 years may be associated with large areas of abandoned agricultural land in the 1940s and 1950s.

The main natural disturbance agent in the region is wildfire. Over the period 2009–2018, 21 595 ha of forest were damaged (or only 0.02%/year) and 13 578 ha were destroyed due to fire damage. Other disturbances had relatively minor impacts.

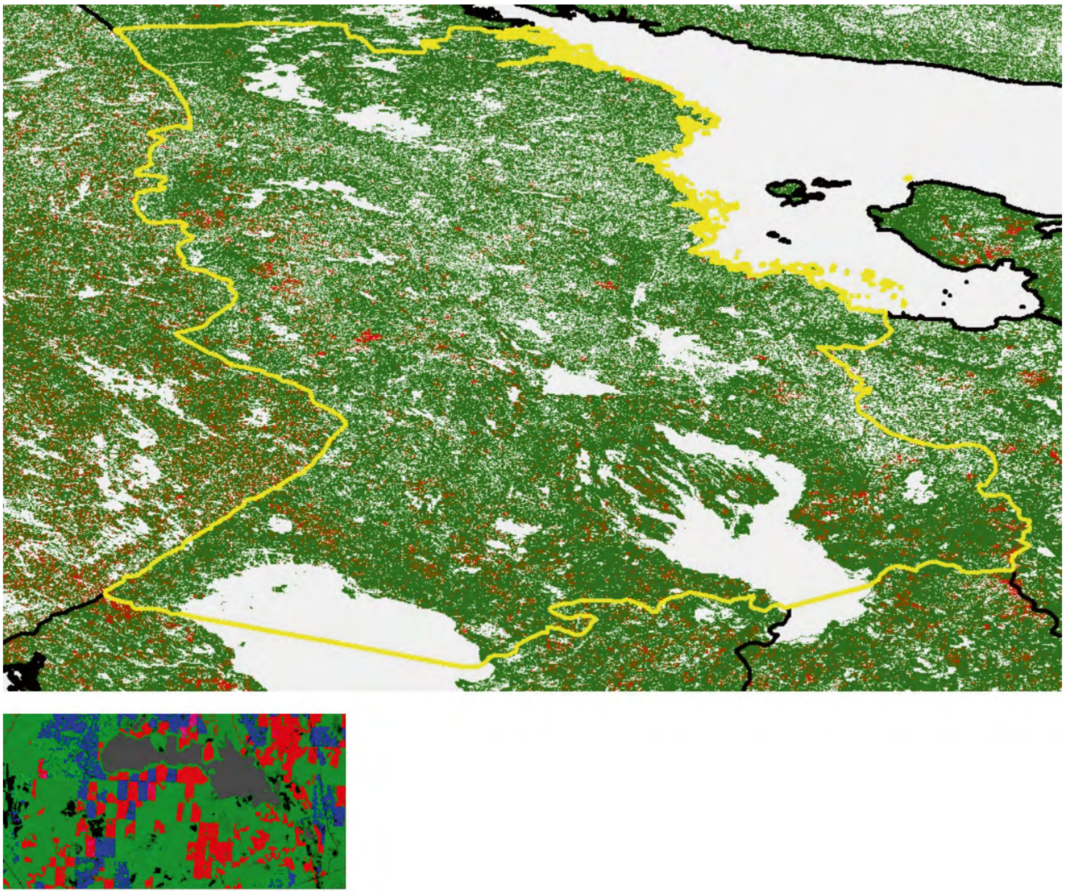

Figure 20. Tree cover changes in the Republic of Karelia (yellow borders) over the period 2000–2018. The green indicates tree cover, red is tree cover loss (harvest and disturbances between 2000 and 2018) and blue indicates tree cover gain (Hansen et al., 2013). Most of the harvesting took place in southern-middle-Karelia and was carried out in a typical checkerboard type of clearcut management (see insert). The border with Finland can clearly be discerned by a denser and finer harvest pattern west of the border.

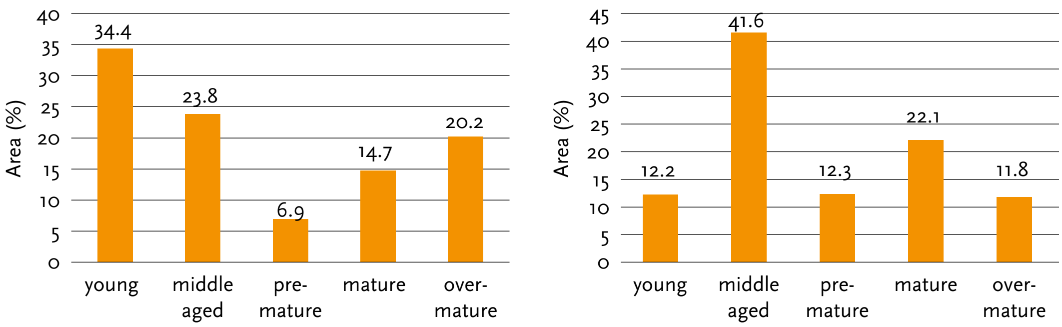

Figure 21. Age structure of coniferous (left) and deciduous (right) forests in Karelia.

Description of the forest sector and wood use

Annual roundwood production gradually increased in the region from 5.7 mill. m^3 in 1997 to 7.2 mill. m^3 in 2018. Wood is mainly used for production of lumber and pulp. Recently, the forest sector in the Republic of Karelia aimed to modernize the paper industry leading to an export of about 20% of produced roundwood, 90% of commercial pulp, 90% of lumber and 80% of paper to Germany, Finland, and Turkey, among others. More detailed statistics are not available due to confidentiality issues. Harvesting is mostly carried out by clearcut methods in relatively large blocks (500 x 300 m; Figure 20), which leads to an increase in the pioneer species birch and aspen in the middle taiga subzone.

5.3.2 Scenarios

Business as usual (BAU):

The rationale of the BAU scenario is that existing trends are largely continued, and no additional efforts are implemented to use forestry as a measure to mitigate climate change or to modify management practices to improve the resilience of Karelian forests in Russia. Specifically, the following actions are assumed:

- Roundwood production is assumed to follow the average increasing trend in roundwood production from 2007–2018 for the next 50 years (i.e. a trend prolongation) and to stabilize thereafter (i.e. increases from current 7.2 mill. m^3/year to 12.7 mill. m^3/year after 50 years);
- The current share of thinnings in total wood removals (7%) is assumed to remain constant;
- The current efficiency of harvesting activities (85% of all felled logs are extracted; Obersteiner, 1999) is assumed to remain constant;
- The current trend that part of the harvested pine and spruce forests naturally regenerate with aspen is continued. It is assumed that after clearcutting, 30% of pine and spruce forests are naturally regenerated with aspen in the southern part of the republic.

The overall rationale behind the CSF scenarios is that an additional effort is made in investments in forestry to mitigate emissions from other sectors. Specifically, the following scenarios and actions are assumed:

CSF scenario 1:

- Harvest levels are assumed to increase steadily but slightly faster than in BAU, reaching 14.4 mill. m^3/year after 50 years;
- Harvesting activities are assumed to increase in efficiency (the ratio between wood removals and fellings is increased to 90%);
- The share of thinnings in total wood removals is assumed to increase to 50%;
- Harvested pine, spruce and birch dominated forests are regenerated with improved breeding materials of the same species, which have a 25% higher growth rate;
- All additionally harvested wood is directly allocated to the production of wood-based textiles.

CSF scenario 2:

- The main reasoning in CSF2 is to protect old-growth forests in the whole territory; the harvest of wood from protective forest is reduced from 36% of total fellings to 18%. The wood that is not harvested from protective forest anymore is now assumed to come from commercial forests, but totaling the 12.7 mill. m^3/y as in BAU;
- Harvested forests are regenerated with the same species and same productivity as in the previous stand;
- Other actions and overall volume of fellings requested are the same as in the BAU scenario.

CSF scenario 3:

- Here the main reasoning is to focus on carbon storage in the forest of the northern taiga subzone and its protective forests, but under the same total wood production. Therefore the forests in the middle taiga subzone are used in a more intensive way.
- Other actions are the same as in CSF scenario 1.

5.3.3 Results

In the simulations, the emission balance for the living biomass stock, HWP and material substitution effects were estimated for BAU and CSF scenarios. Those estimations were dependent on the impact of management strategies on forest growth and the amount of timber removed from the forest (Figure 22).

CSF scenarios 1 and 3 have a significant effect on growing stock, increment and total wood removals compared to the BAU scenario. The positive effect on growing stock and increment is mainly due to the larger share of thinnings in total wood removals and the application of improved breeding materials in both scenarios. The removal regimes of CSF scenarios 1 and 3 are the same in terms of total removal volume per time step, but CSF3 specifies different removal volumes per region. The removal is increased with 50% in the middle taiga and decreased with 50% in the northern taiga. This is visible in Figure 22c, where roundwood removal volumes for both scenarios develop similarly until the demand for removal of wood in CSF3 is not met anymore in the period 2056–2066. The natural regeneration of aspen on pine and spruce clearcuts in the BAU scenario, leads to an area increase of aspen from 52 000 ha in 2016 to 137 000 ha in 2066. In the CSF scenarios, this is counteracted by regenerating harvested coniferous forests with the same coniferous species.

The main outcome of the simulations in Karelian forests is that, even when a much higher harvest level is employed in CSF1 than in BAU, under CSF1 the increment is maintained at a significantly higher level (additionally about 0.5 m^3/ha/year) and thus the growing stock even increases to a higher level, despite a higher harvest. The removal regimes of the BAU and CSF2 are the same in terms of total removal volume per time step, but CSF2 specifies a relatively lower removal volume from protective forests and a relatively higher volume from commercial forests. The effect of CSF2 is mainly visible in Figure 22d. The area of old growth forest (i.e. older than 150 years) on protective sites has significantly increased over the course of the 50-year time period, compared to the BAU. This contributes to biodiversity but had only a limited effect on carbon balances over the entire Karelian forest area.

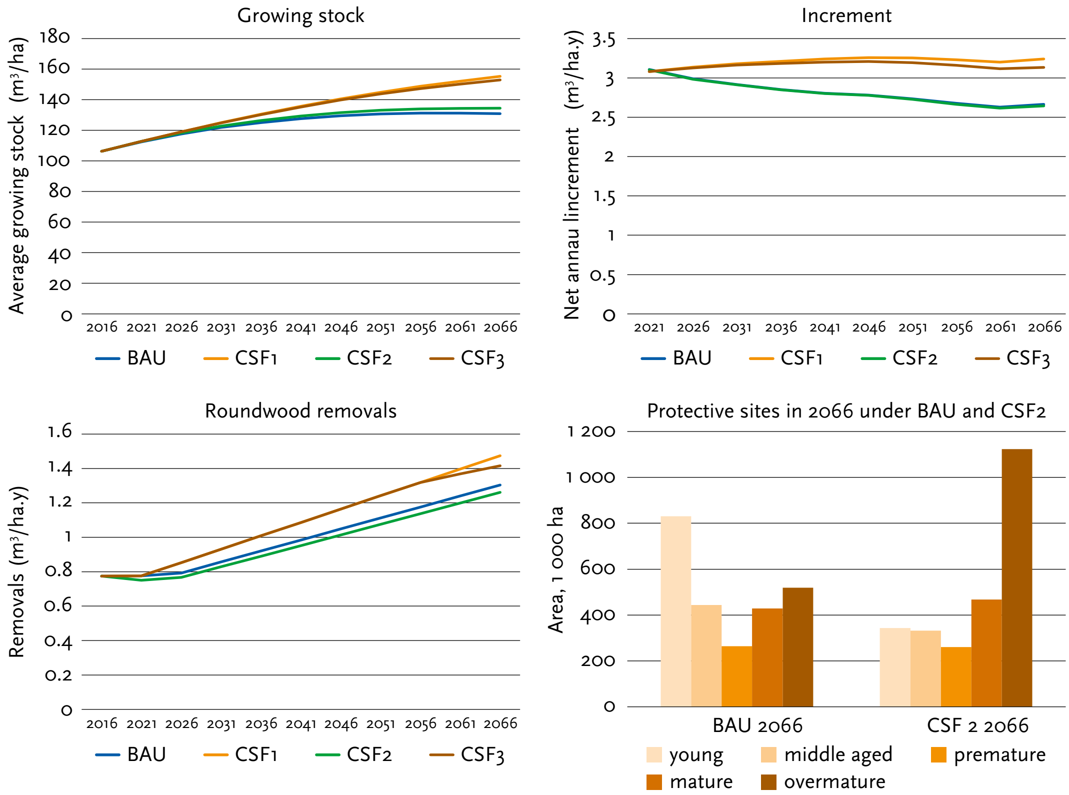

Figure 22. Projected development of (a) growing stock, (b) annual increment and (c) roundwood removals in Karelia under BAU and three alternatives (BAU is similar to CSF2). Furthermore, graph (d) depicts the age distribution in protective sites in 2066 for the BAU and CSF2 scenario.

Based on the impact of management strategies, the emission balance for the living biomass stock, HWP and material substitution effects were estimated for BAU and CSF scenarios (Figures 23 and 24). Carbon balances of HWP and for substitution effects were only estimated for wood harvested in addition to the wood harvested already in the BAU scenario, i.e. no substitution effects are assumed for wood that would be harvested without CSF measures.

The forest area in Karelia is projected to act as a carbon sink over the entire period for CSF1 and 3, while it turns into a source around 2060 in the BAU and CSF2 scenario. The increased share of thinnings and the application of improved breeding materials in CSF scenario 1 and 3 maintain forest covers and stimulate the net annual increment enough to compensate for the increased removals (compared to the BAU scenario).

5.3.4 Key findings

The Karelia region with its 9.5 mill. ha of relatively productive forests is, under the assumption that investments in improved regeneration can be made, able to increase its production of wood from the current 7.2 mill. m^3/year to 14.4 mill. m^3/year, while even maintaining a sink, although decreasing.

CSF scenarios 1 and 3 retain a carbon sink in Karelian forests for the projected period, although it decreases from current 15 Mt CO_2 to 5 Mt CO_2. The BAU and CSF2 show a fast saturating sink that turns into a source in approximately 30 years and ends as a source of 5 Mt CO_2/year after 50 years.

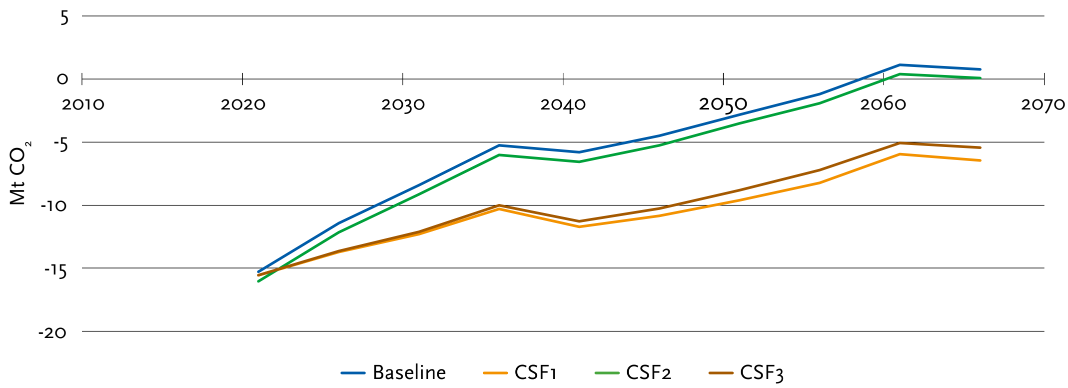

Figure 23. Carbon balance in living biomass for the BAU and the CSF scenarios in Karelia. Positive values are emissions and negative values are removals of CO_2.

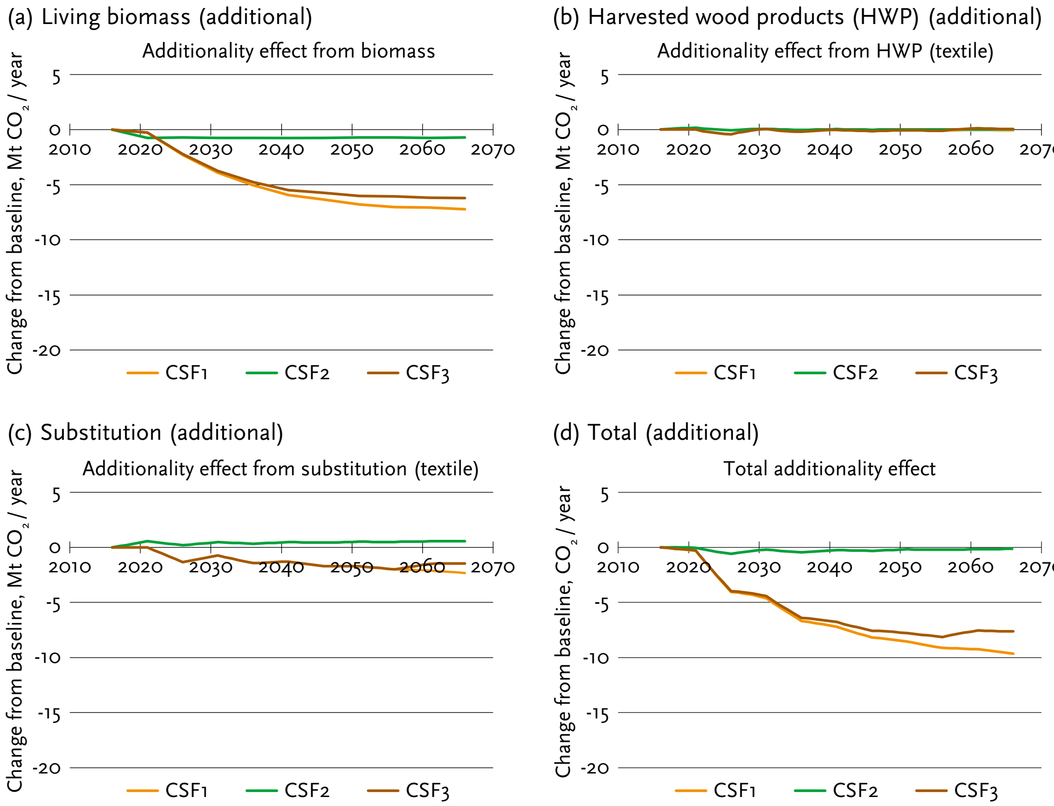

Figure 24. Projected emissions (positive values) and removals (negative values) of CO_2 for the BAU and the CSF scenarios in Karelia. Results show the difference between the CSF and BAU scenarios for additionality effect in forest biomass (a), harvested wood products (HWP) (b), substitution effect (c) and the total (d).

CSF scenarios 1 and 3 meet higher removal demands than the BAU and create a higher substitution effect, due to the allocation of wood to textile products. The removal demand in CSF scenario 3 is met until 2061. After 2061, there is a small gap between realised removals and the removal demand.

CSF 2 strongly stimulates the increase in area of old growth forests on protective sites compared to BAU, which supports biodiversity preservation and high stocking on those preserved sites. However, the CSF2 scenario creates almost no positive climate mitigation effect compared to the BAU, because the total harvest is the same (i.e. has to be found in other forest areas). In addition, in CSF2, the large areas of old forests show a somewhat reduced increment.

5.4

Case study: Republic of Mari El

5.4.1 Trends and issues

Description of forest resources

The Republic of Mari El is composed of 18 territorial forest districts, the specialized state autonomous organization "Avialesookhrana" (Aerial Forest Protection Service), and more than 200 forest land tenants. The forest area of Mari El covers 1.1 mill. ha (54% of total land), the total timber stock is 187 mill. m^3, the total net increase in growing stock is 4.4 mill. m^3. On the one hand, the age and tree species structure of the wood stock and its dynamics show an undesirable trend of replacing coniferous stands with deciduous, less economically valuable tree species. On the other hand, a significant stock of maturing deciduous stands suggests an increase in allowable cut in the coming years. The proportion of protective and production forests is 46% and 54%, respectively. Planted forests correspond to 16%.

The share of coniferous stands is 44%, and deciduous stands is 56%. In the forest fund, middle-aged stands are predominant, corresponding to 37% of the total forested area. Young forest stands represent 22.8%, premature 18.4%, while mature and over mature correspond to 21.7% of the total area. Regarding the species composition, birch covers 40% of the forest area of Mari El, pine 36%, spruce 8%, lime 6%, aspen 6%, and other species represent 4%.

The higher share of broadleaves is primarily due to the increase of post-fire birch trees after the forest fires of 1921, 1972, and 2010. In the last decade, because reforestation was carried out, the area of forested land increased from 953 400 ha to 1 168 800 ha. The average stock of stands has slightly increased from 165 m^3/ha to 167 m^3/ha as the stand age has also increased. Because of the natural regeneration following the 2010 forest fire, the increase in stock of forest land went from 3.0 m^3/ha to 3.3 m^3/ha. In some forest districts, a shift in species composition also occurred following the harvesting of some spruce stands after the drought of 2010–2012.

Regarding the forest disturbances, weather conditions and soil-climatic factors are listed as the main causes of damage in forest stands of Mari El, representing 46% of the total damaged stands for the period of 2007–2018 (Table 5). Pests, diseases and wildfires (27%, 20% and 7%, respectively) are other main causes of damage. Weather conditions and soil-climatic factors are also the main causes for dieback (42%), with wildfires (26%), pests (20%) and diseases (11%) being mentioned as other reasons.

Description of the forest sector and wood use

Forestry in the Republic of Mari El is quite intensive. In particular, the percentage of the annual allowable cut that was actually harvested was one of the highest in the Russian Federation; over the period 2009–2017, 82% of the annual allowable cut was harvested.

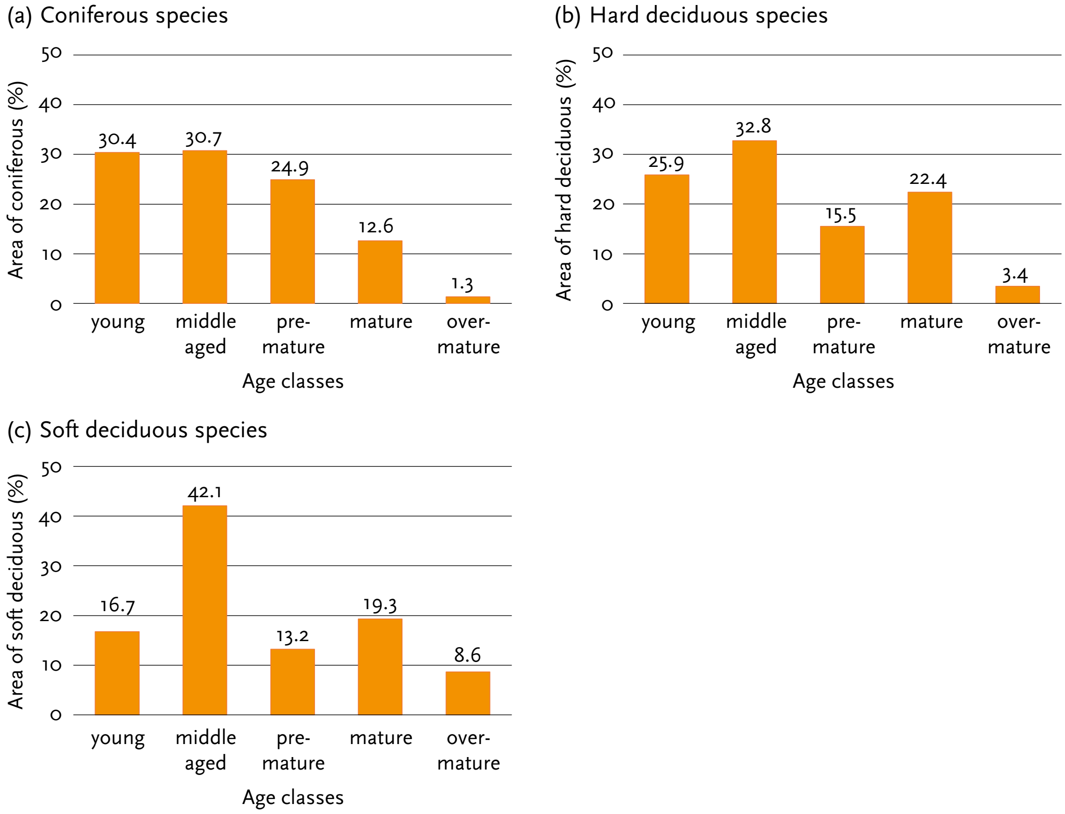

Figure 25. Age structure of (a) coniferous, (b) hard deciduous and (c) soft deciduous tree species in Mari El.

Table 5. Overview of areas affected by disturbances of Mari El forests in the period 2007–2018

Causes	Damaged stands (ha)			Destroyed stands (ha)
	2007–2018	Degree of damage in the stands		2007–2018
		10–40%	> 40%	
Wildfires	418.3	12.8	399.3	372.4
Insect damage	1540.2	830.8	471.2	288.8
Weather and shallow soil conditions	2682.4	1320.7	835.2	589.9
Forest diseases	1166.3	580.4	232.6	160.5
Anthropogenic factors	1.5	-	1.5	1.5
Total	5808.7	2777.7	1939.8	1413.1

In Mari El, the volume of processed wood is approximately two times higher than the harvested volume. To meet the demand, roundwood and lumber come from neighbouring regions, such as Kirov oblast, Komi Republic, Udmurtian Republic and Perm kray. The roundwood production volumes have decreased by 5% per year, along with the reduction in logging companies. There is a greater demand for coniferous species. A change in species composition and the annual allowable cut contributed to a decrease in the volume of harvested deciduous at a faster rate when compared to coniferous.

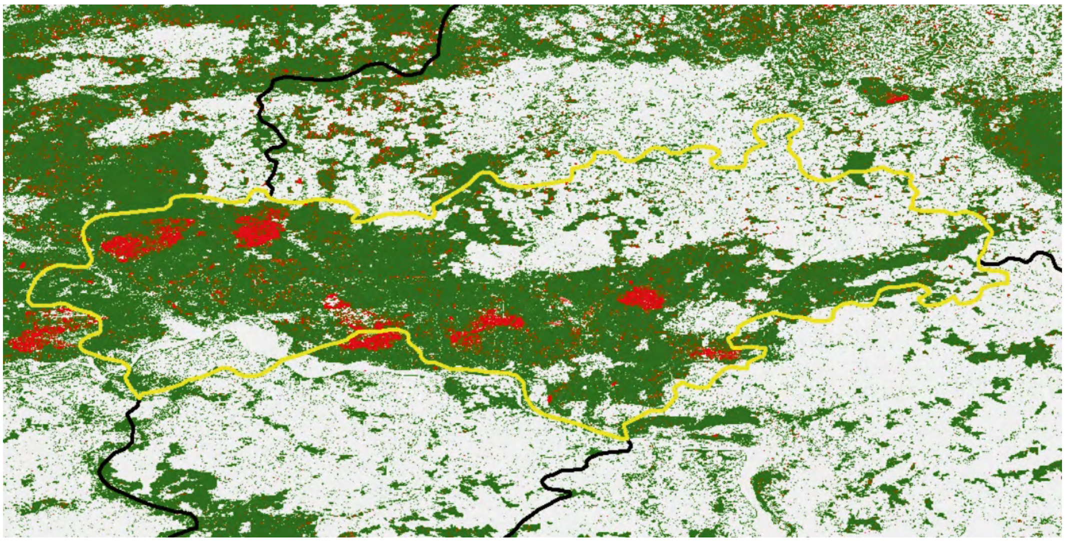

Figure 26. Tree cover changes in the Republic of Mari El over the period 2000–2018. The area is within the yellow line, tree cover is shown in green, tree cover loss, i.e. harvesting and disturbances, is shown in red and the white areas are agricultural lands. Source: Hansen et al., 2013.

The installation of new timber processing plants is planned for the region for the next few years, which will likely increase the competition for raw materials. The main wood-based products manufactured in Mari El are lumber, veneer, wood chips, doors and windows, wood pellets for energy, fiberboards, paper and cardboards. A decrease in the production of doors and windows has been observed in the past few years, but the demand is expected to increase with the development of the wood construction for housing in the region. Regarding the use of wood for energy, the active gasification of the municipal territories of the region is contributing to a decrease in demand of wood for this purpose.

5.4.2 Scenarios

The rationale of the BAU scenario is that existing trends are largely continued, and no additional efforts are implemented to use forestry as a measure to mitigate climate change or to modify management practices to improve the resilience of forests. Specifically, the following actions are assumed:

BAU scenario:

- Harvest is assumed to remain constant over the next 50 years at its current level (i.e. 1.2 mill. m^3/year), as the current level of roundwood production is already 82% of the allowable annual cut;
- The share of thinnings in total wood removals is assumed to be 20% and remain constant over the next 50 years;
- The current efficiency of harvesting activities (85%; Obersteiner, 1999) is assumed to remain constant;
- Species-specific rotation lengths and the period when thinnings can be conducted are based on current management recommendations and are assumed not to change.

CSF scenario:

- The period during which thinnings could be conducted is extended by 10 years before the final fellings;
- The harvesting volume is increased by 5% compared to the BAU scenario;
- Harvesting activities are assumed to increase in efficiency (the ratio between wood removals and fellings is increased to 90%);
- The share of thinnings in total wood removals is assumed to increase to 33%;
- Harvested pine, larch, spruce and oak-dominated forests are regenerated with improved breeding materials of the same species, which have a 25% higher growth rate;
- The share of deciduous tree species was increased to reduce forest fire risk; upon final harvest, 30% of harvested pine, larch, spruce and fir stands would be converted to forests dominated by oak, birch and lime;
- Natural afforestation in 25% of abandoned agricultural lands was included in the CSF scenario, being 123 776 ha of young deciduous species (50% birch and 50% aspen) and 52 557 ha of pine. N.B.: Considering that this natural afforestation started in the 1990s, the area of afforestation was split equally between age classes 0–10, 11–20 and 21–30 years.
- Future roundwood production and other management actions are assumed to develop similarly as in the BAU scenario;
- Additionally, harvested wood is allocated to the production of engineered wood products for construction.

5.4.3 Results

One of the requirements defined for the CSF scenario was to increase the share of deciduous tree species as a strategy to help reduce the forest fire risk.

The area of deciduous tree species (divided into soft and hard deciduous) increased a little from 2017 to 2067 in the CSF scenario, when compared to the BAU (Figure 27). This is also one of the reasons for having less coniferous (pine larch, spruce and fir) in the youngest age-classes in 2067 under the CSF scenario, as 30% of the harvested coniferous stands were regenerated with selected species of deciduous trees.

In the BAU scenario, the annual increment was projected to decline over time (Figure 28b), which is likely determined by the ageing of forest resources as shown in Figure 27. The assumed harvest level remained below the annual increment, resulting in an increase of the growing stock (Figure 28a). However, the rate of increase was slowing down, which is associated with a decline of the forest sink in Mari El over the next 50 years.

The management options in the CSF scenario resulted in an increase in the growing stock and the net annual increment when compared to the BAU scenario. This is the result of the combined effect from increasing the period in which thinnings could be conducted, increasing share of thinnings in total wood removals, increasing efficiency in harvesting activities and stimulating the regeneration of coniferous and oak with better provenances and improved breeding materials.

In the simulations, the emission balance for the living biomass stock was estimated for BAU and the CSF. Those estimations were dependent on the impact of management strategies on forest growth (Figure 29).

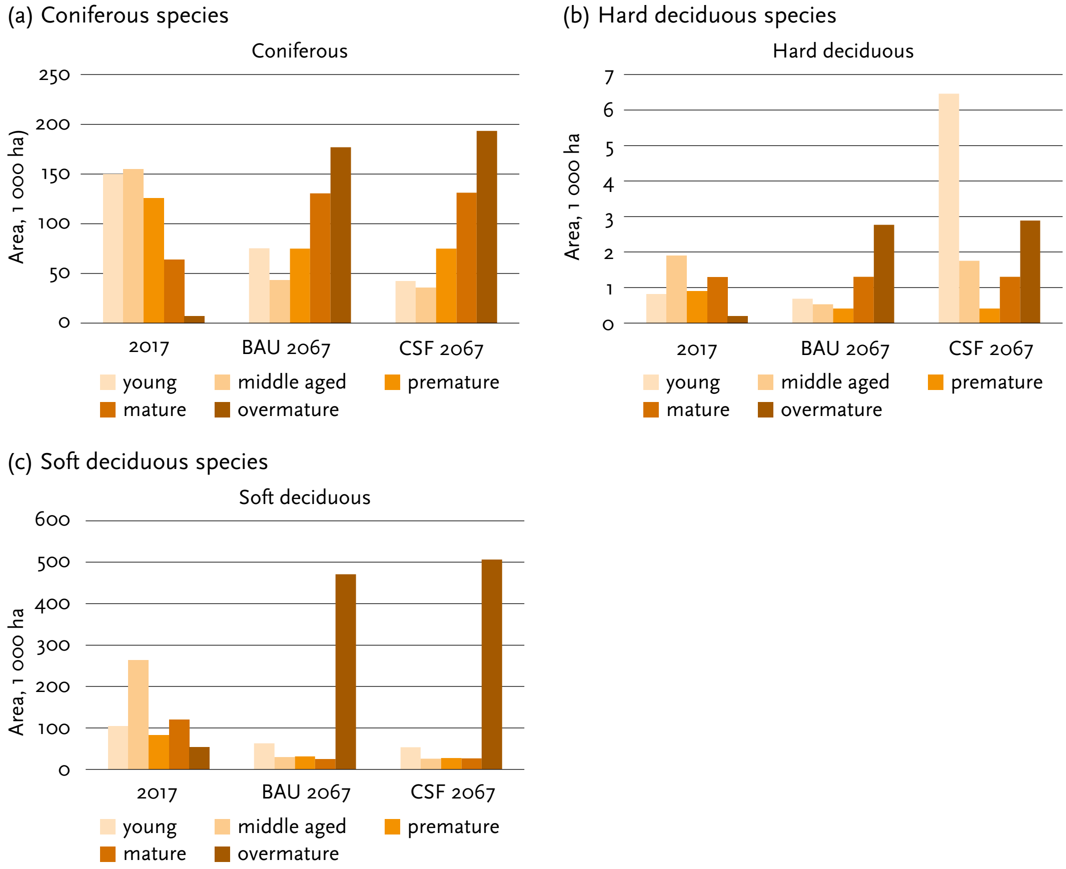

Figure 27. Age distribution of (a) coniferous, (b) hard deciduous and (c) soft deciduous tree species in 2017 and 2067 under BAU and CSF scenarios. N.B.: Age classes for conifers and hardwoods are as follows: young: 1–40 years; middle aged: 41–60 years; premature: 61–80 years; mature: 81–100 years; overmature: >100 years. Age classes for deciduous are as follows: young: 1–20 years; middle aged: 21–30 years; premature: 31–40 years; mature: 41–50 years; overmature: >50 years.

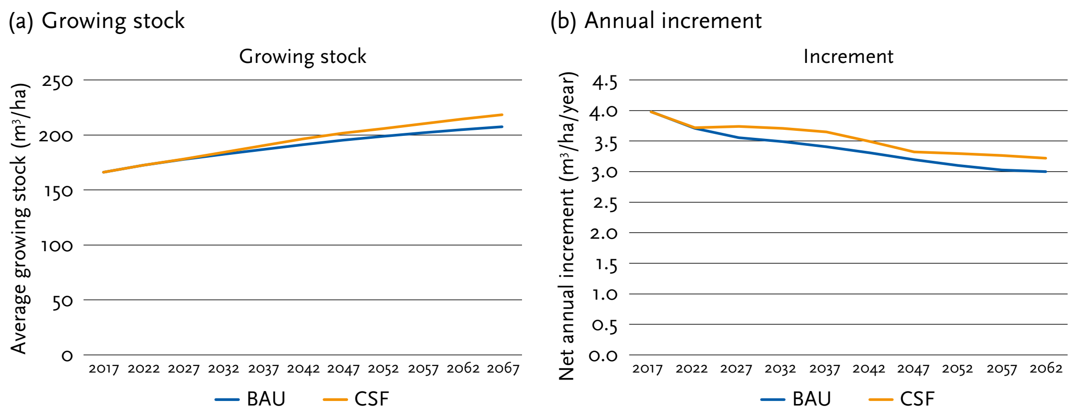

Figure 28. Projected development of (a) growing stock and (b) annual increment (including wood removals) in Mari El.

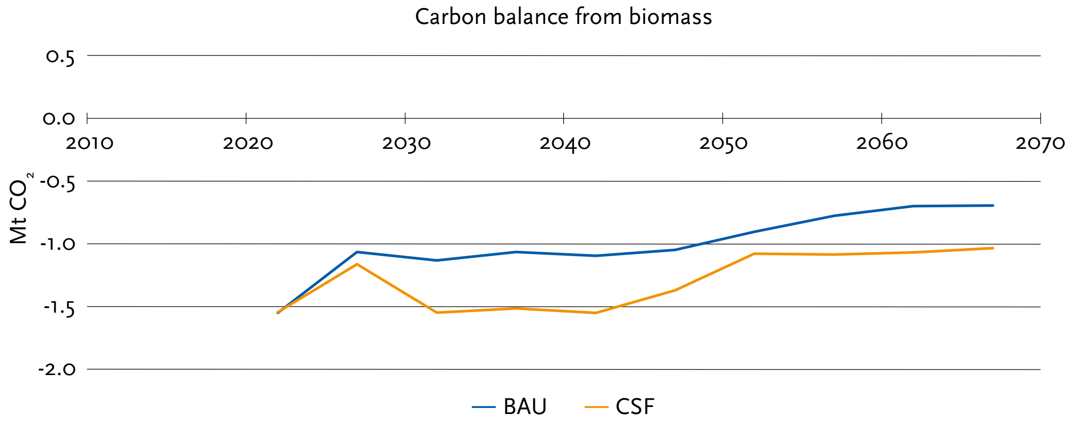

Figure 29. Carbon balance in living biomass for the BAU and the CSF scenario in Mari El. Positive values are emissions and negative values are removals of CO_2.

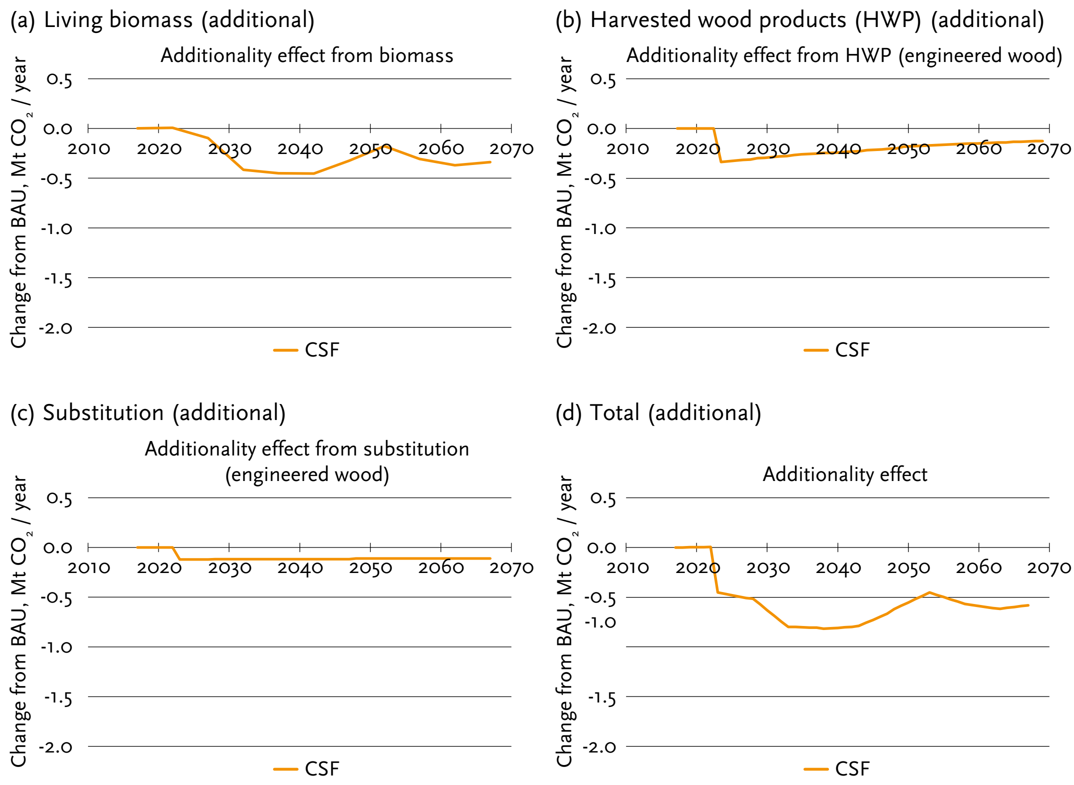

Figure 30. Projected emissions (positive values) and removals (negative values) of CO_2 for the BAU and the CSF scenario in Mari El. Results show the difference between the CSF and BAU scenarios for additionality effect from living forest biomass (a), harvested wood products (HWP) (b), substitution effect (c) and the total (d).

The measures adopted in the CSF scenario resulted in larger forest sink, compared to the BAU scenario while still increasing the level of wood production (Figure 30a). The additional harvested wood was assumed to be used for the production of engineered wood products, resulting in additional carbon stored in wood products (Figure 30b) and providing substitution benefits (Figure 30c). Altogether, the measures considered in the CSF scenario resulted in a sink of 28.4 Mt CO_2 after 50 years.

5.4.4 Key findings

The CSF management strategies adopted for Mari El resulted in a slightly larger average growing stock and net annual increment, while increasing the harvest levels with 5% compared to the BAU scenario; at the end of the 50-year period, the average growing stock was 5% higher and the net annual increment was 7% higher in the CSF scenario compared to the BAU.

The forests of Mari El were already a carbon sink and remained so (although declining) for the projected time period; the CSF scenario was responsible for a higher carbon sink compared to BAU. By adopting forest management strategies following a CSF approach, the total CO_2 emissions from living biomass were reduced for the analyzed period.

5.5

Case study: Angara macro-district (Krasnoyarsk kray)

5.5.1 Trends and issues

Description of forest resources

The Angara macro-district covers 26.4 mill. ha of forest (24% of total forest area in the Krasnoyarsk kray). The forest area is characterized by a fairly large share of mature and overmature forests (Figure 31). The forest area which is commercially managed totals 13.7 mill. ha. Only the commercial forest area was included in our simulations. There was not enough detailed information on forest area that was selectively logged or on forest reserves to initialise these two types in the EFISCEN model.

Table 6 and Figure 32 display the extent of disturbances in the different districts of the Angara macro-district in the year 2018. Insects and forest fires are the largest factors, damaging 1.1 mill. ha and 278 687 ha, respectively. However, forest fires damaged an even larger area in Krasnoyarsk kray in 2019.

Table 6. Extent of disturbances (ha) in 2018 in the different districts of the Angara macro-district.

Municipal District (within Angara macro-district)	Causes of weakening (death)						
	Anthropogenic factors	Forest diseases	Forest fires	Non-pathogenic factors	Insect damage	Weather conditions and soil-climatic factors	Total
Boguchansky	3 090	10 562	111 646	594	28 585	22 785	185 263
Yeniseisky	354	2 541	27 118	-	843 073	773	873 858
Kazachinsky	-	-	78	-	7 681	-	7 759
Kezhemsky	9 930	2 610	53 243	-	8 976	425	75 184
Motyginsky	20	4 321	36 421	-	16 254	429	57 444
Pitovsky	555	2 042	514	28	23 362	725	27 225
Severo Yeniseisky	-	1 400	41 667	-	178 357	8 249	229 673
Total	**13 949**	**23 475**	**278 687**	**622**	**1 106 287**	**33 386**	**1 456 407**

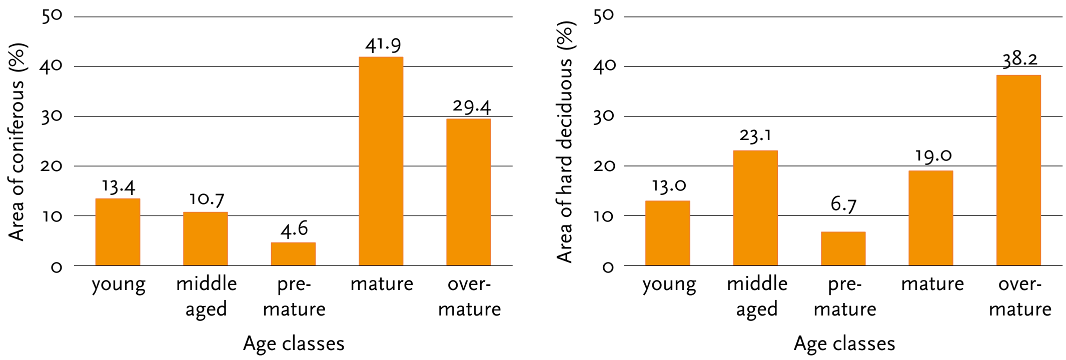

Figure 31. Age structure for coniferous (left) and deciduous (right) species in Angara macro-district, totaling 13.6 mill. ha.

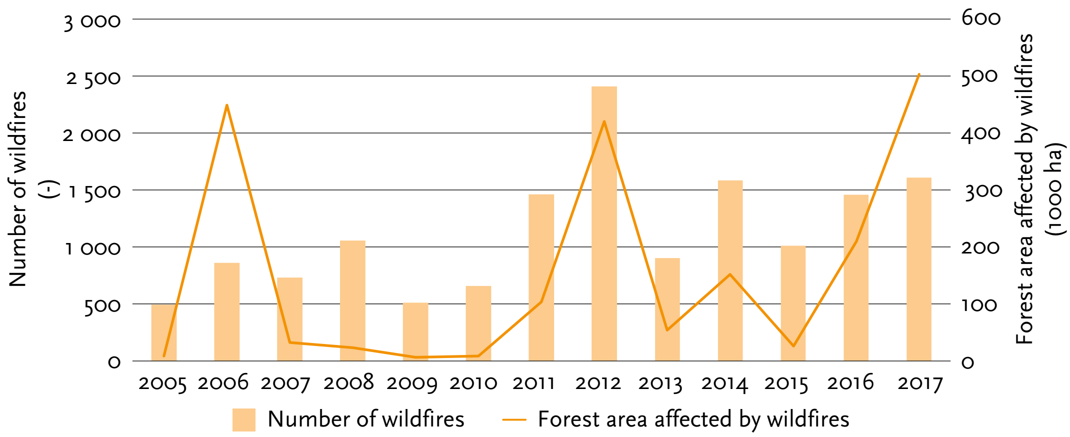

Figure 32. Dynamics of forest fires in the Krasnoyarsk kray for 2005–2017.

5.5.1.2 Description of the forest sector and wood use

Most areas of the province with large reserves of wood are at large distance from the road network and hence there is low forest exploitation. About 20% of the total amount of wood produced in the Russian Federation comes from the Krasnoyarsk kray. Harvest in Krasnoyarsk kray has increased sharply in recent years from about 14 mill. m^3 in 2010–2013 to nearly 29 mill. m^3 in 2018, of which 57% came from the Angara macro-district.

The main products of the forest complex of this territory are roundwood, lumber, fiberboards, pellets, briquettes, and wood panels. The production of fiberboard, pellets and wood panels is done mainly by large producers of the forest complex of the Krasnoyarsk kray (from 99% to 100%). They account for 25.7% of the volume of logging, 26.4% of the production of roundwood, 53% of the production of lumber. The rest of the production comes from small private producers. The total amount of investments used at the end of 2018 was 430 mill. USD, the average percentage of development of funds planned for this period was 23% (1.9 bill. USD). According to public information published by the Federal Customs Service in 2017, the export of unprocessed timber amounted to 1.3 mill. m^3, the same export volume of processed timber.

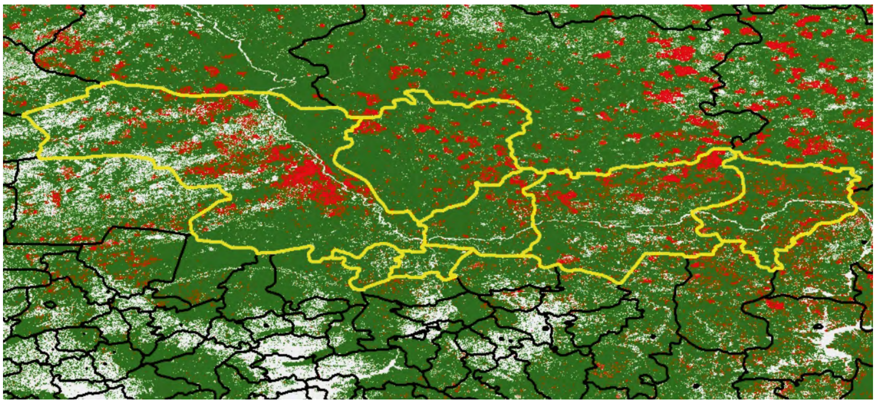

Figure 33. Tree cover changes in the Angara macro-district. The area is within the yellow lines, tree cover is shown in green, tree cover loss, i.e. harvesting and disturbances, is shown in red and the white areas are agricultural lands. Source: Hansen et al., 2013.

Figure 34. Checkerboard type of clearcut visible here through one clearcut block. Photo: Forest Protection Service of the Krasnoyarsk kray.

Figure 35. Typical mature middle taiga forest consisting of spruce mixed with birch. Photo: Forest Protection Service of the Krasnoyarsk kray.

5.5.2 Scenarios

The rationale of the BAU scenario is that existing trends are largely continued and that no additional efforts are implemented to use forestry as a measure to mitigate climate change or to modify management practices to improve the resilience of forests in Angara macro-district. Specifically, the following actions are assumed:

BAU scenario:

- Harvest levels are assumed to remain stable at the absolute level of the 2018 harvest rate; i.e. 16 mill. m^3/year total from thinning and final felling;
- Current tree species composition is maintained;
- 10% of the total fellings come from thinnings;
- The current efficiency of harvesting activities (85%) (Obersteiner, 1999) is assumed to remain constant;
- Species-specific rotation lengths and the period when thinnings can be conducted are based on current management recommendations and are assumed not to change;

CSF scenario:

- Harvest levels are assumed to decrease to a level that maintains the existing growing stock; i.e. 12 mill. m^3/year from the total of thinning and final felling;
- Harvesting activities are assumed to increase in efficiency (the ratio between wood removals and fellings is increased to 90%);
- The share of thinnings in total wood removals is assumed to increase to 50%;
- Upon final harvest, 30% of harvested pine and larch area would be converted to forests dominated by birch to reduce wildfire risk and 70% is regenerated with improved breeding materials of the same species, which have a 25% higher growth rate;

CSF measures should also address wildfire risk, but these effects could not be modelled.

5.5.3 Results

In the simulations, the emission balance for the living biomass stock, HWP and material substitution effects were estimated for BAU and the CSF scenario. Those estimations were dependent on the impact of management strategies on forest growth and the amount of timber removed from the forest (Figure 36).

The CSF scenario has a significant effect on growing stock and increment compared to the BAU scenario. In order to keep the growing stock in the forest at a stable level the harvest level was reduced in Angara macro-district in the CSF scenario and the lower harvest level (compared to BAU) causes the growing stock to increase at a small rate. This measure was combined with an increased share of thinnings, regeneration with improved breeding materials and a decreased harvest level. The increment in the CSF scenario increases at a higher rate than the BAU scenario, primarily due to the application of improved breeding materials and an increased share of wood coming from thinnings. The measures in the CSF scenario lead to a more balanced age distribution, compared to the BAU scenario (see Figure 37).

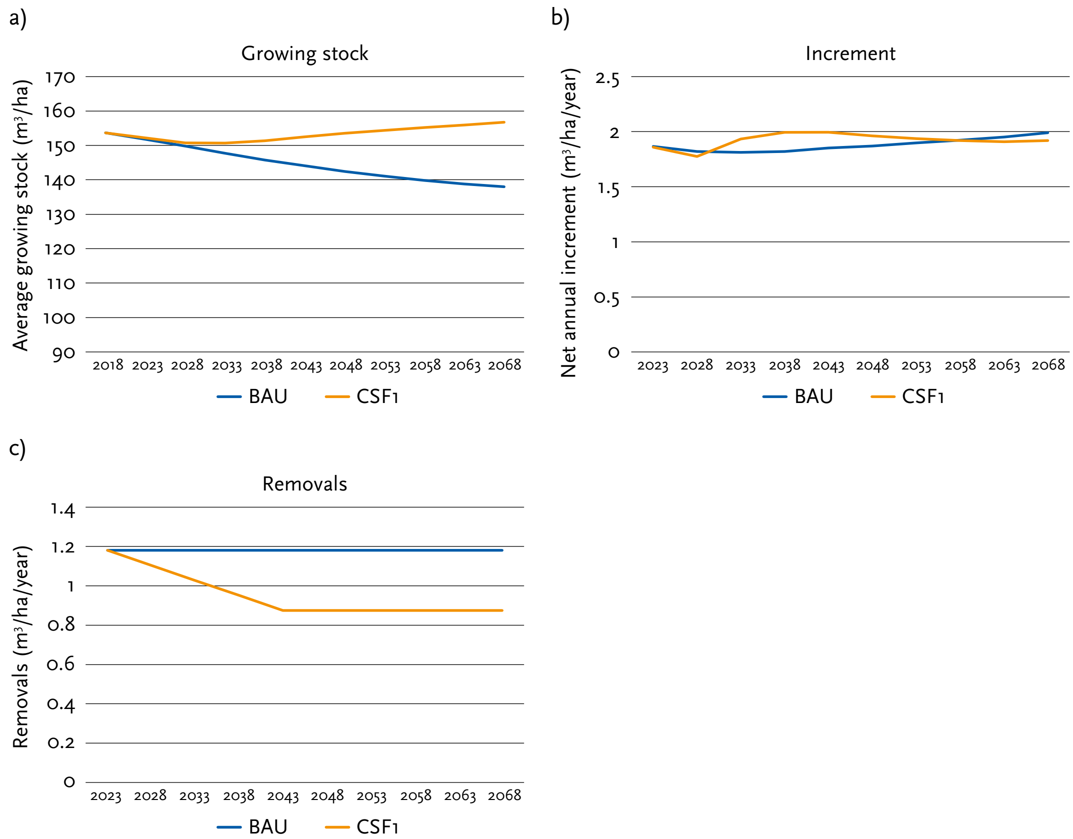

Figure 36. Projected development of a) growing stock, b) annual increment and c) roundwood removals in Angara macro-district under BAU and one alternative.

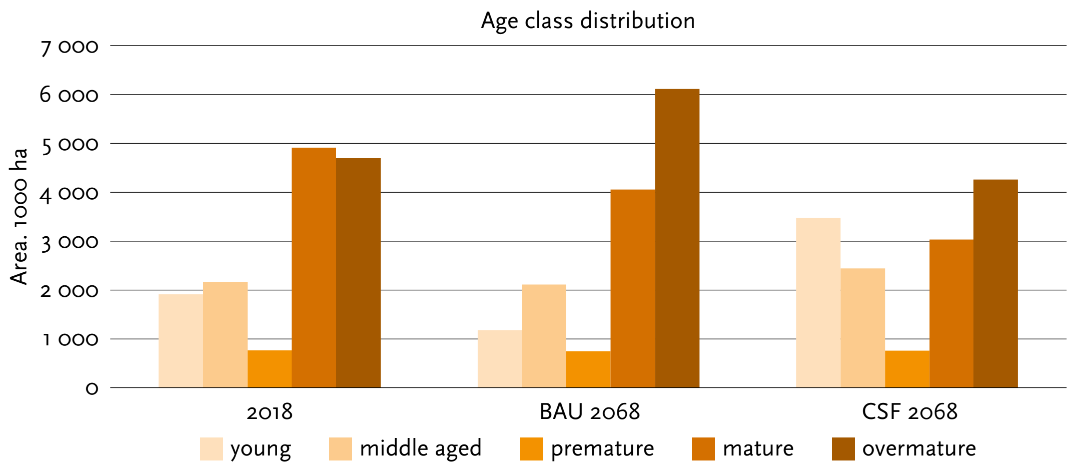

Figure 37. Age distribution for BAU in 2018 and for BAU and CSF after 50 years.

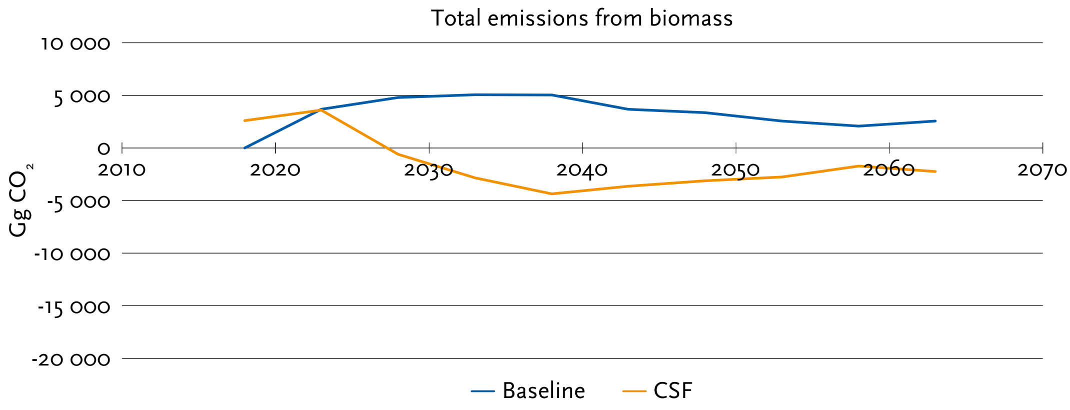

Figure 38. Projected emissions (positive values) and removals (negative values) of CO_2 from living forest biomass in Angara macro-district under BAU and CSF.

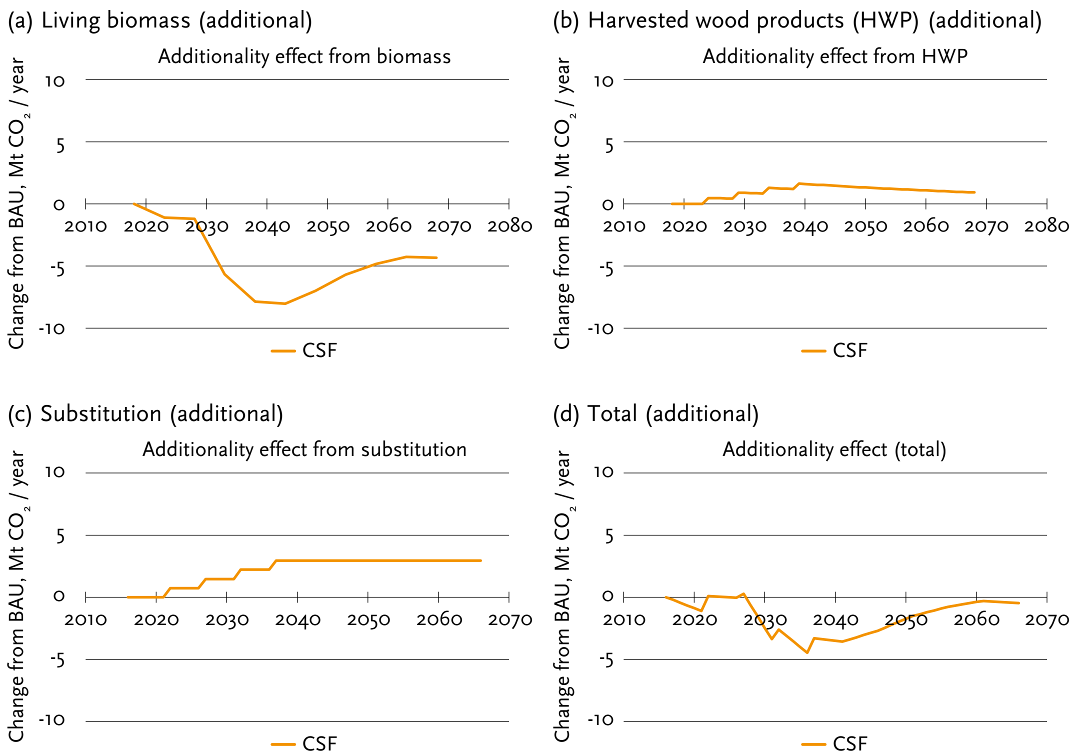

Figure 39. Projected additional emissions (positive values) or removals (negative values) of CO_2 for between the BAU and the CSF scenario in Angara macro-district. Results show the difference between the CSF and BAU scenarios for additionality effect from living forest biomass (a), harvested wood products (HWP) (b), substitution effect (c) and the total (d).

The carbon balance in biomass shows a carbon source in all scenarios at the start of the simulations (Figures 38 and 39). This effect is due to the high harvest level, with higher removals compared to the increment. The net carbon source turns into a net sink in the CSF scenario after 25 years.

In order to keep the growing stock in the forest at a stable level the harvest had to be reduced in Angara macro-district in the CSF scenario. This means less wood is available for HWP and thus additional emissions for the HWP itself and for the substitution effect as can be seen in Figure 39.

5.5.4 Key findings

Harvest levels in the Angara macro-district have increased rapidly in recent years, with a large share of the wood coming from final harvest (clearfelling). Our projections show that this harvest level cannot be sustained over a longer period of time. The stock of old growth forest shows a very small annual increment rate (estimated at approximately 1.7 m^3/ha/year) and under the current harvesting level, the growing stock was projected to decline rapidly from 153 m^3/ha currently to 138 m^3/ha in 50 years.

Consequently, the forests are estimated to act as a source of carbon in the BAU scenario of some 5 Mt CO_2/y after 20 years, gradually declining to some 2 Mt CO_2/yr after 50 years. In the CSF scenario, the carbon source is projected to decrease. In the CSF scenario, the carbon source turns into a carbon sink after 15 years. However, due to the lower harvest level in the CSF scenario, there is less production of HWP resulting in net emissions from HWP and substitution (i.e. wood products no longer produced are assumed to be replaced by fossil-intensive products).

Wildfires are major disturbance agents in the Angara macro-district. However, wildfire risks could not be modelled in EFISCEN, although measures to reduce wildfires risk have been modelled. The share of deciduous forests, which are less prone to wildfires, can be increased. This has been implemented in the CSF scenario, by means of planting birch on 30% of the pine and larch clearcuts.

A measure to improve the infrastructure by constructing roads cannot be modelled in EFISCEN. The effect of a better infrastructure on wildfires are also not clear. Improved infrastructure may facilitate access to firefighters to suppress and extinguish wildfires but may also increase the risks of human-induced wildfires. On the other hand, access via roads may also increase harvesting pressure, and/or may be a prerequisite to improve forest management (Niskanen et al., 2003).

5.6

Concluding remarks, discussion and implications

In this chapter, we applied the CSF approach to three case studies in Russia, so as to provide insights into the climate change mitigation potential of alternative strategies while creating options for the Russian woodworking forest sector. Due to the significantly varying regional circumstances across Russia, we analysed a portfolio of CSF measures that were specific for each region and together provided climate benefits. Our results complement the study by Nabuurs et al. (2018) on CSF in three European countries. We did not follow the conventional climate accounting rules. Instead, we sum the impacts of the forests and forest sector to CO_2 mitigation as the atmosphere "sees it". If emissions are reduced, these reduced emissions are, according to current emission reporting rules reported by other sectors (e.g. the energy sector), but in our study, we attributed the wood products substitution effects to the forest sector. We did not consider bioenergy; large scale production of pellets has not started yet in these three regions.

We did not consider all possible mitigation measures and did not optimise or maximise them. Instead, we tried to design mitigation measures taking into consideration the local conditions and infrastructures and analysed their impacts by considering all carbon pools and substitution effects. These measures could include increasing harvest levels to be able to increase the resilience of forests. Drastic but needed conversions that could temporarily cause forest ecosystems to act as a source may also be part of a long-term mitigation strategy.

All CSF measures were implemented at a pace that was judged realistic, but still with additional effort towards climate mitigation compared to the current management. We summarise the mitigation impacts of all measures for each case study in Table 7. In all three case studies, we considered that, under CSF, forests dominated by coniferous species (pine, spruce, and larch) would be regenerated with improved breeding materials of the same species with a 25% higher growth rates. These growth gains are large, but in line with expected growth gains that are considered achievable in the Baltic and Nordic countries (Rytter et al., 2016). The introduction of better adapted tree species and improved breeding material can mainly be achieved through artificial regeneration. However, natural regeneration is the dominant means of forest regeneration in the three case studies at the moment. This leads to increases in areas of birch and aspen, of which only birch has some commercial value. Changes are therefore needed to how forests are currently regenerated and managed. In these large forest areas this will require a large effort and a large investment, even when done at the gradual pace as simulated here.

Similarly, we assumed in all case studies an increase in the share of thinnings. This may not be in line with current practices and guidelines. Thinnings are currently executed to a very limited degree. Increasing the share of wood coming from thinnings could result in significant gains in carbon storage in biomass because the forest cover is maintained and higher quality wood products can be produced. Thinning more will not negatively affect the total roundwood production volumes, as we see from the results for Karelia and Mari El. To implement the CSF measures in practice, a change is thus needed to how forests are currently managed.

Table 7. Summary of the average annual additional mitigation impacts over a 50-year period due to CSF ($Mt\ CO_2$/year). A negative number denotes an additional climate mitigation effect vis-à-vis BAU.

Case study		Republic of Karelia			Republic of Mari El	Angara macro-district (Krasnoyarsk kray)
Scenario		CSF1	CSF2	CSF3	CSF	CSF
Forest area included (mill. ha)		9.3			1.4	13.6
Scenario		CSF1	CSF2	CSF3	CSF	CSF
Additional mitigation in pools:	Living biomass	-4.81	-0.69	-4.33	-0.27	-4.83
	HWP	-0.10	0.03	-0.07	-0.19	1.00
Material substitution		-1.34	0.43	-1.23	-0.10	2.21
Total mitigation effects for the whole region *($Mt\ CO_2$/year)*.		-6.25	-0.24	-5.63	-0.56	-1.44
Total mitigation effect ($Mg\ CO_2$/ha/yr)		-0.67	-0.03	-0.61	-0.51	-0.11

The estimated climate benefit of CSF varies from region to region depending on the baseline management, which is considered a continuation of current practices. As shown in Table 7, CSF led in all three regions to an improved CO_2 balance (additional sink and/or substitution), although effects are relatively small (in these slow growing systems) with a maximum additional benefit of ~0.7 Mg CO_2/ha/yr.

In this chapter, we present the outcomes of model-based scenario analyses. These scenarios should not be understood as what will happen or what is most likely to happen in the future, but what could happen if certain measures would be taken at a certain pace and if other assumptions remain unchanged. Obviously, there are many uncertainties (e.g. future forest management, wood market development, climate change, etc.) that affect the future development of Russian forest resources. Climate change will likely affect tree species range, productivity and disturbances (see Chapters 3 and 4). While we anticipated in our scenarios the impacts of climate change by formulating management options to increase the resilience of forests to climate change (e.g. a change of tree species), we did not consider climate change impacts as such in terms of likely growth rate changes. Furthermore, disturbances could not be included because of the lack of detailed data for the case studies and the difficulty to model their impacts. Hence, it was not possible to quantitatively assess their influence on the future forest resource development and forest carbon balances. However, ignoring the impacts that climate change may have may underestimate the benefits that CSF could provide.

The outcomes of the presented scenarios critically depend on the quality of the data that have been used as a basis for the projections. Firstly, we tried to use as much as possible the best available Russian data, but not all required data were available. For example, for increment we had to use yield tables and instead of data from Russian forest inventories. The main reason for this was that the concepts on annual increment differ between Russian and western European forestry (Pisarenko et al., 2000). For our simulations we needed net annual increment, which includes the increment on trees, which have been felled during the reference period, but excludes trees which have died during the reference period (UNECE-FAO, 2000). However, the increment reported in the Russian inventories refers to the remaining growing stock and thus excludes the growth of trees that have been cut.

Secondly, wood removals are a key factor that determine the development of forest resources and their associated carbon balances. Data on wood removals are usually associated with uncertainty and this will also apply to Russian conditions. Such uncertainties could relate to the reported volumes and assortments of wood felled and removed from the forests, losses of wood during harvest and transport, and the consumption of residential fuel wood (cf. Obersteiner, 1999).

Thirdly, we included the carbon pools in forest biomass and HWP and considered the effects of substitution, but we excluded impacts on the soil carbon pool. While this carbon pool is considered to be very important for Russia, we could not assess impacts of the scenarios on these pools because the data on the initial state are too uncertain and because the current sink/source functioning of the permafrost is too uncertain. Normally the soils would be frozen for 4–6 months, allowing machines to operate, but there are indications that with climate change it becomes increasingly difficult to harvest wood in the winter period (Global Wood Markets Info, 2020). Under current unfrozen conditions, the soil damage will be large, resulting in large soil carbon losses. Furthermore, most soil model can only deal with mineral soils not with peat soils which are very extensive in Russia. We may assume however that with less clear-cuts, the CSF approach may be beneficial for the soil carbon.

In our analyses, we focused on the effects of forest management, but there are also other forest-related measures that could provide mitigation benefits. The Russian Federation is considered to have a large potential for afforestation or restoration; for example, Bastin et al. (2019) estimated that 151 mill. ha could be restored, which may provide mitigation potentials of up to 351 Mt CO_2/year (Griscom et al., 2017). We did not focus on afforestation and restoration in our case studies, mainly because the three case studies are mostly forested regions with limited possibilities for additional afforestation. However, afforestation may be very relevant for other Russian regions.

Overall, our results indicate that more active management particularly affects the development of the forest biomass carbon sink in the coming decades. For all three case studies, we show that a larger share of thinnings, regeneration with improved breeding materials, improved harvest efficiency and other measures can increase the forest biomass carbon sink and for case studies in Mari El and Karelia also the HWP balance improves compared to a development without such measures. In Angara macro-district, harvest levels had to be decreased to reach sustainable levels. Together with the other measures, this improves the forest biomass carbon balance, but worsens the HWP and substitution balance. The exact substitution effect will depend on the type of wood product, the type of non-wood material that is replaced and the post-use fate of the wood (Leskinen et al., 2018). Properly accounting for substitution effects – and attributing them to the forestry sector – is crucial to define optimal (forest management) strategies to mitigate climate change.

Altogether, the results from our case studies show the possibilities and the limitations of forestry in Russia. The generally limited productivity in Russia, the required rate of implementation (e.g. of improved growth rates after clearfelling), the difficulties of implementing better practices in the field, the remoteness of many areas in combination with limited transportation network and very long hauling distances, will make it in practice very difficult to implement the scenarios as portrayed here. Developing regional action plans including required investment funding is a required first step.

5.7

Key messages

- Climate Smart Forestry can help to both increase forest productivity and harvesting while maintaining the sink at a higher level
- Artificial regeneration is a means to be able to introduce better adapted tree species and provenances using improved breeding material. The use of these better site-adapted species and high-quality forest genetic resources can increase the productivity and reduce susceptibility of forests to disturbances
- Increasing the share of thinnings in total wood removals maintains forest cover and allows to select better performing trees. Increasing the share of thinnings contributes to maintaining a large forest carbon sink
- Increasing the forest protected areas in the Russian Federation will contribute to maintaining the carbon stocks in tree biomass while it can help to concentrate the sustainable management investments in other areas.
- Turning more of the harvested forests into long-lived wood products or with large substitution benefits will increase the mitigation benefits from the CSF scenario.

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