What Science Can Tell Us

Russian forests and climate change

Pekka Leskinen, Marcus Lindner, Pieter Johannes Verkerk, Gert-Jan Nabuurs, Jo Van Brusselen, Elena Kulikova, Mariana Hassegawa and Bas Lerink (editors)

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Executive summary

The key aim of this report is to show how the forest sector can help the Russian Federation to meet its Paris Agreement targets and, at the same time, how the sector can contribute to improve the economy. This is linked to building an innovative strategy of sustainable forest management, addressing conservation as well as productivity, emphasizing the country's aims of low carbon society, boosting the investment sector on forest products and introducing technical innovation measures of the bioeconomy, as represented by new and emerging wood-based products.

We provide a systematic analysis of the Russian Federation's forest resources; their potential for carbon sequestration and contribution to the Paris Agreement targets; the impacts of climate change; and the risks associated with biotic and abiotic disturbances. We also present three regional case studies with varying degrees of opportunities and solutions for protecting forest resources and enhancing ecosystem services both for carbon sequestration and for wood-based products, using the framework of Climate Smart Forestry (CSF). We also look at the climate change mitigation potential and opportunities arising from forest bioeconomy and the transformation of Russia towards a low carbon society including various innovative solutions for new wood-based products and industrial sectors.

This report synthesizes the current scientific understanding on Russian forests and climate change, and identified the opportunities as well as challenges with respect to adaptation, mitigation and bioeconomy. The key findings and recommendations for the next steps can be summarized as follows:

- Currently, Russian forests represent a large carbon sink, but there are also large areas in the Northern and Eastern parts of Russia, which act as a carbon source. These areas are typically located either on permafrost or in disturbed forests. However, the several years of large wildfire disturbances with subsequently increased tree mortality may lead to substantial decrease of the Russian forest carbon sink.
- Future natural disturbance impacts are critical: attention should be paid to preventing of disturbances and enhancing forest restoration/reforestation. Climate change impacts will put the current forest sector severely at risk. The potential to reach the Paris Agreement targets through a significant contribution of the bioeconomy cannot be achieved without active forest management with a strong focus on natural disturbance prevention and enhancing forest resilience.
- Investments in sustainable and climate-smart forest management are needed and should be aimed at long-term goals rather than short-term lease contracts, as well as to improved infrastructure especially in the accessible forests. Without active, climate-smart forest management, the potential of bioeconomy can-

not be achieved. In other words, investing in bioeconomy would enable funding for improved forest management and infrastructure, which could further lead also to protecting biodiversity and ecosystem services.

- Another important focus is forest restoration since there most likely will be large-scale natural disturbances also in the future. If the aim is to sustain and even enhance the forest sector contribution to climate change mitigation, active support for large scale forest restoration would be needed.
- Regional differences should be taken into account when developing action plans for implementation.
- A holistic view is needed for effective climate change mitigation and adaptation as well as biodiversity protection. Climate-smart forestry is proposed to connect mitigation with adaption measures, enhance the resilience of Russian forest resources and ecosystem services, and meet the needs of society.
- Successful development of bioeconomy markets linked with circular economy can create a new economic foundation instead linear economy based on fossil materials.
- Implementation of the research results in practice would be the next challenge, and successful utilization of forest resources in the future would strongly depend on the evolution of forest governance. The potential benefits from concepts such as Climate Smart Forestry requires major changes in policies and management responsibilities. The following topics are suggested for further consideration and for implementation:
  - Improving forest policy by taking into account forest-based circular bioeconomy development and effective climate change mitigation and adaptation
  - Developing national strategy, and national and regional action plans for forest-based circular bioeconomy development
  - Improving national forest inventory and forest monitoring taking into account integration of modern ground-based measurement methods and remote sensing capabilities
  - Developing forest management on abandoned agricultural lands for preventing disturbances, and for improved wood production and carbon sequestration
  - Considering the possibilities for emerging sectors of bioeconomy such as using wood in construction, textiles, and biofuels production, with respect to economic development and deep decarbonization targets

1.

Introduction

Riccardo Valentini, Pekka Leskinen, Pieter Johannes Verkerk, Gert-Jan Nabuurs, George Safonov and Elena Kulikova

The Russian Federation has large forest resources and a need for economic transition towards decarbonization following the sustainability targets of global environmental policies. By focusing more on the role of the forest sector in climate change adaptation and mitigation, and on new opportunities of an emerging forest-based bioeconomy, the Russian Federation can play an important role in global climate policies.

The Paris Agreement requires major societal and economic reforms to ensure that the global average temperature rise at the end of century remains well below 2°C pre-industrial levels with an additional effort to get close to 1.5°C. The recent UN Environment Programme (UNEP) Gap Report (2019) warns that with current policies and plans, it will not be possible to keep the 1.5°C target and it will be extremely unlikely to keep even the 2°C target. An annual 7.6% decrease of global greenhouse gas emissions between 2020 and 2030 would be needed to get on track towards the 1.5°C goal.

In addition to the Paris Agreement, the fight against climate change is part of a more comprehensive challenge, which is grounded on the Agenda 2030 and its transformative approach to sustainable development. In particular, the Sustainable Development Goals (SDGs) represent a set of universal goals that meet the urgent environmental, political and economic challenges facing our world.

Forests and the forest sector can have a significant role with SDGs and the climate policy agendas in reducing carbon dioxide concentration in the atmosphere, accelerating the decarbonisation of global economy and improving the socio-economic conditions of rural communities and protecting the environment. In other words, investing in forests could provide benefits on many individual SDGs and produce synergies and win-win solutions with multiple goals simultaneously. This makes the forest sector important when aiming to implement new policies in practice.

In the context of climate change, while reducing deforestation and forest degradation lowers greenhouse gas emissions, forest management can maintain or enhance forest carbon stocks and sinks. Wood products can store carbon over medium and long-term, as well as substitute for emissions-intensive materials such as concrete and steel in the construction sector (IPCC, 2018). Furthermore, forest carbon sinks could be enhanced to compensate the remaining anthropogenic emissions such as the ones coming from energy, and transport sectors. The 2017 UNEP Gap Report noted that the agriculture and forestry sectors are amongst the most cost-effective and therefore attractive means to bridge the gap in ambition to achieve the Paris Agreement's temperature goal. Presently the land use, land-use change and forestry (LULUCF) sector is expected to contribute to about a quarter of the pledged global emission reductions in Nationally Determined Contributions (NDCs) (Grassi et al., 2017).

Russia was persistent and rather successful in promoting the role of forests during the negotiations of the Paris Agreement. As indicated in its Intended Nationally Determined Contribution (INDC), the Russian Federation has committed to limit 2030 emissions to 75% of 1990 levels, under the condition of full accounting of forest carbon sinks (from the current emission level of approx. 50% below 1990). The overall Paris Agreement target of reaching climate neutrality in the 21st century calls for ambitious mitigation goals, in which forest sinks can play a significant role. It is therefore important to understand in detail what the opportunities and challenges for the role of Russian forests could be in implementing the Paris Agreement. This holds true with future development of forest ecosystems and forest management, as well as the required transformation of society and its decarbonisation. Overall, the aim is to secure the sustainability of forest ecosystem service provisioning and at the same time, maintain economic opportunities and well-being.

'*Natural climate solutions*' (Griscom et al., 2017) have been suggested as important means to mitigate climate change that can contribute up to 37% (23.8 Pg CO_2 eq. / year) of the required global emissions reduction by 2030. Approximately two-thirds of the total mitigation potential from these natural climate solutions could be achieved by storing carbon in forest ecosystems (Griscom et al., 2017; Roe et al., 2019) and the rest with material substitution. However, forests, which are the primary source for non-food and non-feed renewable biological resources globally, are under unprecedented pressure from climate extremes, as manifested by the increase of forest fires, storm damages and pest outbreaks. Climate change is expected to further exacerbate these disturbances, together with other impacts on forests and soils, such as productivity changes, tree species changing, permafrost thawing, etc. There is thus a need to adapt to the impacts of climate change in addition to mitigating climate change. Adaptation is needed for forest resilience and for continuing to provide ecosystem services to the society. As Russia has such vast, and partly remote, forest resources, it is important not only to mitigate climate change but also to reduce or prevent related disturbances, which may push the overall carbon balance of Russian forests from being a sink to a source of carbon. Unfortunately, mitigation and adaptation are often not considered together in national strategies for implementing actions under the Paris Agreement (i.e. NDCs).

There is a need for new, more efficient approaches to forestry and forest management and planning. Climate-Smart Forestry (CSF) (Nabuurs et al., 2017; Verkerk et al., 2020) could be a useful approach to connect mitigation with adaption measures, enhance the resilience of forest resources and ecosystem services, and meet the needs of a growing population and expanding wealth in the society. CSF is grounded on the concepts of sustainable forest management, with a strong focus on climate and ecosystem services. It builds on three mutually reinforcing components:

- Increasing carbon storage in forests and wood products, in conjunction with other ecosystem services by taking into account related climatic and anthropogenic vulnerabilities;
- Enhancing the health and resilience of forests through adaptive forest management; and
- Using wood resources sustainably to substitute non-renewable, carbon-intensive materials.

The bioeconomy development can play an extremely important role of deep decarbonization in the Russian economy. Wood-based biofuels (solid, liquid and gaseous) can substitute a large share of domestic fossil fuel consumption and become highly demanded export products for Russian businesses; bio-textile production is a low carbon alternative for traditional textiles with promising perspectives in the world markets; bioplastics and many other products using wood biomass with low carbon footprint are potentially the large-scale market changers in the new low carbon economy, where Russia has an opportunity to become a world leader. The country has the natural resources and human capital to expand the bioeconomy sectors, and thereby reach the national goals of modernization, introduction of innovations, and efficiency improvement.

The key aim of this report is to show how the forest sector can help Russia to meet its targets of the Paris Agreement and, at the same time, how the sector can contribute to improve the economy. This is linked to building an innovative strategy of sustainable forest development, addressing conservation as well as productivity, emphasizing the country's aims of low carbon society, boosting the investment sector on forest products and introducing technical innovation measures of the bioeconomy, as represented by emerging wood-based products.

This report has seven main chapters. After this Introduction, Chapters 2–4 deal with a systematic analysis of the Russian Federation's forest resources; their potential for carbon sequestration and contribution to the Paris Agreement targets; the impacts of climate change; and the risks associated with biotic and abiotic disturbances. Chapter 5 analyzes three regional case studies with varying degrees of opportunities and solutions for protecting forest resources and enhancing ecosystem services both for carbon sequestration and for wood-based products, using the framework of Climate Smart Forestry. Chapter 6 presents the climate change mitigation potential and opportunities arising from forest bioeconomy and the transformation of Russia towards a low carbon society including various innovative solutions for new wood-based products and industrial sectors. Finally, Chapter 7 summarizes the main overall findings of the report.

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2.

State of Russian forests and forestry

Dmitry Zamolodchikov, Anatoly Shvidenko, Sergey Bartalev, Elena Kulikova, Alexander Held, Riccardo Valentini and Marcus Lindner

2.1 Major characteristics of Russian forests

Dmitry Zamolodchikov, Anatoly Shvidenko and Sergey Bartalev

The term "forest resources" is used in many ways in Russian forest literature. In a narrow, product-oriented sense, forest resources include the growing stock volume and non-timber products in forests and other land covered by tree and shrub vegetation (Moiseev, 1974). In a wider sense, forest resources refer to forested areas, including all biotic components (plants, animals, fungi, microorganisms) on land as well as their associated features that create forest environments and a broad range of products and services (Sheingauz and Sapozhnikov, 1983).

The Russian system of classification of forest related land is rather complicated, as shown in Figure 1. It is important to understand that official forest inventories only consider land managed by the state forest authorities, i.e. the forest fund (see Box 1). Land abandonment and natural succession can result in tree cover also on other land areas. Such areas may meet the criteria of the national forest definition, but they are excluded from official forest inventories. However, forest resource assessments based on satellite imagery do not distinguish forest fund land and other land with forest cover, which explains considerable differences in forest area references between official (inventory-derived) information and other assessments.

Russia has the largest area of forest in the world. Table 1 presents a compilation of recent forest statistics of the State Forest Register.

Table 1 does not include areas covered by forests on land not accounted for by state forest statistics. After the social and economic reforms which began in the early 1990s, 48–56 mill. ha of agricultural lands were abandoned (Kotlyakov and Luri, 2012). Natural

Box 1. Definitions of important forest land categories.

Forest fund – all land managed by the state forest authorities

- forest land – land designated for growth of forests
- non-forest land – land that is either unsuitable for forest growth, or intended for other purposes related to forestry

Forest land is further divided into

- forested area – forest land covered by forest at the moment of the inventory (according to national definition of forest*), and
- unforested area – land designated for forest, but temporarily without forest cover, including burnt areas and dead stands due to disturbances impacts, clear-cuts and regeneration areas as well as sparse forests not meeting the national definition of forest

* National forest definition in Russia (following Lesoustroitelnaja Instrukzija, 2018): Forest is defined as land covered by i) forest vegetation including forest stands of natural and artificial origin (with a relative stocking of at least 0.4 for young forests and at least 0.3 for other forest stands), ii) shrubs (where tree species cannot grow due to harsh natural conditions or dedicated shrub farms including willows, nut-bearing, and industrial crops), iii) forest tree plantations in short rotation.

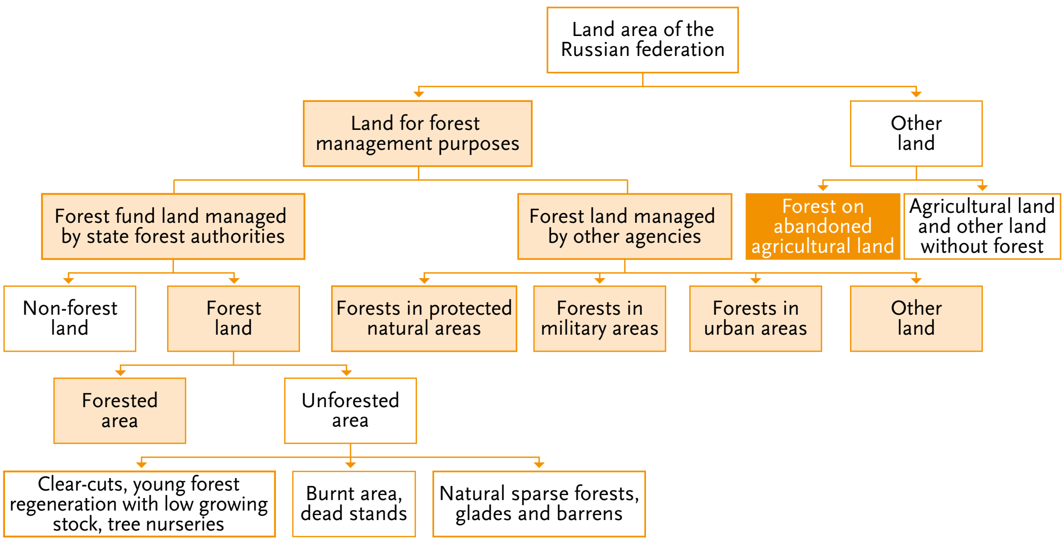

Figure 1. Overview of land-use/land cover categories of Russian forests. The shaded boxes are indicated as forest land according to the national forest definition in official statistics (see Box 1). Forest on abandoned agricultural land includes areas outside of official forest statistics that may be detected as forest with remote sensing observations.

Table 1. Area of major forest cover categories in Russia, mill. ha (cf. Figure 1). Source: Russian Ministry of Ecology and Natural Resources, 2015.

Land with forest in the Russian Federation accounted by official statistics	Area of land with forests, mill. ha				
	Total	Forest land	Forested area on forest land		
			Total	Including forests with dominance	
				coniferous	hardwood deciduous
Forest fund land	1146.30	864.54	770.12	524.69	18.24
Forests in urban areas	1.44	1.20	1.13	0.39	0.97
Forests in protected natural areas	26.68	17.77	16.76	11.14	0.76
Forest land of other categories	8.76	7.34	6.51	2.34	0.51
Total	1183.2	890.86	794.51	538.56	19.61

succession and increasing tree cover (Lyuri et al., 2010) occur on 39.1 mill. ha of abandoned agricultural land, according to recent remote sensing estimates (Lesiv et al., 2018). The latest estimate of forested area on abandoned arable land (i.e. area with tree cover that meets the forest definition) is around 18 mill. ha (Schepaschenko et al., 2015a).

The data of the State Forest Register (SFR) should be used with caution because a substantial part of the data is outdated with unknown bias. According to the official SFR data, about 50% of Russian forests were last inventoried about 30 years ago. Recently several "wall-to-wall" estimates of the Russian forest area based on remote sensing data have been published. An assessment with a spatial resolution of 150 m estimated the total forested area at 757.7 mill. ha (Schepaschenko et al., 2015a) compared to 794.5 mill. ha for the year 2015 in the SFR, with lower forested areas detected from remote sensing especially in the northern Asian region. An even lower forest area estimate of 725.5 mill. ha was reported by Bartalev et al. (2016), excluding sparse forests and shrubs growing in marginal conditions, which in the SFR are included as forested areas.

The average share of forest cover on the total Russian land area has been rather stable during the last decades, currently it is 46.5% (IIASA, unpublished data). However, forest cover varies strongly by region and bioclimatic zone, from 0.2% (Republic of Kalmykia) to 82.5% (Irkutsk oblast). Around two-thirds of all the forests in the Russian Federation are growing on permafrost, which is widely spread in Siberia and the Russian Far East. Over the last three centuries, large areas of forest were converted into agricultural and other land categories, resulting in relatively low forest cover values in the densely populated central regions of the European part of Russia.

The forested area per capita is high, at 5.30 ha for the whole of Russia, with variation from 0.03 ha (Stavropol kray) to 162.2 ha (Republic of Sakha) (Figure 2). It is the highest in North-Eastern Russia (Republic of Sakha, Chukotka autonomous okrug, Magadan oblast and Kamchatka kray) due to very low population density. Overall, regions with high population densities have lower availability of forest resources, the lowest values are in the southern half of the European part of Russia. The most important forest resource indicator is growing stock volume (GSV). The total GSV of all Russian forests, according to the SFR 2016 data, was 82.8 billion m^3 of which 79.7 billion m^3 were in forests of

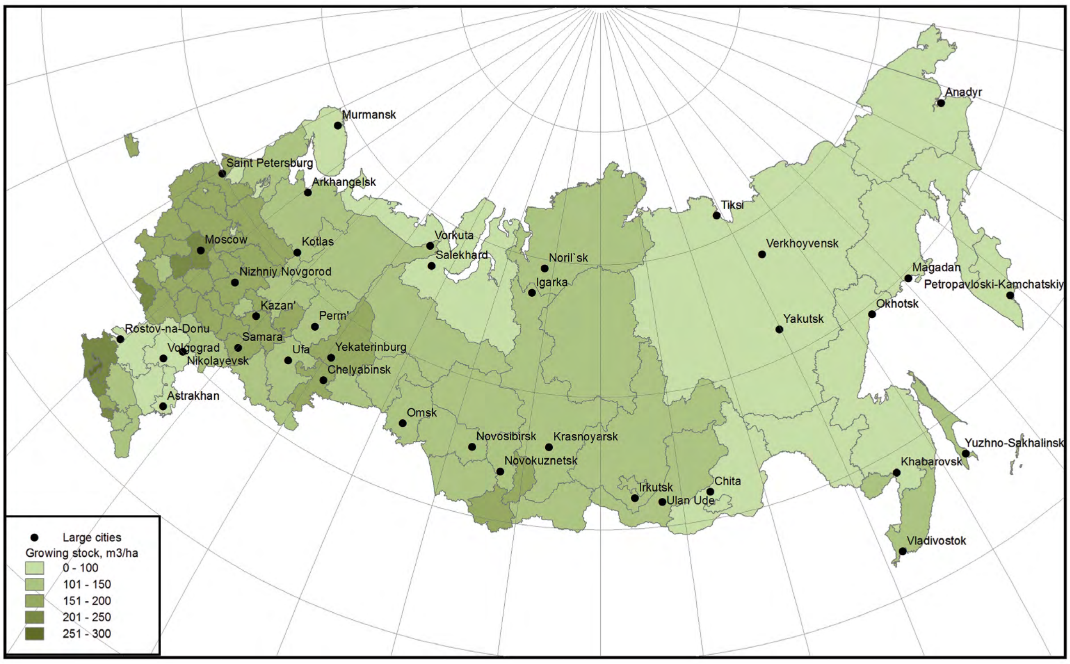

Figure 2. Growing stock per area unit by administrative regions of the Russian Federation. The map uses data from www.fedstat.ru, 2019.

the forest fund (www.fedstat.ru, 2019). These values do not include the GSV of forests on abandoned agricultural land. Republic of Sakha and other regions of North-Eastern Russia have relatively low GSV per hectare (56.0 m^3/ha; Figure 2). Higher average GSV (160–210 m^3/ha) are inherent for forests of Central and North-Western Federal Districts. The highest average GSV are found in mountainous regions of the South Federal District, for example, Republic of Adygeya (289 m^3/ ha) and Krasnodar kray (229 m^3/ha).

Several studies report that growing stock volumes in Russian forests were underestimated by ground forest inventory by at least 10–20% (Shvidenko et al., 2007; Vyvodtsev et al., 2003). An expert system developed at the International Institute for Applied Systems Analysis (IIASA) to correct outdated state forest inventory results calculated a GSV of 94.3 billion m^3 for 2014, which was 19.0% larger than in the State Forest Register (Shvidenko et al., 2019). Slightly higher average GSV values for 2014 have been estimated by remote sensing (S. Bartalev 2020, personal communication).

2.2

Natural forest disturbances

Sergey Bartalev, Anatoly Shvidenko and Alexander Held

2.2.1 The main natural forest disturbances and climate inter-linkages

Russian forest dynamics are highly impacted by diverse disturbances. In 2014–2017, according to the state statistics (Rosstat, 2018), damages[1] in Russian forests were caused by fires (63%), insects (15%), weather conditions (11%), diseases (10%), and other factors such as industrial pollution (~1%). Despite the limited reliability of forest statistics in absolute figures, these shares nevertheless reflect the relative impact of different disturbances. This chapter focuses on assessment of disturbances in Russian forests using well established remote sensing techniques. However, attribution of the detected forest changes to various disturbing factors often cannot be performed based on remote sensing data alone. Therefore, we focused our analysis on forest disturbances caused by fire, windstorm as well as the combination of biotic factors, which are difficult to separate using available data.

Different forest disturbances are often inter-linked and may have strong linkages to climate factors and human activity. Drought, for example, often triggers insect outbreaks in addition to its direct impacts on forests, and both factors may lead to increasing fuel amounts and higher risk of fires. These forest disturbances are also affected by climate change. Humans influence their natural regimes directly (by inducing and/or suppressing fires, insect outbreaks, etc.) and indirectly by altering the environmental conditions.

2.2.2 Forest fires

Compared to the global trend of declining burnt area over the last two decades (Andela et al., 2017), Russian forests are prone to accelerated extent, frequency and severity of wildfires and other natural disturbances, such as insect outbreaks. There are a number of reasons for this, including 1) dominance of highly flammable coniferous forests, 2) increasing risk of lightning-caused fires, particularly in sparsely populated remote territories, 3) unsatisfactory forest protection against fire and biogenic disturbances, and 4) overall decline of forest management and governance.

The MODIS sensor detected 8000 to 20 000 fire events annually in 2001–2019 (Loupian et al., 2017; Loupian et al., 2019), affecting a forested area between 2 and 11 mill. ha (Figure 3), with an average burnt area of about 5.6 mill. ha (Bartalev et al., 2015;

1 Damaged forest area refers to the amount of damage that occurred in the year of reporting. The reports consider a forest area as "dead forest" when at least 2/3 of trees in a forest stand are defoliated or when the relative growing stock volume of living trees is below a threshold of 0.3.

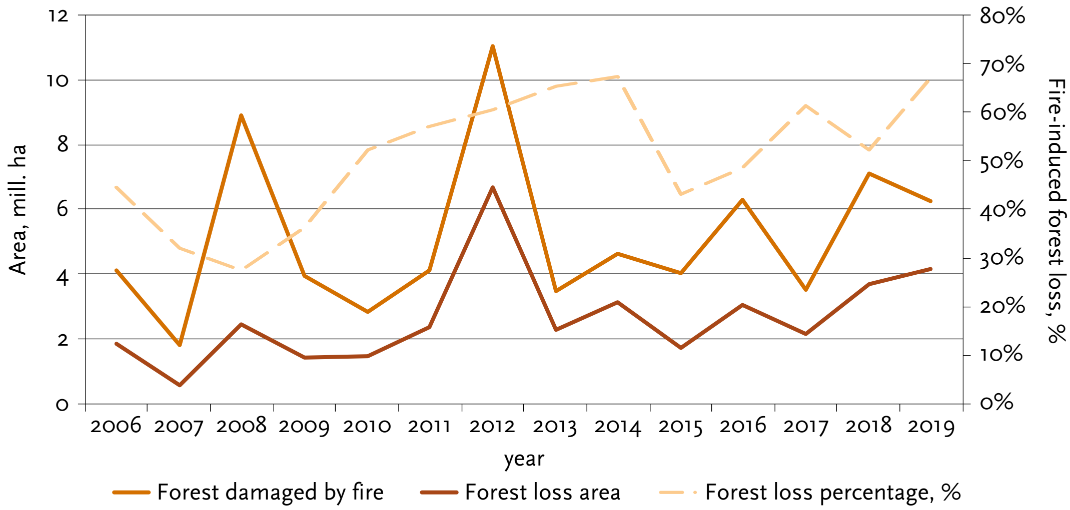

Figure 3. Multi-year dynamics for forest burnt and dieback area as estimated with MODIS data.

Bartalev, personal communication). While there is large year-to-year variability, there is a **statistically** significant positive burnt area trend. The time series ends with two years of extreme fire danger in a row, 2018 and 2019; a unique phenomenon as consecutive years with high fire impacts have never before been recorded in Russia.

The average size of forest fires (Figure 4) has also increased since 2007 according to data derived using the method of Bartalev et al. (2013). Moreover, the burnt area affected by extremely large fires, often referred to as megafires (Tedim et al., 2018), is particularly large in extreme years such as 2012, 2016, 2018 and 2019. Catastrophic fires, covering areas of tens and hundreds of thousands of hectares, lead to forest degradation with negative effects on the biodiversity, economy and living conditions (Bowman et al., 2017).

The distribution of fire characteristics over the country is far from homogenous. The fire frequency is higher in the populated regions of the European part of Russia, Southern Siberia, and the Russian Far East. However, the burned area is significantly higher in less populated Central Siberia and the northern Far East where fire protection is also lower. These regions have drastically higher average fire sizes in comparison to the rest of the Russian forests, especially in Western Siberia and the European part of Russia.

Fire impacts on tree dieback depend on many factors, including fire types (crown, ground or underground) and severity, tree species composition and age, fire occurrence over the season and meteorological conditions. Since the 1950s, on average over the country, ground fires constituted 77%, with 22% crown fires, and 1% reported as peat fires (Korovin, 1996). The MODIS-derived estimates of the area of stand-replacing fires (Figure 3) ranged from 0.6 to 6.7 mill. ha between 2006 and 2019 with tendency to increase (Bartalev et al., 2015; Bartalev personal communication).

It is important to note that while forest fires are generally considered a natural phenomenon in boreal forests, the majority of fire ignitions in Russia are human induced. Analysis of the fire records for 1981–2001 shows that in the forest protection zone (which covers about 2/3 of state forest fund area) about 81.1% of the fires were attributed as human induced, 12.1% as lightning induced, and the remaining fires has no attributable

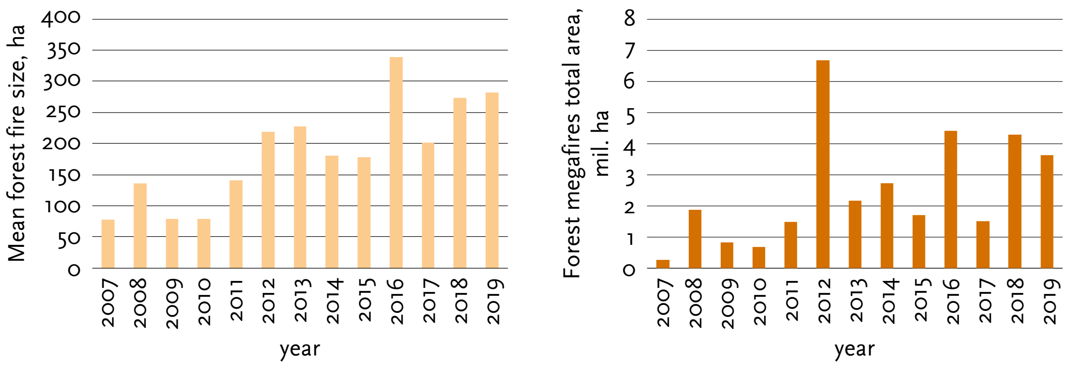

Figure 4. Recent trends in a) forest fire size (left panel) and b) area burnt by extreme wildfire events larger than 10 000 ha (right panel).

cause (Korovin and Zukkert, 2003). The share of human induced versus natural causes varies between years, in some years, e.g. 1989–1992, the lightning induced fires exceeded 25% in the entire country. In the European-Ural part of Russia the share of human induced fires is higher (93.5%), while in the Asian part their share is estimated at 77% compared to 19% of lightning ignitions. The average area of lightning induced fires is about three times higher compared to human induced ones, and the share of lightning induced fire areas is approximately 40% in the forest protection zone.

Over the last 50 years, megafires increased the area of deforested land by up to 20 mill. ha, mostly in the North of the Asian part of Russia (Yefremov and Shvidenko, 2004). These fires may transform forests to barren land with postponed reforestation for an indefinitely long period (so called green desertification). These territories can only be rehabilitated through expensive ameliorations, while the natural reforestation may require hundreds of years.

The direct fire carbon emissions are estimated at 40 to 90 Mt C /year (Shvidenko et al. 2013a, Shvidenko and Schepaschenko 2014). The average composition of combustion products in 2000–2012 was: CO_2 – 84.6%, CO – 8.2%, CH_4 – 1.1%, non-methane hydrocarbons – 1.2%, organic carbon 1.2%, and black carbon – 0.1%. The highest content of CH_4 and CO in the combustion products is observed in emissions from peat fires (Shvidenko et al., 2011). Significant emissions are also observed in forests due to postfire dieback after non-stand-replacing fires which may last from 2 to 8 years. Estimates show that on average the postfire emissions due to decomposition of dead wood is close to the direct fire emissions.

2.2.3 Biotic disturbances

Russian forests are exposed to massive biotic disturbances that may affect millions of hectares as insect and disease outbreaks are induced by a combination of favourable weather and forest conditions every 15 to 25 years (Im et al., 2007). Harsh climatic conditions have limited these outbreaks to areas below 60 degrees of northern latitude. However, with increased warming, outbreaks may occur in the forests north of this line.

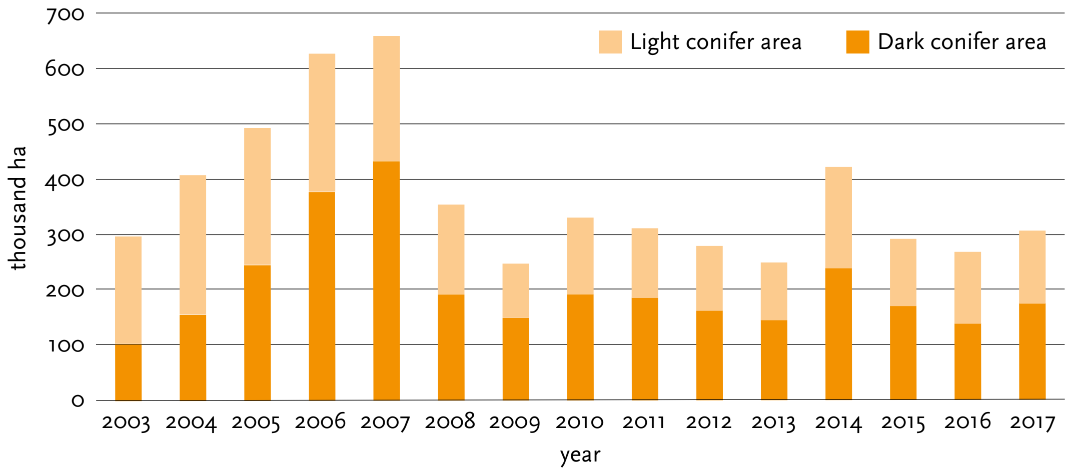

Figure 5. Evergreen coniferous forest dieback areas in Russia due to a combination of non-fire disturbances including biotic and abiotic factors during the years 2003–2017. Dark conifers species are spruce, fir and Siberian pine, whereas evergreen light conifers are other pine species. Source: Bartalev et al. personal communication.

From 1880 to 1969, about 13 mill. ha of East Siberian forests were destroyed by the Siberian silk moth (*Dendrolimus sibiricus*), representing a loss of 2 billion m^3 of growing stock (Shvidenko et al., 2013b). Insect outbreaks heavily damaged more than 1 mill. ha in the mid-1990s and affected an area of more than 10 mill. ha of Northern larch forests in 2000–2001 in latitudes where this insect had rarely been observed before (Shvidenko et al., 2013b).

Several studies point out that a warmer and drier climate would induce large-scale outbreaks of defoliators (e.g. Pleshanov, 1982). For instance, a clear northward shift of Siberian silk moth and Gypsy moth (*Limantria dispar*) has reached territories where outbreaks have never been observed before (FAFMR, 2010). Other large-scale disturbances caused by a combination of biotic and abiotic factors are reported for different regions. Several waves of tree dieback were observed in Far Eastern spruce-fir forests during the second half of the 1960s, in 1970–1980 and 1989–1993, but no generally accepted explanation was found (Manko and Gladkova, 2001). Dark coniferous forests are very vulnerable to the bark beetle (*Polygraphus proximus*) invading from the Far East, affecting about one-third of the Siberian fir area during the last 10–15 years (Bystrov and Antonov, 2019).

Data derived from MODIS for evergreen coniferous forest mortality in 2003–2017 estimated the total affected area at about 5.54 mill. ha ((Bartalev et al., personal communication, Figure 5). The damaged forest area due to spruce, fir and Siberian pine dieback varies across years, ranging from 0.25 to 0.65 mill. ha.

2.2.4 Impacts of windstorms

Earth observation data provide a valuable information source for studying forest damages caused by windstorms; these can be assessed over large areas based on Landsat data at regional level (Shikhov, 2013) and for the entire country (Krylov et al., 2012).

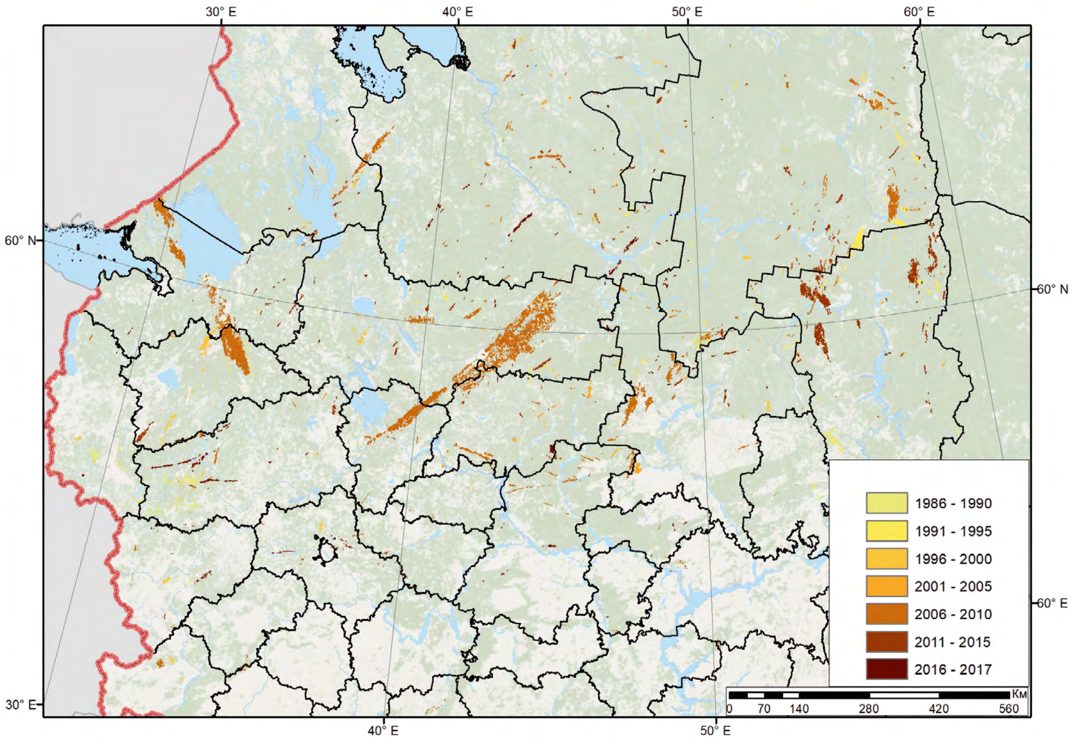

Figure 6. Forest disturbances related to windstorms in the European part of Russia during 1986–2017. The long-term trend of detected cases with forest damage by windfalls shows a multifold increase for the period since 2009 with extremely large damages observed in 2010, 2012 and 2017. The map uses data from Shikhov and Chernokulsky, 2018.

A representative database of wind damage occurrence in the forests of the European part of Russia has been developed for 1986–2017 (Shikhov and Chernokulsky, 2018) based on the analysis of Landsat data and the Global Forest Change Map of Hansen et al. (2013) (Figure 6). In 2010 the area of forests damaged by wind reached a historical maximum for the entire observation period since 1986, estimated at about 128 000 ha. In other years, the damaged area ranged between 300 ha and 27 100 ha.

2.3

Forest governance and use

Elena Kulikova and Anatoly Shvidenko

2.3.1 Forest use categories

In accordance with the Forest Code (2006), forests located on forest fund lands are divided into three forest use categories. *Operational forests* (51% of the forest fund land) are exploitable forests available for industrial harvesting. *Protective forests* (26%) include forests that fulfil numerous protective and regulative services. These forests include, for example, nature protection areas, urban forests or water protection forests. *Reserve forests* (23%) include remote forests without plans for wood harvesting until 2026, except for citizens' own needs. Two-thirds of reserve forests are located in the Far North, where they provide the life support basis for a significant part of the local population. Given insufficient infrastructure development in huge remote areas in Siberia and the Far East, they cannot be considered as manageable and no economic activity is carried out, nor are any formal protection measures applied.

Forest use types of the Forest Code (2006) relate mostly to resource utilisation such as wood, non-wood products, mineral exploitation or recreation in urban forests. Much less attention is paid to forest conservation and forest restoration (Petrov et al., 2018). Protective functions are the guiding management objective in forests in water protection zones, protective forest belts, at forest ecotones, etc. Altogether, around 20 different protective functions are defined. Biodiversity protection is mainly considered in protected forests under the category of specially protected natural territories, such as state nature reserves, national parks, natural parks, natural monuments, and other specially protected natural territories established by federal laws. One dedicated protection status is an *especially protective forest plot,* which can be established in all types of forests including exploitable forests to protect e.g. habitats of rare and endangered wild species of plants and animals.

Wood resource utilisation is possible in both exploitable and protective forests, but the type of management is regulated according to the major protective function. In most protective forests, clear cuttings are prohibited; in some categories, also the intensity of selective logging may be constrained.

2.3.2 Governance structures in Russian forestry

The Forest Code of the Russian Federation (Federal Law of the RF No 119-FZ, 2006) is the main document regulating forest-related matters in Russia. Federal forest legislation has changed several times over the last 25 years, including about 40 amendments of the Forest Code (2006). A broad range of forest stakeholders are calling for a new Forest

Code to strengthen the considerations of forest and forestry compared to the interests of the forest industry (Otvetstvennost, 2019; Lesopromishlennii, 2019).

State forest management at the federal level is exercised by the Ministry of Natural Resources and Environment and its subordinate body, the Federal Forestry Agency of the Russian Federation. Forest management is decentralized, and state supervisory functions related to forests are transferred to government authorities in 85 administrative regions (subjects of the Russian Federation), which are grouped into eight Federal Districts.

The Federal Forestry Agency has responsibility for the following national services: (1) state forest inventory and forest planning; (2) forest pathology monitoring; (3) seed growing; (4) aerial forest fire protection operations; (5) scientific research; and (6) additional post graduate professional training and education. These services are provided by institutions and enterprises subordinate to the Federal Forestry Agency or through tenders (FAO, 2012). The Forestry Agency has Forestry Departments in Federal Districts operating at inter-regional level.

The following plenary powers have been transferred to government authorities of the subjects of the Russian Federation (regions): (1) elaboration and validation of forest plans, legal forestry regulations, implementation of state expertise on forest exploitation projects; (2) lease and concession of forest parcels, conclusion of contracts for purchase and sale of wood stock, organization and carrying out of wood auctions; (3) issuance of mining permits on forest land; (4) organization of management, conservation, protection and regeneration of forests; (5) maintenance of state forest register; (6) implementation of federal forest supervision; and (7) establishment of lists of officials authorized to perform federal forest supervision (FAO, 2012). These plenary powers are implemented by state structures within the bodies of executive power of the federal subjects. At the local level, the structures are represented by 1650 state forest management enterprises (*lesnichestvo*) (FAO, 2012).

Wood harvesting is carried out on the basis of lease agreements for forest plots, permanent use, and contracts for the purchase and sale of forest stands. The most common legal form of forest use is forest lease agreements (contracts), which are concluded for a period of up to 49 years. There are about 80 000 lease agreements for forest plots, covering 27.5% of the forest area (excluding reserve forests). On average, more than 600 000 contracts annually cover the purchase and sale of forest stands on auctions (valid for up to 1 year; without lease of the forest plots). These are mainly directed at forest use for local needs and meeting the wood demand of the local rural population. Rights to conclude contracts are acquired by legal and natural persons through forest auctions. Tenants carry out forestry operations on leased land accounting for over 14% of forest estate land (*forest fund*). Authorized unitary enterprises and autonomous entities carry out forestry operations on unleased land (FAO, 2012).

The currently valid strategic forest policy documents include: “Fundamentals of state policy in the field of use, guard, protection and reproduction of forests in the Russian Federation for the period up to 2030” (2014), the Forest Code (2006), the “Strategy for the development of the Russian Federation’s forest complex until 2030” (2018) and the State program of the Russian Federation “Forestry development for 2013–2020” (2013).

2.4

Ecosystem functions and services of Russia's forests

Anatoly Shvidenko, Dmitry Zamolodchikov, Riccardo Valentini and Marcus Lindner

Russian forests provide numerous ecosystem services that are vitally important for society and national economy. They regulate climate by impacts on major biogeochemical cycles; supply hundreds of millions of cubic meters of high quality wood and other forest products; prevent and mitigate damage of catastrophic weather events (storms, droughts, floods); regulate the hydrological regime at various scales; purify water; contribute to the creation and maintenance of water reserves in rivers, lakes, aquifers; form the soil and protect it from destruction; regulate nutrient cycles; fulfil the pollination function and biological control of plant diseases; serve as habitats for more than half of the known plant and animal species of Northern Eurasia; etc. (Isaev, 2012).

2.4.1 Overview on ecosystem services of Russian forests

A comprehensive review of all diversity of ecosystem functions and services of Russian forests is beyond the scope of this report. Therefore, we focus on tree species diversity and present information on a selection of provisioning and protective ecosystem services.

2.4.2 Tree species diversity

More than 90% of Russian forests are boreal forests (Figure 7): that means a relatively simple structure and species composition of forests, but at the same time, a huge diversity of growth conditions and forest types. The Russian system of forest inventory divides all forested areas by major forest forming species (MFFS), other species and shrubs, which are accounted as forested areas in territories where "high forests" cannot grow due to harsh climatic conditions. Forests dominated by MFFS cover 90% of the inventoried Russian forested area and include forest dominated by coniferous (68.0%), hardwood deciduous (2.4%) and softwood deciduous (19.6%) tree species. Native coniferous include four genera: larch (35.7%), spruce (10.1), fir (1.9%), and pine, which is divided in two-needle (mainly Scots pine, 15.5%) and three-needle (Siberian and Korean pine, 5.1%) sub-genera. Dominant softwood deciduous species are birch (15.3%) and aspen (3.1%). Deciduous hardwoods comprise only a small share, but include a significant number of valuable species (oak, ash, beech, maple, etc.).

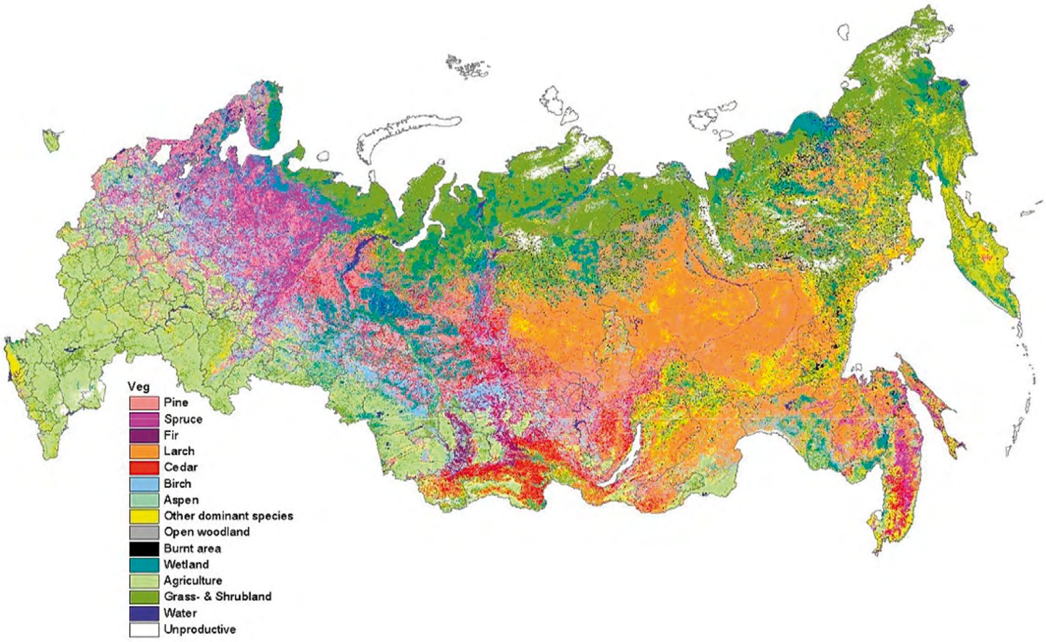

Figure 7. Major classes of land cover and major forest forming species in Russia. Source: Shvidenko and Schepaschenko, 2014.

Diversity at the tree species level is substantial. For example, the genera *Pinus* includes 8 native tree species and more than 20 introduced species. Larch is the most representative dominant tree species in Russia, forming indigenous forests in the East European North and all taiga regions of the Asian part (Figure 7). Two species – *Larix gmelinii* and *L. kajanderi* – grow in the most northern regions on permafrost under annual average temperature down to -15 °C. Spruce and pine dominate in the Northern European part and in taiga regions of Siberia and Far East besides the extreme north (forest tundra and northern taiga). Large areas are covered by *Picea ajanensis* in the Russian Far East. The pioneer species birch, often with aspen, occupy a huge area across all bioclimatic zones of Russia, dominating at early succession stages in secondary forests after stand-replacing disturbances (harvest, fire) in indigenous coniferous forests.

There is a distinct gradient of increasing floristic diversity of the boreal biome from north to south. For Siberia, Zyryanova et al. (2010) studied the spatial gradients in plant species diversity of terrestrial ecosystems (including vascular plants, mosses and lichens) on 13 experimental territories located along the 108° E meridian over a length of 2120 km – from the upper reaches of the Lena river to the most northern island forests of the world in the Arctic tundra zone (72 ° 30'N, 102 ° 30'E). South-taiga forests are characterized by the largest species diversity (472 species), whereas the minimum (180 species) was found in the northern tundra subzone.

The Russian forest inventory classifies forest stands into age groups: young (separated in two first age classes), middle-aged, immature, mature and over-mature forests. The age ranges for each group depend on the dominant tree species, geographical zone and growth conditions, productivity, and major forest use category. Naturally, distribution of forests by age groups changes over time. In 2015, Forest Fund forested area of

MFFS consisted of young forests (17.2%), middle aged (25.6%), immature (10.6%), and mature and over-mature (46.6%).

Forests in Russia are mostly naturally regenerated, and trees of different ages are often mixed. About 60% of immature, mature and over-mature Russian taiga forests have an uneven-aged structure.

2.4.3 Provisioning services of forests – wood products

The annual allowable cut (AAC) defines an official norm for sustainable wood harvesting. In 2016, it amounted to 703 mill. m^3/year (Strategy of development, 2018), which is 0.85% of the total growing stock volume indicated in the SFR. During the last 15 years, the AAC varied from about 690 to 750 mill. m^3/year. Because the AAC does not take into account the economic accessibility of forests, many scientists argue that the official AAC overestimates the real sustainable harvest level by about twofold (Yaroshenko, 2014; Sokolov and Baginsky, 2014).

Historically, the amount of harvested wood has varied in conjunction with political, social and economic changes in Russia (Felling in Russian Federation, 1996; www.fedstat.ru, 2019). As show in Figure 8, there was a period of substantial growth (from about 160 to 350 mill. m^3/year) during the restoration after World War II (1945–1960s); relatively stable utilization around 350–370 mill. m^3/year in the 1960s–1990s; decline in the late 1990s to 150–160 mill. m^3/year due to collapsing Soviet forest industry; and the slow growth thereafter, with a clear intensification during recent years (238.6 mill. m^3/year in 2018, or 32.7% of the official AAC). The extensive exploitative model of use of forest resources led to overharvesting and impoverishment of forests in economically developed regions. It was a reason for shifting part of the logging enterprises into the Asian part.

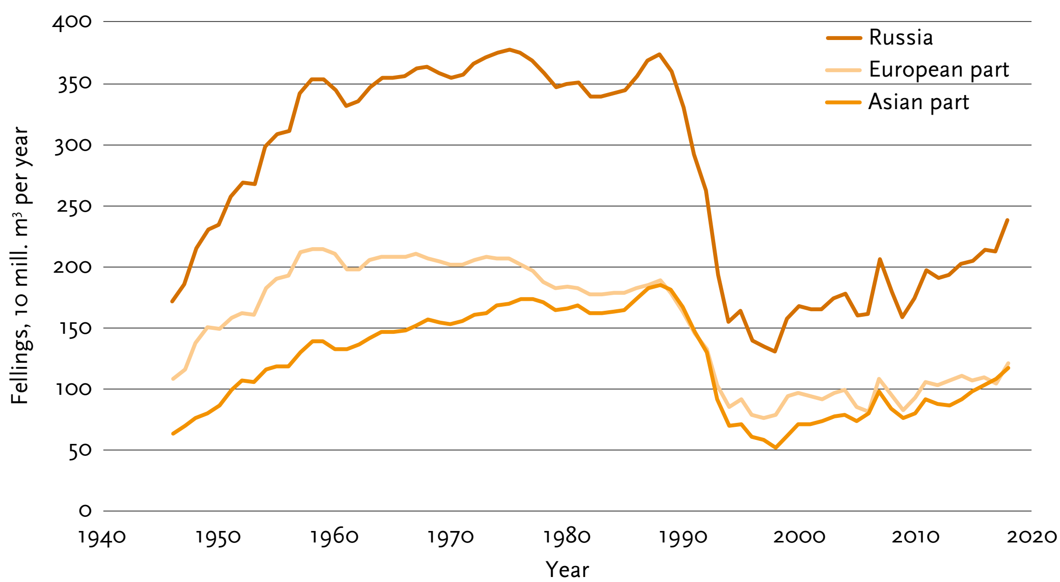

Figure 8. The dynamics of wood harvesting in the Russian Federation in 1946–2019. Data source: Official state statistics.

The current total amount of wood harvesting in the European and Asian parts of Russia is similar. The average GSV in the European part is about 1.5 times higher than in the Asian part. However, the harvested areas in the Asian part are concentrated in the southern regions, particularly in mountains of Southern Siberia and Far East with rather high average GSV of mature stands. The often-reported felling-intensity, estimated by harvested m^3 per 1000 m^3 of GSV by large administrative regions is substantially higher in regions of the European part of Russia (6–10 m^3/1000 m^3) compared with Northern Siberia and the Far East (1–4 m^3/1000 m^3).

2.4.4 Water protection, water regulation and soil protection role of forests

The protective role of Russian forests is manifold. Of the 17 protective forest categories covering an area of 278.3 mill. ha (SFR, 2014), three categories are directly destined for water protection and regulation: spawning protection strips (56.8 mill. ha), water protective zones (11.1 mill. ha), and protective strips along water objects (28.0 mill. ha) with a special regime of forest management for the maintenance and improvement of hydrological regimes of water flows. Recent changes to the Forest Code introduced in 2019, however, may have a negative impact the protective functions of the Russian forests. For example, the width of spawning protection strips was reduced from 1 km and more to only 20–200 m (Kobyakov et al., 2018).

Wildfires and unregulated harvest of forests provide the most negative impacts on major functions of water protective forests (Sokolova and Verkhoturov, 2015). Russia has about 430 mill. ha of mountain territories. Mountain forests play a crucial role in regulating the water regime and preventing floods and erosion processes. Forest maintains stability of mountain landscapes and protect from avalanches and landslides. The losses of soil on large burnt areas and clear-cuts in mountain forests are tens to hundreds time higher than in undisturbed forests (Krasnoschekov, 2004). The role of forests and shelterbelts in protecting water and soil is particulary important for agroforestry. Today the country has about 15 mill. ha of anti-erosion forests, as well as significant areas of agricultural land in southern territories with very low amounts of forest.

2.4.5 Past and present carbon budget of Russian forests

Official inventory-based carbon balance of Russian forests

The official inventory of carbon balance of Russian forests is presented in national reports on greenhouse gases emissions and removals, which are produced annually and are available on the UNFCCC website. The procedures of carbon inventory of the forestry sector are developed in full consistence with IPCC guidelines (Penman et al., 2003) and published in scientific papers (Zamolodchikov et al., 2011, 2013a, 2013b) and in a number of national inventory reports (Russian Federation, 2019 and earlier). The calculation system is based on the flux balance method. The State Forest Registry (SFR) provides the initial information about forest areas and growing stocks, differentiated by tree species, age groups and regions. Conversion factors are used to calculate carbon pools in live biomass and woody detritus, and the typical carbon values per area unit for litter and soil. The presentation of information by age groups in SFR (from young to

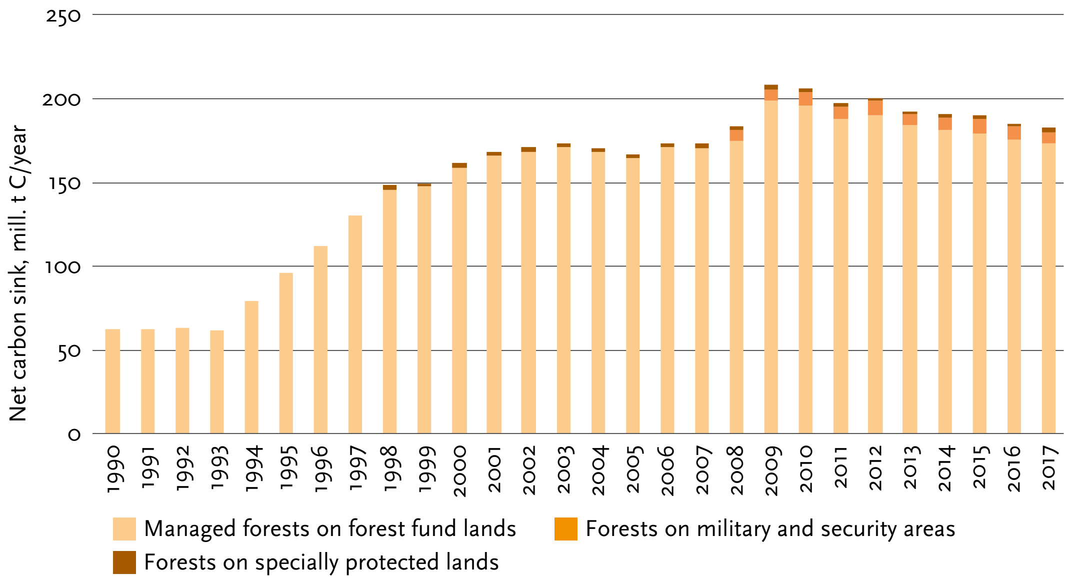

Figure 9. The net carbon sink in Russian forests (without accounting of CH_4 and N_2O emissions from fires and drainage of organic soils) following the national inventory report (2019).

over-mature) is used for calculating carbon increments in all studied carbon pools per area unit. Based on area data per age group, tree species and region, the carbon sequestration due to forest growth is estimated. Carbon losses occur due to forest harvesting, forest fires and other stand replacing disturbances. These are estimated using information on areas of clear cuts, burnt areas and dead stands from SFR with application of forest regeneration periods. This approach, at first, allows smooth interannual calculation of variations of carbon losses, second, to avoid using official statistical data on forest fires, that essentially underestimate the fire influence in the retrospective aspect. The described system has been used in national inventory reports since 2011 and annually verified by UNFCCC experts together with other procedures of national greenhouse gases inventory.

The national inventory report provides information for managed forests of Russia, which includes the forests on forest fund lands (except reserve forests), forests in military areas and in protected natural lands. The net carbon sink of Russian managed forests was 55 Mt C /year in 1990, raised to about 200 Mt C /year in 2010 and then decreased to current 175 Mt C /year (Figure 9). The main driver of carbon sink dynamics was the harvesting level, as described in Chapter 2.4.1.

Russian forest ecosystem carbon budgets assessed with different scientific methods

Official reporting to the UNFCCC Secretariat on carbon budget of forests is almost completely based on forest inventory data of the SFR (see above), fully in line with IPCC guidelines. However, there is a potential to increase the confidence of the carbon budget assessment with higher level IPCC tier methodology based on scientific evidence. Other methods for studying carbon cycle of forest ecosystems include diverse process-based models (Dynamic global vegetation models, forest landscape models of succession

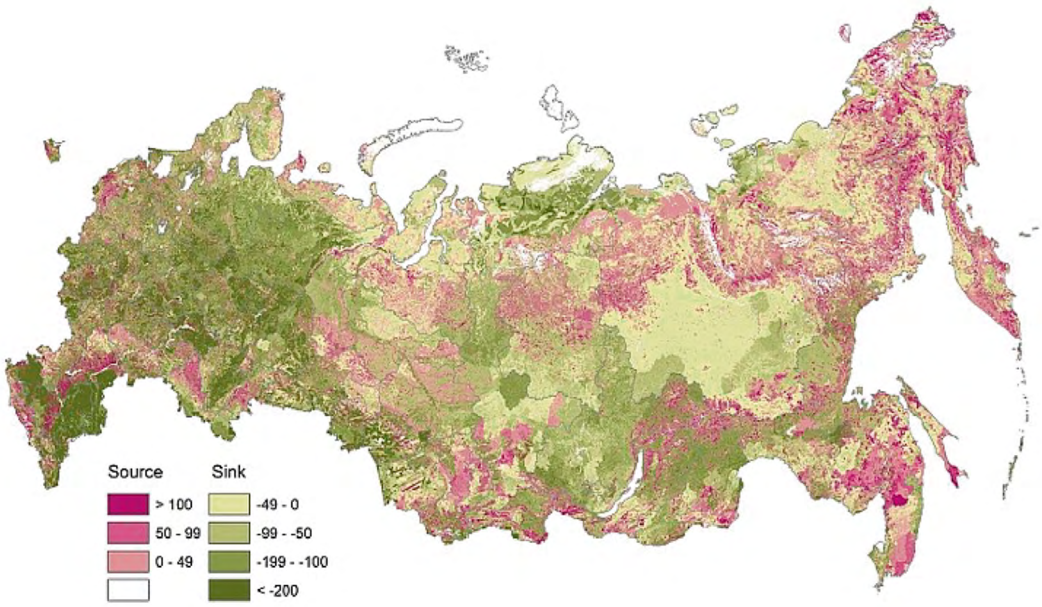

Figure 10. Carbon budget of terrestrial ecosystems of Russia for the year 2014, calculated with the IIASA methodology (g C /m² /year). Overall, Russian forests provide a substantial carbon sink, but there is large regional variation. Substantial areas act as a carbon source (pink color); these are located either on permafrost or in disturbed forests. Source: Shvidenko and Schepaschenko, 2014.

and disturbances etc.); eddy covariance; inverse modelling; and remote sensing applications. All these methods use in one way or another either a stock-change or flux-based approach, or combinations of both.

A prototype of a full carbon account of forest ecosystem methodology has been developed by IIASA using an Integrated Land Information System, which contains a hybrid land cover and numerous attributive data bases using several remote sensing products and geographically weighted regressions validated by Geo-Wiki tools (Shvidenko et al., 2010, 2015a, 2019; Schepaschenko et al., 2015b). A landscape-ecosystem approach defines the studied system with spatially distributed relevant information about ecosystems and landscapes. Forest inventory data from the SFR were updated from the year of the last available forest inventory using available ground and remote sensing information. Major carbon fluxes are distinguished (net primary production, heterotrophic respiration, fluxes due to disturbances, decomposition of coarse woody debris etc.). Fluxes due to disturbances (harvest, fire, biotic disturbances etc.) are assessed by sets of regionally distributed models. Using this methodology, the net carbon sink of Russian forests was estimated for different reference periods at 690±246 Mt C /year for 2000–2012 (Dolman et al., 2012), 546±120 Mt C /year in 2007–2009 (Shvidenko and Schepaschenko, 2014), and 642±141 Mt C /year for 2000–2015 (Shvidenko et al., 2019). Figure 10 shows the carbon balance of Russian terrestrial ecosystems for the year 2014.

The carbon budget of Russian forests has been assessed with different methodologies. The official national communications to UNFCCC are based on data of the State Forest Register. They reported a carbon sink of 150–200 Mt C /year, which is lower than most other estimates. Applying the same approach to all Russian forests instead of only managed forests has resulted in a carbon sink of 206–230 Mt C /year (Zamolodchikov et al., 2017) and similar results of 260 Mt C /year were obtained using the Canadian model CBM-CFS3 with State Forest Register data (Zamolodchikov et al., 2014). Other inventory-based assessments with direct use of official Russian forest inventory data reported a carbon sink between 400 and 650 Mt C /year (Filipchuk et al., 2017; Russian Ministry of Ecology and Natural Resources, 2015). Numerous inverse modelling studies estimated a land carbon sink around 600–720 Mt C /year (Sitch et al. 2015; Shvidenko, Schepaschenko 2014); eddy covariance flux measurements at 15 sites indicated a carbon sink in a range from 760–960 Mt C /year (Dolman et al., 2012) and estimates of dynamical vegetation models (DGVMs) project a sink at around 200 Mt C /year (Dolman et al., 2012).

It is also pointed out that the uncertainty of soil carbon assessment is high (Pan et al., 2011) and soil model simulations showed that water table fluctuation in boreal forests could play a key role in determining the source/sink behaviour of the ecosystem carbon balance (Kurbatova et al., 2008).

Interpretation of different carbon budget assessments

Methodological differences and inconsistent input data can explain large parts of the variation between published carbon budget assessments on Russian forests. The forest or land area reference varies; for example, the official UNFCCC reporting based on SFR data covers only around 75% of the total Russian forest area (i.e. only managed forests). Atmospheric inversions cover all land areas and cannot separate the forest carbon sink from other land uses. Measurements from eddy covariance towers cover also different land uses and may calculate higher carbon sinks than other methods because management and natural disturbance effects are not accounted for. Further differences relate to the representation of important ecosystem processes and disturbances. Many studies neglect the dynamics of soil carbon and disturbance impacts are often incomplete. Estimates of the impacts of biogenic disturbances are highly uncertain and often missing entirely.

With high probability, Russian forests served as a significant net carbon sink during the last decades. Temporal and spatial variability of the carbon sink is high, particularly for individual regions of the country. The temporal variability is mainly caused by interannual variability of seasonal weather and, connected to this, the natural disturbances like fire and insect outbreaks. Despite the average sink, there are vast areas, mostly in disturbed forests and on permafrost, which acted as a carbon source or are close to the neutral state (Figure 10).

The regional differences are affected by variable forest productivity and disturbance regimes as well as underlying differences in population density and related factors such as management intensity, infrastructure and accessibility and fire protection as discussed in Chapters 2.1 and 2.2. The last decade showed a weak trend of a decreasing carbon sink due to frequent and large disturbances, especially large fires. More detailed analysis points out that during the current century, carbon sink dynamics in Russian forests had no statistically significant trend until 2017. But the high level of disturbances in 2018, 2019 and 2020 reached unprecedented levels and once these years are included in the analysis, they will likely result in a substantial decrease of the Russian forest carbon sink. Observations of the Copernicus Atmosphere Monitoring Service (2020) indicated that wildfire related CO_2 emissions for the Arctic cycle during January to August 2020 already exceeded the previous record for annual emissions set in the year 2019, mainly driven by the exceptionally large wildfires in Sakha Republic, Northeastern Russia.

2.5

Key challenges in forest resource management

Anatoly Shvidenko, Elena Kulikova and Marcus Lindner

The gigantic scale of Russian forests with the area of almost 800 mill. ha poses significant difficulties and problems with large sparsely populated remote areas, lacking infrastructure, and the attitude of the population accustomed to the inexhaustible forest wealth (Shvidenko et al., 2017). The resource role of forests dominates over other ecosystem services provided by forests. The state generally underestimates the role of the forest sector (Pisarenko and Strakhov, 2016) and the sustainable forest management paradigm is poorly implemented in practical forest management (Pappila, 2012). The current key challenges in forest resource management were recently identified through a series of scientific debates held in 2015–2019 by the Russian Academy of Science with broad stakeholder involvement (Russian Academy of Science, 2019a). The debates considered a range of topics, which are next discussed.

The most fundamental challenge in Russian forestry is the need to replace the exploitative forest use with *sustainable intensive forest management* (see Box 2). This would allow achieving higher economic efficiency of the forest sector with increasing forest productivity and wood harvesting in territories with developed social and transport infrastructure, while simultaneously preserving protected forests, specially protected and intact natural territories (Russian Academy of Science, 2019a).

Another important challenge is that the political, social and economic changes in Russia have resulted in *deteriorating governance* of Russian forests since the end of the 1990s. Numerous reforms of the forest management system affected the level and specifics of forest management in Russia with insufficiently developed legislation and failures in the subsequent forest management reforms. The most important of them are :

- The elimination of forest guards negatively affected the control of the state as well as the level of protection and use of the forests over the country, including, for example, curbing illegal logging. According to reports of the World Bank and non-governmental organizations, illegal logging happens at a level of 20–30% of the officially harvested wood amounts, while the official estimates are around 1% (FAO, 2012; Russian Academy of Science, 2019b).
- The economic and organizational conditions of the forest fire services deteriorated, and the number of aviation departments and fire-chemical stations decreased gradually. The effectiveness of the remaining aviation security units is hampered due to their remoteness, isolation and insufficient equipment and funding (Korshunov et al., 2019).

- The system of forest protection against pests and diseases has been severely weakened; the scope of measures to localize and eliminate pest outbreaks in Russia has decreased to one tenth over 2007–2013 (Doklad, 2013; Selikhovkin and Smirnov, 2015).
- The information support for Russian forestry and forest management significantly declined. The federal system of forest account was transferred to the regional level and replaced by simplified inventories with substantially decreased financing. Previous informationally sound and comprehensive *Projects for the organization of forestry and forest management of forest enterprises* were replaced by *Forest management regulations* that have neither sound methodological basis, nor adequately funded forestry measures or tools for quality control of forest management in leased forests (Vashchuk, 2016; Account Chamber, 2020). Major sources of forest information are based now on obsolete and biased information as a considerable share of inventory data has not been updated since many decades.
- The economics of forest relations faces many unresolved issues. For example, the forest leasing strategy adopted by the Forest Code (2006) is facing many problems (Petrunin, 2019) and it is not consistent with the strategic objectives of the transition to sustainable forest management. Necessary economic and institutional reforms have not been provided.

The forest sector outlook study with future development scenarios for 2030 (FAO, 2012) stressed the need for new forest policies and significant investments in the Russian forest sector and called for a fundamental reconstruction of the existing and the creation of a new forest sector in Russia, corresponding to the challenges of the 21st century.

Box 2. The need to move from extensive exploitative to intensive sustainable forest management in Russian forestry

Industrial-scale forest use since the Soviet era is dominated by an **extensive exploitative model of forest use**, aiming at maximizing income with only limited interventions (Konzepzia, 2015). The system applies clear cut harvesting, continuously extending into new forest territories, and is characterised by harvest of most productive and accessible stands, an incomplete use of wood of lower quality and less valuable tree species, natural non-assisted regeneration, and a lack of tending in young stands. Thinning or rather selective cutting in young and middle-aged stands was insufficiently performed. As a result, the quality of forest resources degraded with undesirable change of species composition and a decreasing volume of economically accessible forest resources (Knize and Romanuk, 2004; Konzepzia, 2015). Official data document that the share of coniferous species decreased while softwood species share increased substantially in forested area during 1961–2016 (Forest State Account for 1961–2007, State Forest Register for 2008–2016). Harvest usage has been much higher in densely populated regions and there is a lack of high value timber in regions of high demand. For instance, the share of coniferous forests decreased in this period from 89.8% to 76.3% in Arkhagelsk oblast (European North-West) and from 86.5 to 70.8% in Amur oblast (Far East). Even more drastic is the decreasing area of economically accessible mature forests (Sokolov and Baginsky, 2014), which could be exhausted in the North-West Federal District during the next 20 years (Moiseev, 2008). The *ratio of forest regeneration to areas of final felling dropped* from 147% in 2000 to 74% in 2016 (Strategy, 2018), which implies that successful forest regeneration is increasingly delayed or even fails after harvest operations.

Against this background, it is increasingly evident that there is a need for new developments and innovative solutions for forestry practices. Over the last fifteen years, *a concept of intensive forest management* has been increasingly debated among national experts from science, business community and environmental organizations in Russia. In 2015, the “Concept of intensive use and restoration of forests in the Russian Federation” was approved by the Federal Forestry Agency and started to be implemented in pilot regions of North-West Russia and Eastern Siberia (Konzepzia, 2015). The intensive model implies sustainable forest management and ensures the preservation of the biological functions of forests through effective reforestation, tending of young stands and regular thinnings.

2.6

Key messages

- Russia hosts almost 800 mill. ha of forests that fulfil diverse ecosystem services vitally important for human society nationally and globally. Land inventories in Russia use diverse classifications of forest cover. Estimates indicate that 18 mill. ha of abandoned arable land have a tree cover that meets the forest definition but remain excluded from official forest inventories.
- The gigantic scale of Russian forests poses significant challenges with large sparsely populated remote areas and lacking infrastructure. Harvest usage has been much higher in densely populated regions and resulted in degrading quality of forest resources with undesirable changes of species composition and decreasing area of exploitable forests.
- Russian forests were a significant net carbon sink during the last decades, with high temporal and spatial variability mainly caused by interannual variability of seasonal weather and natural disturbances. The estimated carbon sink amount ranges from 150–200 Mt C /year in the official reporting to UNFCCC to more than 600 Mt C in independent scientific assessments, with differences explained by different land area references as well as variable representation of ecosystem processes and disturbances. Despite the average sink, there are vast areas, mostly in disturbed forests and on permafrost, which temporarily act as a carbon source.
- During the current century, carbon sink dynamics in Russian forests had no statistically significant trend until 2017, but an exceptionally high level of disturbances in 2018–2020 will likely result in a substantial decrease of the Russian forest carbon sink.
- Forest disturbances pose the most important threat to Russian forests by damages of 10–15 mill. ha of forests annually with forest fires being the main natural disturbance factor.
- A fundamental challenge in Russian forestry is the need to replace the extensive exploitative model of forest use with the model of intensive sustainable forest management to respond to deteriorating forest resource conditions.
- Improved forest governance with new forest policies and significant investments in the Russian forest sector are needed to reconstruct the forest sector in Russia.

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3.

Climate change in Russia – past, present and future

Riccardo Valentini, Dmitry Zamolodchikov, Christopher Reyer, Sergio Noce, Monia Santini and Marcus Lindner

This chapter shows a synthesis of the past, present and future of climate change in the Russian Federation on a physical and geographical basis. Chapter 4 is dedicated to the analysis of the impacts of changes in the physical climate on the forest sector.

3.1 Observed changes of Russian climate in recent decades

Dmitry Zamolodchikov and Riccardo Valentini

Recent scientifically documented changes in climate have impacts on all climatic features, including temperature, precipitation, wind, and cloudiness. The regional changes can differ from global trends and Russia presents a good example for this, as the average annual temperature anomaly in the whole country has reached about 1.6 °C, which is much higher than the global anomaly of 0.9 °C compared to pre-industrial time (Allen et al., 2018). The slope of the linear trend of annual temperature in 1976–2018 in the whole of the Russian Federation (Figure 11) was 0.47 °C per decade (Roshydromet, 2019), which is 2.5 times more than the global temperature rise for the same period (0.18 °C per decade). Recorded temperatures were observed to increase in all seasons of the year, with the highest increases in the spring (0.61 °C per decade), and marked increases for summer and autumn (0.41°C and 0.46°C per decade respectively). Winter showed the lowest and statistically not significant changes (0.39 °C per decade).

A spatial analysis of the annual temperature changes in Russia is presented in Figure 12. The most rapid increase of temperature was observed in the Arctic regions of Siberia and the Far East, where the linear trend of temperature in 1976–2013 showed more than 0.8–1.0 °C warming per decade (Figure 12). This phenomenon is known at the global scale

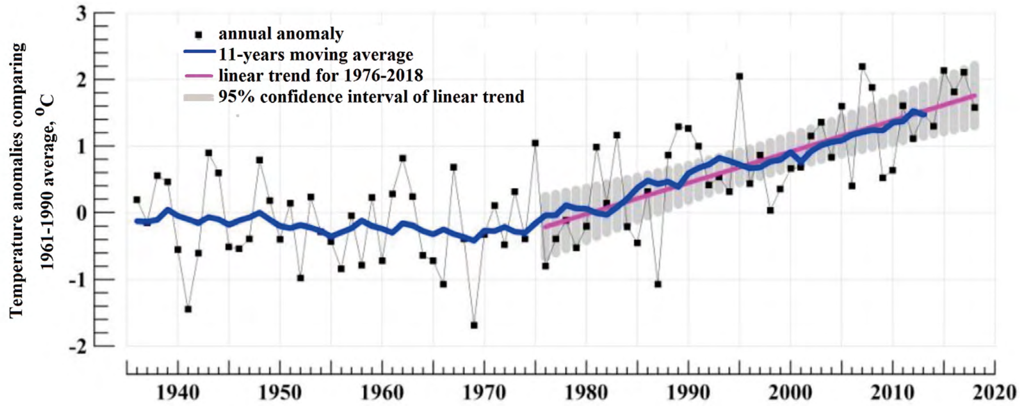

Figure 11. Mean annual temperature anomalies in Russia, calculated as deviations from the 1961–1990 average. Source: Roshydromet, 2019.

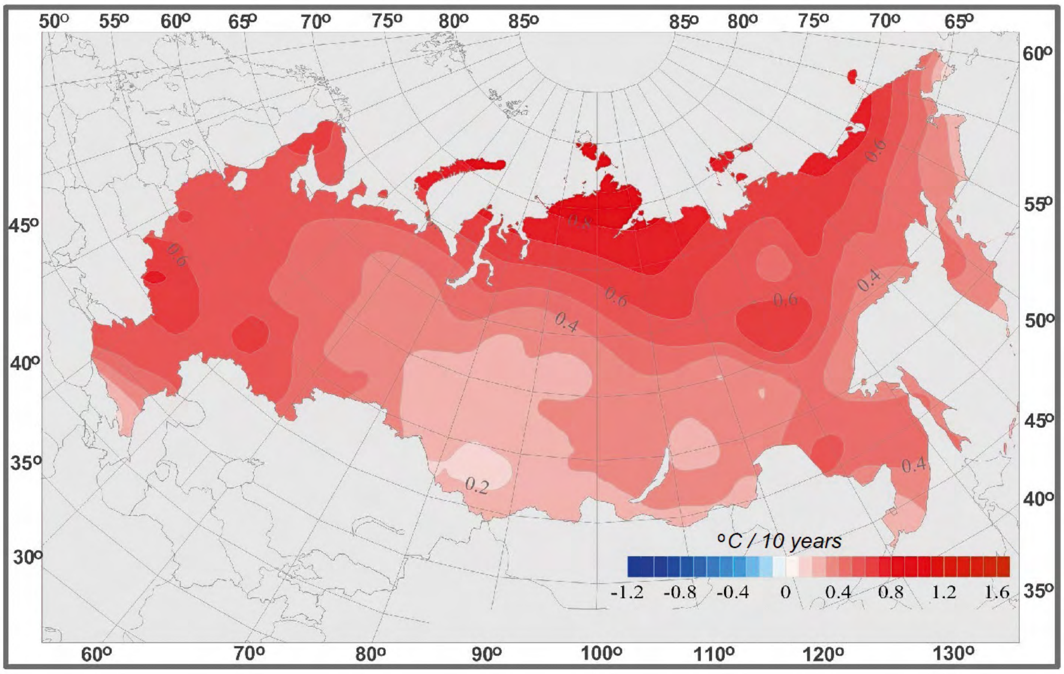

Figure 12. Trends of annual temperatures for 1976–2013 in Russian territory (change in temperature over the 42-year period, expressed as degree / 10 years). Source: Roshydromet, 2014.

as "Arctic amplification" (Cohen et al., 2014). Another hot spot of warming is the western part of European Russia, where trends were around 0.6 °C per decade. Minimal warming trends were observed in the southern part of Western Siberia (0.2–0.3 °C per decade).

In Russia, annual precipitation increased in 1940–1960, decreased in 1960–1980 and has been increasing since 1980 (Figure 13). The linear trend in 1976–2018 is +2.2 mm/month per decade. The maximal increase of precipitation during this period was observed in the spring (+5.9 mm/month per decade), while during the summer the increase was less and the change was not statistically significant (+0.7 mm/month per decade).

The spatial distribution of changes in mean annual precipitation per decade over the 1976–2013 period shows an increase almost in all regions in Russia (Figure 14).

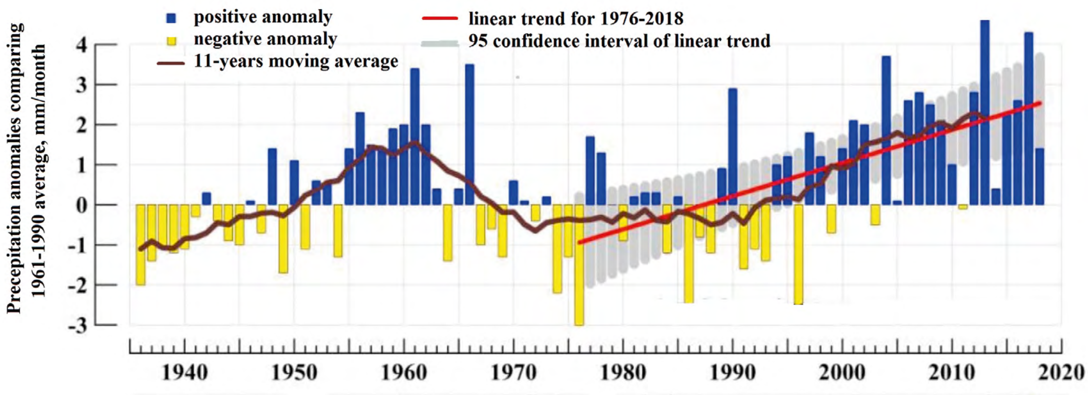

Figure 13. Precipitation anomalies from 1937 to 2018 relative to the mean annual precipitation of 1961–1990 in Russia. Source: Roshydromet, 2019.

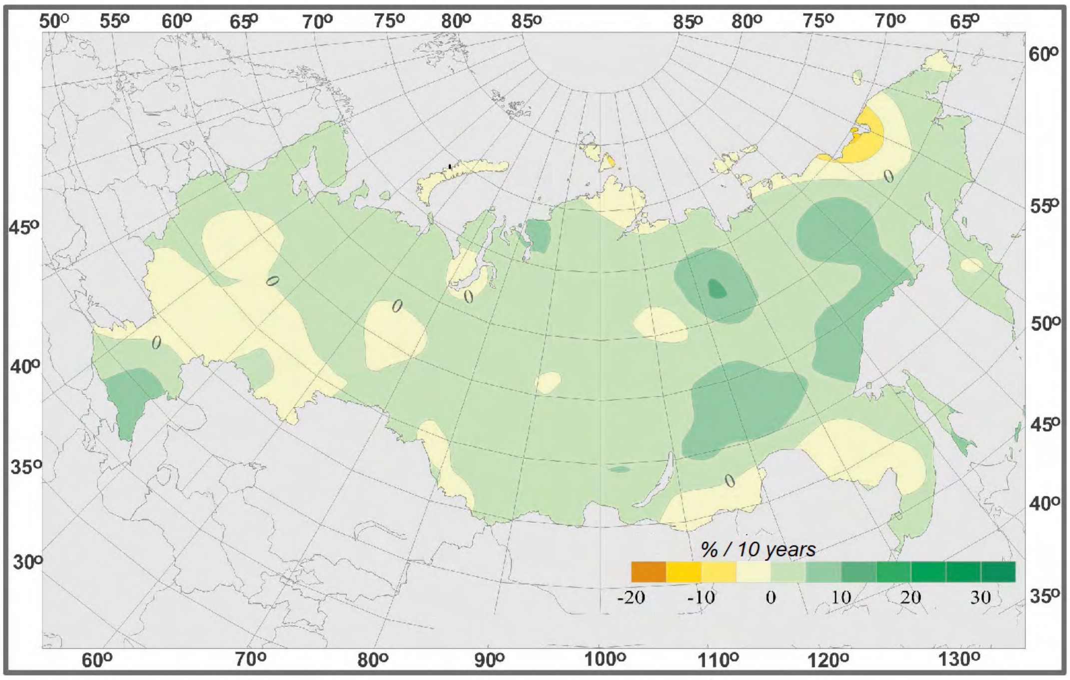

Figure 14. Trends of changes in annual precipitation per decade in Russia expressed as percentage in 1976–2013. Souce: Roshydromet, 2014.

Maximal increases are registered in some central parts of the Far East (up to 15–20% per 10 years). Some decrease was found in the Central and Southern parts of European Russia. The strongest decrease in annual precipitation took place in the north of the Far East (Chukotka autonomous okrug). A decrease of summer precipitation is evident for the total European part of Russia. This decrease of summer precipitation, together with increasing temperatures, often leads to water stress in vegetation, including forest stands.

Another important hydrometeorological factor in Russia is the snow cover as many Russian regions have steady snow cover for 6 months or more, strongly affecting the forest sector. While the temperature rise diminishes the period of snow cover, regionally enhanced precipitation may result in increased snow cover height (Roshydromet, 2019).

3.2

Climate change scenarios

Riccardo Valentini, Christopher Reyer, Sergio Noce, Monia Santini and Marcus Lindner

This Chapter presents climate change scenarios for the Russian Federation, showing anomalies of mean annual temperatures, and accumulated annual precipitation in respect of the historical data[2]. The time span of historical data is 1960–1999. Future projections represent both anomalies in respect of the historical datasets and uncertainties derived from the ensemble analysis of several GCM models[3]. The scenarios here represented are the RCPs 2.6, 4.5, 6.0, 8.5 following the IPCC terminology, where each scenario represents a different degree of radiative forcing. GCM data have been downloaded from the recent ISIMIP2b repository and the ensemble mean, and standard deviation calculated including the 4 GCMs (5GCMs for RCP8.5).

The time slices for the climate scenarios are historical (1960–1999), medium term (2036–2065) and long term (2070–2099). The scenarios can be considered as a mean representation centered at 2050 and 2085 respectively. The temperature anomalies show a similar trend to the observed recent past with a consistent warming in the northern and eastern regions of Russia and to some extent in south-west Siberia (Figure 15). All the scenarios of radiative forcing produce substantial warming already in the medium term (2036–2065). The temperature signal is already clear in the recent past observational period and in several Russian regions mean annual temperature increase exceeds the 1.5 °C target of the Paris Agreement even at lower radiative forcing (RCP2.6).

Figure 16 illustrates the historical mean annual precipitation (center) and the anomalies as the average across different models. Annual precipitation anomalies are somewhat more variable across the regions, showing a greater effect of topography on the land surface hydrological cycle and interaction with the atmosphere. Consensus among the models is relatively lower than for temperature change, showing also regional differences. In particular, less consensus is shown for the most impacting RCP8.5 scenario in Central and North-West Russia. However, a general trend of enhanced hydrological cycle is present all-over Russian territory except for the southern European region where water availability may become a limiting factor.

Besides annual temperatures and precipitation, weather extremes are playing a fundamental role in shaping the response of the forest sector to climate change. The IPCC

2 Historical data are taken from the Water and Global Change (WATCH) forcing dataset (WFD). The WFD is a twentieth century meteorological dataset based on the European Centre for Medium-range Weather Forecasts (ECMWF) Re- Analysis (ERA-40) (Uppala et al., 2005) interpolated to a 0.5 × 0.5° latitude/longitude grid, with successive elevation correction of surface meteorological variables plus monthly bias correction from the Climatic Research Unit (CRU) gridded observational dataset (Piani et al., 2010; Weedon et al., 2011).

3 The following GCM models were included: GFDL_ESM2M, HADGEM2_ES, IPSL_CM5A_LR, MIROC5 and CMCC-CESM, the latter included only for the RCP 8.5 scenario.

special report on climate extremes documented for both European and Asian regions of Russia an increase in climate variability in terms of the number of hot days and enhanced hydrological extremes with increasing rainfall intensity, particularly in the central and far east regions (Seneviratne et al., 2012)

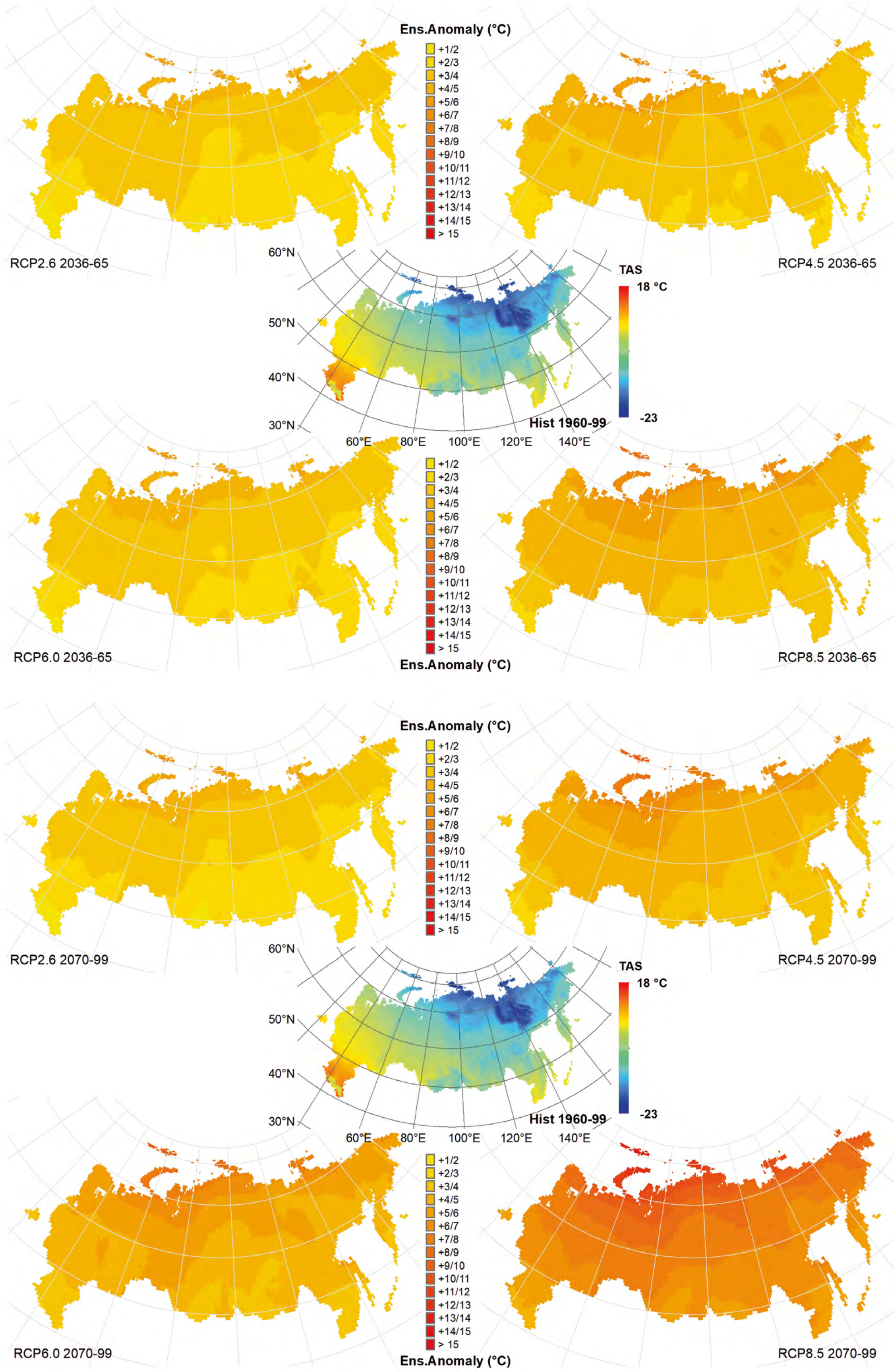

Figure 15. Mean annual temperature scenarios for the time period 2036–2065 and 2070–2099 for the climate forcing RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

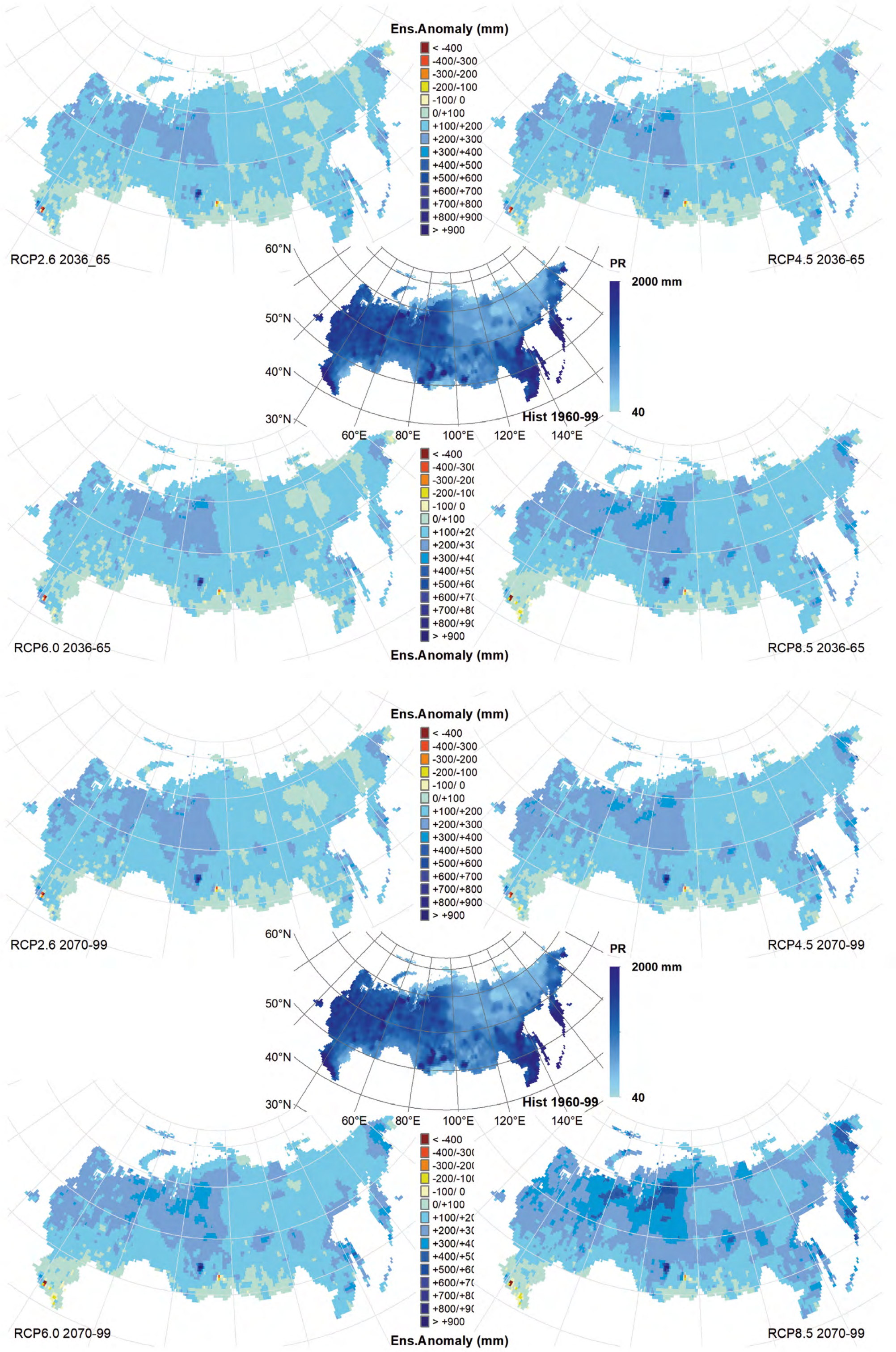

Figure 16. Cumulative annual precipitation scenarios for the time period 2036–2065 and 2070–2099 for the climate forcing RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

3.3

Key messages

Riccardo Valentini and Marcus Lindner

- A general climate warming trend has occurred in Russia over the past 40 years with an average decadal increase of 0.61 °C, corresponding to about 2.5 times the global average increase.
- At the same time, general enhancing of the hydrological cycle with increasing precipitation has been observed across Russia (+2.2 mm per month per decade), particularly in the Central Far East. A slight decrease of precipitation was observed in central and southern European Russia. Extreme events and hydrological hazards increased by almost 3 times between 2000 and 2018.
- Future climate change projections show in all scenarios both at medium (2036–2065) and long term (2070–2099), a continuation of the observed past warming trends with good confidence across models.
- Cumulative precipitation continues to increase on average across Russia with stronger enhancements in Siberia and projected decreases in Southern European Russia. However, climate variability and related extreme events are projected to increase particularly in the central and far east regions of Russia.

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4.

Climate change and Russian forests: impacts, vulnerability and adaptation needs

Christopher Reyer, Marcus Lindner, Dmitry Zamolodchikov, Anatoly Shvidenko, Martin Gutsch and Sergey Bartalev

4.1 Observed impacts of climate change

Dmitry Zamolodchikov and Christopher Reyer

This chapter reviews the existing evidence on climate change impacts in Russian forests. Impacts can be gradual and abrupt. Gradual impacts are related to trends in temperature, precipitation and other climatic parameters, whereas abrupt impacts are related to increased probability of extreme weather events, such as droughts, hurricanes or floods, that lead to fast damage or dieback of forest stands.

4.1.1 Observed changes in species ranges

Species ranges are highly sensitive to changes in climate. At the northern tree line, the expansion of forest vegetation into the tundra has been observed in 30% of sample plots in the Ob river delta (West Siberia), whereas 5% of forest plots transformed into wetlands (Rees et al., 2002). Forest expansion into mountain tundra was also observed in the Polar Ural Mountains with 3.2–5.8 m per year horizontal and 0.3–0.4 m per year vertical tree line shift (Shiyatov et al., 2007). In South Ural, both closed spruce and open-spaced spruce-birch forests moved 14 m upslope during 1973–2006 (Kapralov et al., 2007). At the southern tree line, contrasting tendencies are observed, including expansion of young spruce forests into steppe ecosystems on south-facing slopes of the Hamar-Daban mountains where precipitation increased (Glyzin et al., 2005), and a decrease of oak area by 5–25% from 1988–2009 in the forest-steppe and steppe zones of the European part of Russia (Zamolodchikov, 2011).

During the 20th century species composition of forests in the polar Ural Mountains and in the Central Siberian Plateau shifted from larch dominance to increasing shares of evergreen coniferous species (Kharuk et al., 2005a; Moiseev et al., 2010). In the south of East Siberia increased autumn temperatures more frequent extreme weather suppresses regeneration of coniferous species, which are replaced by deciduous species (Soja et al., 2007).

4.1.2 Observed changes in forest disturbances

The geographical distribution of many pests (cf. Chapter 2.2) is limited by low winter temperatures. Temperature increase allows these pests to expand their area to the north and upslope. In line with observed warming, the outbreak zone of the Siberian silk moth (*Dendrolimus sibiricus*), one of the most dangerous boreal insect pests, shifted north. An outbreak in 2014 in cedar-fir stands of the Yenisei plain, damaged considerable forest areas north of the historical distribution area of Siberian silk moth (Kharuk et al., 2017b). Another example is the Sakhalin-fir bark beetle (*Polygraphus proximus*) which causes dieback of Siberian fir stands, affecting approximately 40% of forest area of the Tomsk oblast (Krivets et al., 2018; Debkov et al., 2019).

Over the 20th century, the frequency of droughts in Russia increased (Groisman et al., 2007) and in 2005–2008, massive dieback of pine and spruce stands occurred near the southern tree line (Allen et al., 2010). Large scale dieback of oak stands occurred in the Middle Volga region, with damages amplified through weather conditions that stimulated insect outbreaks in 1991–1994 (Yakovlev and Yakovlev, 1999). Decreasing soil moisture levels were a main cause of massive dieback of spruce stands in Arkhangelsk oblast in 1990–2000 (Aakala and Kuuluvainen, 2011). Similar dieback processes occurred in fir stands in the Krasnoyarsk kray since 2010, caused by an extreme drought followed by invasion of Sakhalin-fir bark beetle, which was not earlier observed in the region (Kharuk et al., 2019).

Despite the clear overall trends in fire damage presented in Chapter 2.2 there are only few studies that attribute fire to climatic trends. Fire danger, estimated using meteorological data, decreased in the Russian plain in 1935–2000 and increased in the Asian part of Russia during the whole 20th century (Groisman et al., 2007). Dendrochronological analysis showed increased frequency of fires in the Central Siberian Plateau with mean fire return interval decreasing from 100 to 65 years from the 19th to the 20th century (Kharuk et al., 2005b).

4.1.3 Observed changes in phenology, forest growth and productivity

Climate change prolongs the active vegetation period in boreal and temperate zones. In Northern Eurasia, satellite observations of vegetation greenness (normalized difference vegetation index, NDVI) dynamics showed an increase by 14–22 days from 1981–1999, mainly due to longer retention of foliage on trees (Zhou et al., 2001). In the Amur oblast, increasing temperature trends delayed the leaf fall period in aspen and some species of birch (Parilova et al., 2006).

The radial increment dynamics are less clear and blurred by cyclic fluctuations. Increasing radial increment from 1914–2004 was found in larch stands of Polar Ural (Shiyatov and Mazepa, 2007). Spruce stands of the Republic of Mari El demonstrated wave-like changes of increment with a depression until 1973 followed by an increase phase (Demakov et al., 2009). Currently growth depressions are observed in oak stands of Shipov forests (Voronezh oblast) (Milenin, 2012) and in pine stands in the forest-steppe zone of European Russia (Matveev, 2014).

Forest stand productivity trends can be inferred from remote sensing NDVI observations as a surrogate of plant photosynthetic activity. Whereas NDVI increased by 12.4 % in 1982–1999 in coniferous and mixed forests between 40–70° northern latitudes of Northern Eurasia, some regions in the North-East of Russia showed a decrease of the NDVI by 5% (Zhou et al., 2001). Another measure of productivity is the density of forest stands, which increased in Northern Siberia in closed larch stands from 1960–2000 (Kharuk et al., 2004). High rates of density increase were also reported for birch and spruce stands of Southern Russia (Kapralov et al., 2007) and on 50% of explored sites in the Ob river delta (Rees et al., 2002).

4.2

Projected impacts

Christopher Reyer, Martin Gutsch and Dmitry Zamolodchikov

4.2.1 Projected changes in species ranges

The latest species distribution modelling exercise for the Russian territory by Noce et al. (2019) used 9 different types of species distribution models combined with climate change scenarios following the RCP4.5 and RCP8.5 emission pathways for the periods 2040–2079 and 2060–2099 from six climate models to project changes in species ranges. They projected that suitable area for birch, pine and larch is shrinking, while it increases for aspen and fir and remains more or less constant for cedar and spruce. Overall, species suitability ranges shift northward and to a lesser extent eastward. Changes are projected to get much stronger towards the end of the century.

The vegetation period at the end of the century (2090–2099) was projected to lengthen by 25 and 41 days on average across Russia compared to the 1990–1999 period under RCP4.5 and RCP8.5, respectively, leading to a decline of coniferous and increased shares of deciduous trees (Torzhkov et al., 2019). However, tree species distribution shifts may be modulated through changes in land use as forest area increase through the north and eastward expansion of boreal forests into the tundra (ranging between 7–12% depending on the scenario) could be compensated through encroachment of competing land uses such as agricultural or bioenergy crops into forest areas (Kicklighter et al., 2014). Finally, climate change induced species range changes may also feedback on climate. Trees in northern latitudes partly mask the high reflectance of snow (Bonan et al., 1992) and hence further northwards shifts of tree species lead to regionally warmer winter temperatures than if trees were not present, self-amplifying the effects of climate change.

4.2.2 Projected changes in forest disturbances

Recent dramatic fire seasons and insect outbreaks (cf Chapter 2.2) have demonstrated the important role forest disturbances might play for future forests (Seidl et al., 2017). Direct climatic effects appear for example when warmer temperatures reduce fuel moisture and thus increase fire risk, while indirect effects occur for example when climate-induced changes in vegetation composition or productivity increase fuel availability or flammability. Especially boreal forests are likely to face stronger effects of direct and indirect disturbances (Seidl et al., 2017). Uncertainties about future changes in precipitation remain large and these matter: While under warmer and wetter conditions both drought and fire activity might be partly reduced depending on local conditions, warmer and drier conditions will clearly increase the risk of fire, drought and insect outbreaks in European and Asian forests.

Future projections of changing disturbance risk in Russia are rare and usually only consider fire danger. Sherstyukov and Sherstyukov (2014) analysed how fire danger expressed through the Nesterov index changes across an ensemble of 31 climate models following RCP4.5 and RCP8.5. The length of the season with fire danger increases by 10 to 20 days throughout the country for the period 2041–2060 compared to 1980–2000 and at the end of the century (2080–2090) at least an additional 20 fire risk days (and locally up to 50 days) were projected for the European part of Russia, West Siberia, and the south and mid-latitudes of East Siberia. Recent simulations by a regional climate model ensemble confirmed the general increase in fire risk under climate change but found that especially under RCP4.5 climatic fire risk could partly decrease regionally in Central Siberia because of increasing precipitation levels (Torzhkov et al., 2019).

In combination, climate change-induced shifts in species ranges and forest disturbances could affect forest dynamics and functioning more than indicated by individual assessments. The boreal forests of the northern hemisphere have been identified as a tipping element in the global climate system (Lenton et al., 2008). Strong, drought-driven tree mortality interacting with increasing insect and fire disturbances may further increase the susceptibility of forests to large-scale dieback under global warming levels above 3°C global warming (Lenton et al., 2008; Schellnhuber et al., 2016). It is unclear whether the projected disturbance dynamics assessed in this chapter interact at a scale that could result in irreversible forest loss. However, they clearly reach beyond past experiences with increasing risk of unprecedented adverse impacts on forests. Moreover, satellite data analyses suggests that the boreal region contains ecosystems with multiple stable states, meaning that climate-driven vegetation shifts could be abrupt rather than smooth and forests may abruptly switch to a sparsely vegetated ecosystem state and to a certain extend also vice versa (Scheffer et al., 2012). Such transitions to more open vegetation would have important implications for the global carbon cycle and other climate-vegetation feedbacks by reducing the ecosystem carbon stocks, increasing surface roughness and reducing reflectance. However, the feedbacks on carbon cycling and climate feedbacks of such land-cover changes is yet to be assessed and can further amplify warming if for example wetlands or peatlands are invaded by trees (Moomaw et al., 2018). Overall, the evidence for a boreal forest tipping point (Lenton et al., 2008) is ambiguous, but current evidence rather points at an increase of disturbance impacts destabilizing the forests, with less indications supporting an increase in tree cover.

4.2.3 Projected changes in forest productivity and carbon balance under climate change

Simulations with two global vegetation models (LPJmL and ORCHIDEE-MICT from Reyer et al. 2019) show consistent increases in net primary productivity under RCP2.6 and RCP8.5 in 2036–2065 compared to 1961–1990 levels. Only the most south-western and western parts of the country show slight net primary productivity (NPP) decreases (Figure 17, middle panels). This pattern of NPP changes remains mostly the same in the 2070–2099 period under RCP2.6 and RCP8.5 for the Western parts of the country – hence no further increases in NPP are projected. However, the 2070–2099 period under RCP8.5 is marked by much more pronounced NPP increases in the Central and Eastern Parts of Siberia compared to 1961–1990 levels (Figure 17, lower right panel). These results are consistent with projections from regional studies and larger ensembles of global vegetation models that also show mostly increasing NPP in boreal regions even under high levels of global warming (Kurbatova and Tarko, 2017; Friend et al., 2014, Ito et al. 2020)). Yet even though these trends are partly in line with those shown by recent observational products for the boreal region (Exbrayat et al., 2018), the uncertainty of the projections remains high (Friend et al., 2014; Ito et al., 2020).

One main issue is whether the simulated productivity increase that can be largely attributed to very strong responses of vegetation productivity to increasing levels of atmospheric CO_2 in the models, is realistic. Recently, model and observational studies have disputed the continuous, ubiquitous effects of CO_2 fertilization (Hickler et al., 2015; Jiang et al., 2020). To account for this uncertainty, Figure 18 shows sensitivity simulations of projected NPP changes under RCP8.5 for the 2036–2065 and 2070–2099 period without including further beneficial effects of CO_2. In these simulations, the projected NPP changes show a much more marked pattern: NPP still increases in Central and Eastern Siberia while it strongly decreases in the Southern and Western parts of Russia (Figure 18 lower right panel). Another issue is that the models only account to a very limited extent for large-scale forest disturbances such as fire or insect damage. While fire interactions are included to some extent, none of the models includes dynamic simulations of damages from insects or storms. However, even with these deficiencies, the models simulate large changes in carbon residence time, which essentially means a faster turnover of vegetation because of higher mortality due to drought and other factors (Friend et al., 2014). Finally, the models do not include forest management effects nor are the actual species distributions as influenced by forest management prescribed. The projected increases in NPP have to be considered at the backdrop of these limited representations of forest dynamics and management. Hence, even though the models adequately represent changes in forest productivity in line with ecological theory, it is important to note that the models largely ignore management and disturbance effects on productivity, biomass and carbon stocks.

Another group of forest simulation models accounts for changes in forest management and enables studying different forest management scenarios. However, they usually do not consider the effects of changing climate on productivity. Zamolodchikov et al. (2013, 2014) applied the CBM-CFS3 model and a range of forest management scenarios including a "no harvesting increase", "moderate" increase to 157% in 2050 from 2010 levels and "intense" increase in 2050 to 314% from 2010 levels. The "intense" scenario suggests a rise of harvests until allowable cuts are reached separately for Russian administrative regions and reforestation activities were assumed to be proportional to harvesting increases. The results showed a strong influence of logging on the forest carbon sink: Depending on logging intensity, the forest sink decreased from 270 Mt C per year in 2010 to 80–90 Mt C per year and 30–40 Mt C per year under a moderate and intense harvesting scenario in 2050, respectively. Simulations of global wood demand impacts using the Global Timber Model (Sohngen et al., 2005) indicated that Russian forests could switch from a carbon sink into a carbon source of up to –30.5 Mt C in 2030. This decrease in sink was mostly driven by demand and price changes leading to earlier harvests. After the mid-century the sink increased again when the previously harvested forest started to regrow. Forest product stores (but no substitution effects; see more on substitution from Chapters 5 and 6 of this report) were accounted for in the analyses but represented only a small carbon stock that could not balance increasing carbon losses from decay.

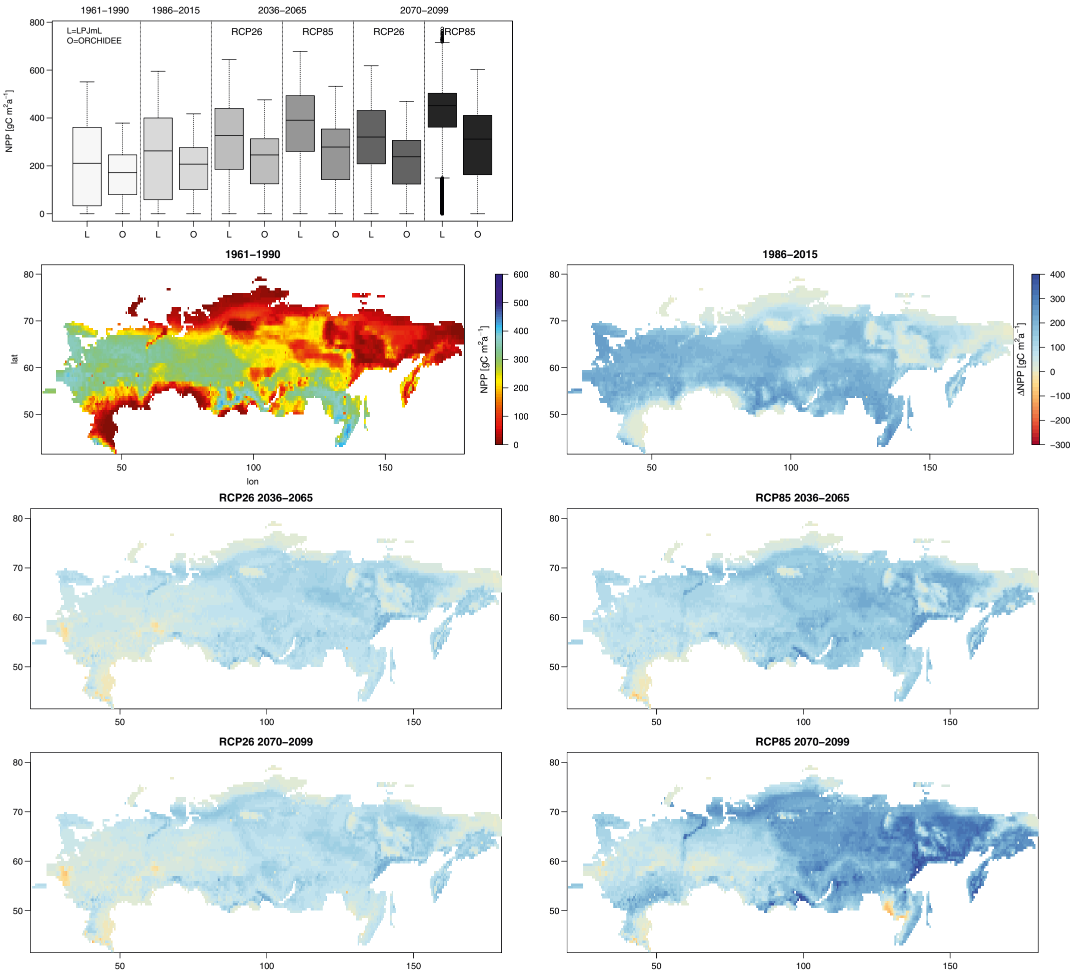

Figure 17. Climate change impacts on forest NPP of the Russian Federation. The boxplots show the absolute NPP over the Russian Territory for the two different DGVMs (ORCH= ORCHIDEE and LPJml) over four different time periods (1961–1990; 1986–2015; 2036–2065; 2070–2099). The map in the upper left shows the multi model mean NPP over 1961–1990 as simulated by the 2 DGVMs under different historical climate forcing from the 4 GCMs. The map in the upper right as well as the middle and lower maps show changes in the multi model mean relative to the 1961–1990 period from an ensemble of 2 DGVMs and 4 Global Climate Models driven by the RCP2.6 and RCP8.5 emission scenario for the period (1986–2015; 2036–2065; 2070–2099).

Torzhkov et al. (2019) considered scenarios of felling (from Zamolodchikov et al., 2013, 2014) and climate change. The projected carbon sink was 187–251 Mt C per year, as the influence of climate change compensated for the increase of logging. Izrael et al. (1997) projected the Russian forest carbon balance depending on different forest felling rates and climate change. Simulating a recent forest carbon sink of 150 Mt C per year in 1995, their three different forest felling scenarios featuring increasing harvest levels from 206 mill. m³ in 1996 to 420, 488 and 608 mill. m³ in 2040, lead to a stable sink (150–160 Mt C per year), a reduced sink (100 Mt C per year) and a strongly reduced sink (40 Mt C per year) in 2040, respectively. More regional simulations with a forest model in the Kostroma oblast north of Moscow including detailed forest management

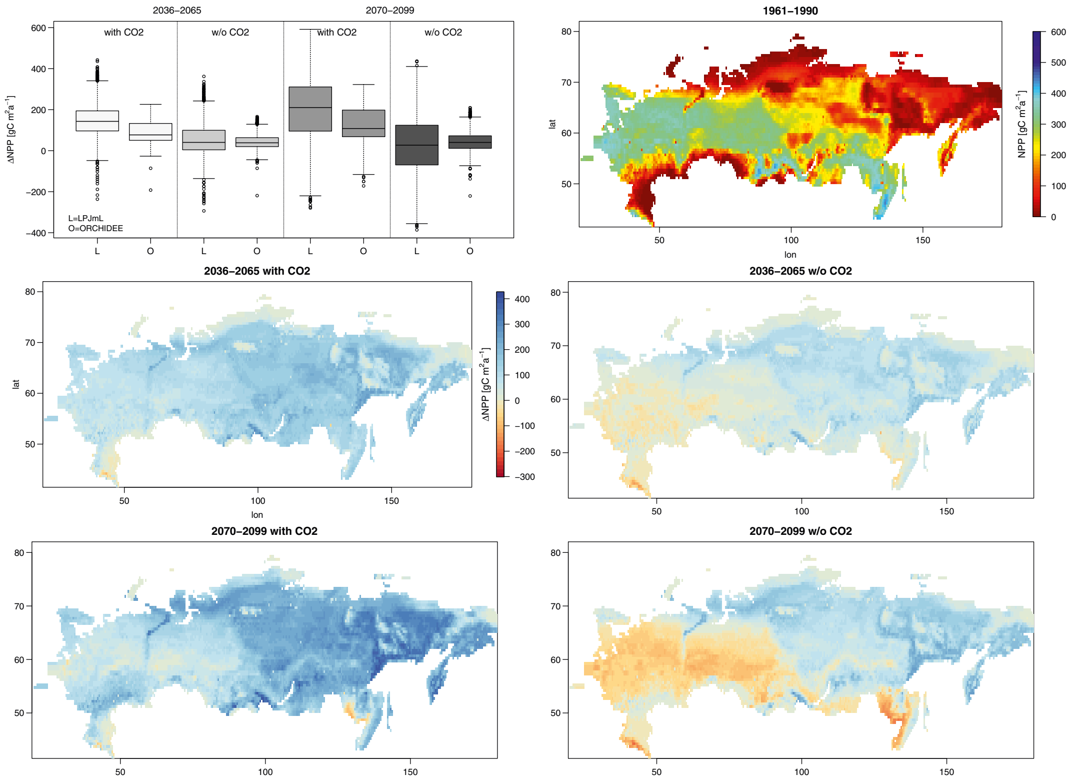

Figure 18. Sensitivity of climate change impacts on forest NPP to changing atmospheric CO_2 concentrations. The boxplots show the absolute change in NPP over the Russian Territory for the two different DGVMs (ORCH= ORCHIDEE and LPJml) for two different time periods (2036–2065; 2070–2099) relative to 1961–1990 with and without ("w/o CO_2", by keeping CO_2 concentrations constant at 2005 levels) including effects of increasing levels of CO_2 in the models. The map in the upper right shows the multi model mean NPP over 1961–1990 as simulated by the 2 DGVMs under different historical climate forcing from the 4 GCMs. The maps in the middle and bottom row show changes in the multi model mean NPP relative to the 1961–1990 period from an ensemble of 2 DGVMs and 4 Global Climate Models driven by the RCP8.5 emission scenario for the periods 2036–2065 (middle row) and 2070–2099 (bottom row). The left panels in these rows are showing future changes including effects of increasing CO_2 while the right panels show changes keeping CO_2 concentrations constant at 2005 levels.

activities showed that forest management had a stronger influence than climate on forest carbon dynamics (Shanin et al., 2011). They also found increases in forest productivity due to climate change which might however be compensated by increasing fire damage in their simulations.

Altogether, the different lines of evidence from these future model studies can be reconciled as follows. While climate change improves growing conditions for forests in large parts of the country under all warming scenarios in the mid-future, uncertainties about the role of CO_2-fertilization effects and large-scale disturbances dominate the projections for the second half of the 21st century. There is a risk of climate-induced reduction in forest productivity alongside changes in species ranges and suitabilities. Projections including different management scenarios confirm the strong role of forest management on forest carbon stocks, even potentially tipping the forest from being a sink into a source of carbon.

4.3

Vulnerability assessment

Anatoly Shvidenko and Christopher Reyer

IPCC (2014) defines vulnerability as "the propensity or predisposition to be adversely affected", it further states that vulnerability "encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt". Knowledge on vulnerability of forests, national forest management systems, forest-dependent people and related branches of the economy is key for identifying risks and adequate adaptation options (FAO and CIFOR 2019). The huge area and diversity of Russia's forests reflects a similar diversity of current and predicted climates as well as of related stress factors and risks. The level of vulnerability substantially depends on the intensity of climate change exposure: while a future climate in line with the Paris Agreement (RCP2.6) may on average have favorable effects for Russian forests with only limited changes in the current forest sector vulnerability, scenarios with limited emission reductions (like RCP 6.0 and RCP8.5) project critical forest growth conditions that threaten in vast regions the survival of major forest species (Tchebakova et al., 2009; Gauthier et al., 2014, 2015).

The vulnerability of boreal forest ecosystems depends on their adaptive capacity, which is supposed to be relatively high because of their huge genetic populations, high fecundity, high levels of genetic and ecosystem diversity, as well as historically formed mechanisms of tolerance to natural disturbances (Aitken et al., 2008). On the other hand, boreal forests evolutionary formed under cold climates and are sensitive to warming, because of the nature of their landscapes and soils with a wide distribution of wetlands and permafrost. The high frequency and projected increase in disturbance severity like fire and insect outbreaks are further crucial vulnerability drivers affecting the forest sector under climate change.

The risks for forests will be the highest in hotspot regions exposed to major direct (high summer temperature, water stress) and indirect (accompanied disturbances) drivers. The highest risks for forest survival are expected at the transition zones between forests and treeless areas at the northern and particularly southern limits of the forest zone. Forests in the southern taiga zone and at mid-latitude forest steppe ecotones are particularly vulnerable due to water stress (Tchebakova et al., 2009), with particular risks for biodiversity, wild fauna and livelihood of the local population (e.g. Tchebakova et al., 2009; Kharuk et al., 2017a). Shifting species distribution ranges (see Chapters 4.1 and 4.2) substantially enhance vulnerability of forests due to disparity between the rate of natural tree migration in the high latitudes – less than 100 m per year (Aitken et al., 2008), compared with the northward shift of climatic conditions that is 10 to 50 times faster (Thuiller 2007). Taking into account the natural barriers in Northern Asia (rivers, high latitudinal mountain ridges), real migration rates may be even slower. Permafrost territories above 500 mill. ha Russian forests represent a vast hotspot region, which contain a huge amount of carbon. Thawing permafrost combined with increased aridity of the hydrological regime on hundred million hectares may trigger drastically increased fire risks and release enormous amounts of greenhouse gases, representing a "tipping point" in the Earth system (Lenton et al., 2008).

Vulnerability of forests also affects people. Russia has about 260 000 people belonging to 39 small indigenous nations, many of whom directly depend on forests. Also, social and economic changes in Russia after the 1990s have led to the slow death of several thousands of taiga villages located around former industrial facilities. The remaining population in these settlements is almost completely depending on forests. Moreover, large parts of the regional population in forested regions is vulnerable to extreme weather events and accompanying catastrophic disturbances because of inadequate forest fire protection and weak capacity and preparedness in disturbance risk management. This may lead to critical health impacts, premature deaths of thousands of people, and large economic losses (Bastos et al., 2014; Shvidenko et al., 2020).

Vulnerability of Russia's forests to disturbances represents the most dangerous current and particularly future risk. Regional disturbance regimes are projected to intensify, as extent, frequency and severity of wildfires and outbreaks of dangerous insects and pathogens substantially increase. It is very likely that the vulnerability of mid-latitude forests of Eurasia will be critically magnified by diverse dangerous biotic agents including alien insects and pathogens. While local reasons of observed resilience decline and death of forests differ (e.g. periods with severe drought, invasions of insects and pathogens, changes of the hydrological regime, planting forests in inappropriate conditions, lack of satisfactory forest management), there is increasing evidence that all these processes have been directly or indirectly affected by climatic and environmental changes (Shvidenko et al., 2017). Consequently, a tipping point of boreal forests may be reached under lower levels of warming than earlier anticipated (Lenton et al., 2019). Recent experiences question the ability of current national forest management systems including legislation and forest management manuals, institutional structure, and forest protection capacities to meet the challenges of the fast-changing world.

Vulnerable forests lead to a high vulnerability of the Russian forest industry. The most valuable tree species for the Russian forest industry are pine and spruce, which are also very vulnerable to climate change. Catastrophic fires and insect outbreaks have in recent decades completely destroyed highly productive forests on hundreds of thousands of hectares which were then regenerated by early successional species of lower economic value. A crucial problem for the Russian forest sector is the poor transport infrastructure, especially the lack of all-season roads (Goltsev at al., 2011). In most regions with abundant forest resources, logging companies can access remote forest areas only during wintertime. The logging and transport of wood heavily depend on weather conditions. During the warm Decembers in 2006, 2007, 2011, 2019 and 2020, loggers had substantial difficulties in wood removal (Prokopyev et al., 2018; Lebedeva, 2020). According to estimates, warm winters decreased the amount of wood harvesting, delivering and processing by about 30%. This may lead to an increase in prices for forest products by 15–20% (Fomicheva, 2020).

The ability of Russian forestry and forest management to ensure the sustainable growth of target species of high productivity is an indispensable condition for Russia's transition to sustainable forest management. This will be particularly challenging considering the increased vulnerability and diverse threats that climate change brings to Russian forests. The Russian forest sector outlook study until 2030 provided by FAO

(2012) concluded that the sector is in a critical state, and real management does not satisfy requirements of sustainable, risk resilient forest management. This study analysed three scenarios of Russian forest sector development until 2030 and found that the Russian forest sector requires radical reconstruction, otherwise it will negatively impact its sustainable functioning and supply of wood to national economy. Without that the Russian forest management will not be able to meet challenges of dramatic climate change.

Despite numerous studies on impacts of global change in Russian forests, many ecological processes and tendencies are poorly understood, and uncertainty of climatic, social and economic projections remains high. These uncertainties create special difficulties to the development of future strategies of co-evolution of human and forests in high latitudes.

4.4

Adaptation needs

Dmitry Zamolodchikov, Marcus Lindner and Sergey Bartalev

The information presented in the previous chapters shows the magnitude of projected climate changes in the Russian Federation and the climate impacts on national forestry. In this regard, the development and implementation of adaptation programs that reduce negative effects and build on benefits from positive effects is extremely important. Russian national forestry authorities included climate change in forestry planning in 2017, when the forest plans for all Russian regions were supplemented by a section "Information on planned measures to preserve the ecological potential of forests, adapt to climate change and increase the sustainability of forests" (Order of the Ministry, 2017). The annex to the standard forest planning form contains a list of typical adaptation measures, grouped by the risks of climate change (Table 2).

Table 2. The list of adaptation measures according to the standard form of the regional forest plan. Source: Order of the Ministry, 2017.

Climate change induced risk	Adaptation measure
Change in forest productivity due to changes in average temperature and rainfall	Adjustment of the duration of the reforestation cycle and forest care rules taking into account forest productivity
	Correction of the list of species used in reforestation and afforestation processes
	Salvage cuttings in dead and damaged stands
	Diversification of forest management goals for forest products and services
Changes in the species composition of forests	Orientation to the cultivation of uneven-aged mixed-species stands
	Adapt tree species in reforestation and afforestation processes to predicted climatic changes
	Formation of specially protected natural areas for the conservation of vulnerable species and habitats
	Identification and control of invasive tree species
Increased incidence of forest fires and areas covered by fires	Improvement of the effectiveness of fire safety measures in forests, including forest fire prevention, fire hazard monitoring in forests and forest fires
	Correction of plans to extinguish forest fires in connection with an increase in the frequency of occurrence of forest fires and areas covered by fires
An increase in the frequency of outbreaks of pests in forests	Improvement of the system of forest pathological examination
	Improvement of pest prevention measures
Increased frequency of extreme weather events in forests	Adjustment of the duration of the reforestation cycle to minimize the risks of windfall and windbreak in forests
	Improvement of timber harvesting technologies to minimize the risks of wind damages in forests
	Formation of uneven-aged mixed and multi-tiered stands

The requirement to develop adaptation measures in forest plans is a progressive step in Russian forestry. However, an analysis of new forest plans adopted in the regions of the Russian Federation in 2018 showed that the adaptation measures do not correspond to the seriousness and severity of the possible consequences of climate change (Grigoriev et al., 2019). A common problem with new plans is that, still, measures to protect forests from fires or pest outbreaks are developed without considering climate change due to the lack of systematic and consistent projections of climate change and its impacts on forests at the regional level in the Russian Federation.

Climate change already leads to changing disturbance regimes (see Chapter 4.1.2) with increasingly catastrophic fires across the entire country. An adaptation program for Russian forests to deal with future disturbance regimes is urgently needed. Potential strategies to reduce vulnerability entail a transition to adaptive risk resilient forest management, aiming at reducing stressors, mitigating sensitivity, and enhancing adaptive capacity of the forest sector and forest ecosystems. Decreasing vulnerability and adaptation of forest management requires the inclusion of risk management in planning processes, the selection of robust, diversified, and no-regret adaptation actions, and the adoption of appropriate institutional frameworks. Improvement of knowledge and operational monitoring is central for the implementation of adaptive forest management (Gauthier et al. 2014, 2015, FAO 2012, Shvidenko et al., 2017).

With increased extent and severity of wildfires, adaptation measures should go beyond typical fire safety and prevention. Elements for a new system of forest fire protection should include the analysis of present and future regional fire regimes and the development and implementation of more efficient forest fire protection concepts. This requires appropriate adaptation of forest landscapes to future climate conditions (adapted species composition, land cover and forest structure, control of fuel amount, etc.), the development of efficient fire monitoring and creation of mobile systems of fire suppression, improving the legislation and institutional structures of forest management, and better international cooperation (Mokhov et al., 2006; Malevsky-Malevich et al., 2008; Shvidenko and Schepaschenko, 2013). Likewise, changes in the distribution of forest pests threaten forest functioning. Modern scientific approaches allow detection and prediction of pest outbreaks. It is necessary to strengthen the staff and resources of forest pathological services and to expand biological pest control methods (e.g. application of biological pesticides to spread insect viruses).

A common problem with existing forest plans is that measures to protect forests from disturbances or to restore them afterwards are developed without considering their feasibility at the scale and magnitude of Russian forests. All plans need to consider this scale and the lack of access / forest infrastructure as well as resources to implement the plans. Therefore, measures would often have to rely on air support and techniques that could cover large areas in a relatively short time window. Tree seeding from aircraft could be a tool, as well as the use of aerial ignition for large scale prescribed burning to reduce available fuel loads before the fire season. A proven technique to burn so-called "open-ended fire breaks" using aerial ignition has been developed in Australia and Southern Africa (de Bruno Austin et al., 2011). Research would be needed to adapt such techniques and tools to Russian conditions to create strategically placed large fire breaks / fuel buffer zones in the extensive Russian forests. This is easier said than done and extensive training would be needed to create and enable fire managers to apply fire skilfully.

The huge Russian territory and its spatial specificities of climate change impacts require the development of regional adaptation measures. In colder regions, with positive precipitation trends and increasing forest growth rates, it might be possible to shorten rotation periods and increase the estimated harvest area. In areas with negative precipitation trends close to the southern treeline, adaptive management responses could aim to mitigate productivity losses and increased drought risk by modifying thinning regimes. Thinning reduces water consumption and can support changing of the species composition and structure of forests. New silvicultural strategies are needed to support changing the dominant tree species, considering experiences on selecting appropriate genetic resources (Galdina et al., 2012; Nakvasina et al., 2018). Assisted migration can support species conversion at local to continental scale (e.g. Aitken et al., 2008). The regional wood industry needs to anticipate potential changes in wood assortments. Moreover, harvesting schedules and wood quality might be disrupted by increasing disturbance activities.

The success of adaptation measures largely depends on the modification of reforestation techniques. Forest restoration should aim to establish more climate-resilient forests with reduced forest fire risk. Forest fund land that is temporarily not covered by forest vegetation after logging or natural disturbances (fires, diseases, etc.) is mostly regenerating naturally. According to forest inventory data, over 30 mill. ha required reforesting in Russia and artificial reforestation annually covers less than 1% of this area (Proderevo, 2018). Natural regeneration favours in many cases deciduous species (birch, aspen) replacing coniferous evergreen species (spruce, fir). More active restoration efforts are needed to maintain or increase the share of species demanded by the forest sector for wood production.

Insufficient infrastructure of the Russian forest sector currently hinders sustainable forest management, use and protection of forest resources. Wood harvesting and transport infrastructure is expected to be adversely affected by warmer winters with limited duration of winter road usage. Investments into year-round road networks are crucial to secure resource accessibility in many Russian forest regions, with positive side effects on improving forest protection and disturbance risk mitigation. The effective implementation of adaptation measures requires a change in many regulatory documents. It is proposed that operational changes should be reflected in forest management instructions, thinning and reforestation rules etc. All regulatory documents at the federal level should be audited to identify and edit the sections that are most relevant to adaptation measures.

There is an urgent need for improved monitoring of forest conditions and ecosystem services to inform climate mitigation and forest management decision-making under climate change. A decision support system for the Russian forest sector would be an important tool for addressing risk management and economic opportunities in relation to governmental and regional policies for the development of the forest sector.

Furthermore, a strategic approach to adaptation also requires a change in the training system for forestry. The existing educational standards and programs of higher forest education as well as retraining courses for present forestry staff should be supplemented with sections on the impact of climate change on various areas of forestry.

4.5

Key messages

Christopher Reyer, Marcus Lindner and Dmitry Zamolodchikov

- Projections indicate mostly increasing net primary productivity due to warming, longer growing seasons and CO_2 fertilization, but high uncertainty remains whether CO_2-induced productivity increases will substantiate and to what degree disturbances may counteract these trends.
- Permafrost thawing over this century under higher-end warming will substantially impact the hydrological regimes of vast territories in the high latitudes, destabilizing the intimate coupling of forests and permafrost. Targeted research and management assistance are required to avoid further declining resilience of these forests.
- Future disturbance regimes show increased risks and higher intensity of forest damages with consequent carbon release and disruptions of a steady forest resource flow. Adapting to disturbance risks is therefore of high importance for the Russian forests and forest sector and more efforts in forest restoration after disturbances are needed.
- Disturbances might accelerate forest change and hence offer possibilities for adaptation to the changing climate (e.g. adjusting species composition).
- The decrease of the area of productive forests, and disturbance impacts on quality and quantity of harvested wood as well as the lack of regeneration of commercially valuable tree species are key factors affecting the Russian forest sector.
- The current forest management system requires substantial improvements with a more reliable and operative system of forest inventory and monitoring as well as more effective forest protection under future disturbance regimes.
- The regional specificity of climate change impacts requires different adaptation measures adjusted to local conditions. The southern ecotone between the forest and arid zones is especially threatened.
- A strategic approach to adaptation also requires a change in the forestry education system. Information on climate change and forest sector adaptation measures should be part of forestry high school education and retraining courses for existing staff of forestry institutions.

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5.

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

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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

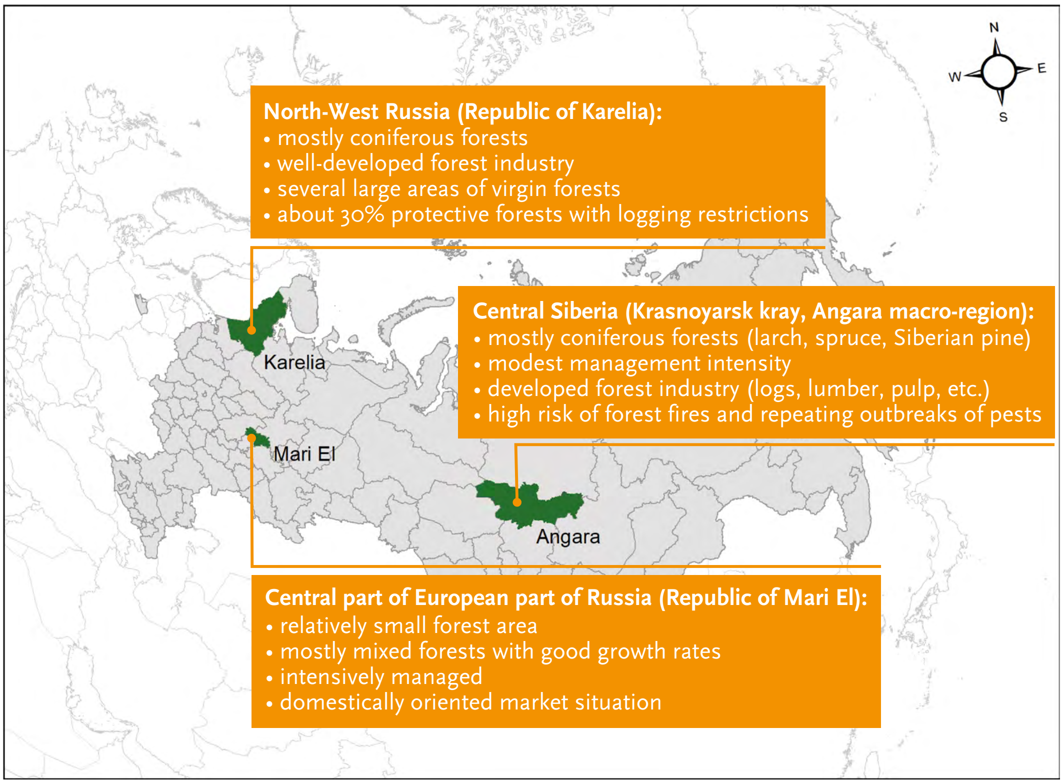

Figure 19. Overview of the three case study regions covered.

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.

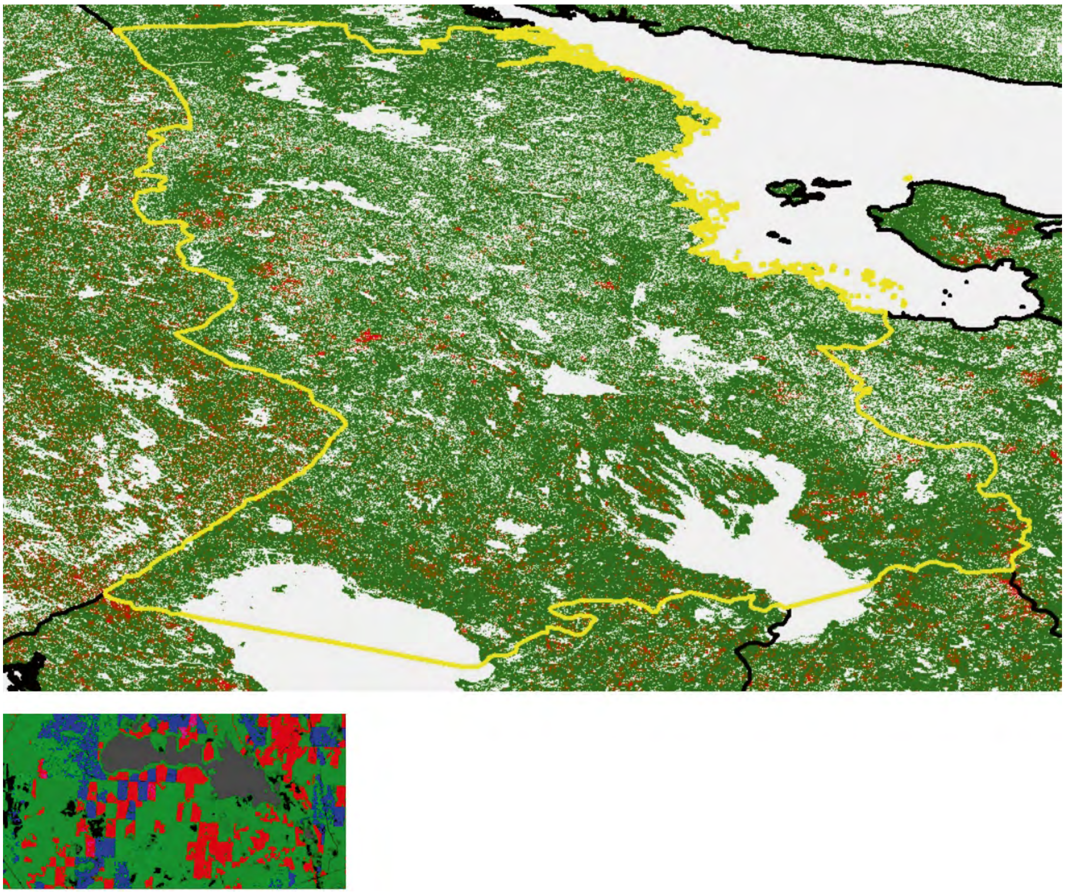

Figure 20. Tree cover changes in the Republic of Karelia (yellow borders) over the period 2000–2018. The green indicates tree cover, red is tree cover loss (harvest and disturbances between 2000 and 2018) and blue indicates tree cover gain (Hansen et al., 2013). Most of the harvesting took place in southern-middle-Karelia 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.

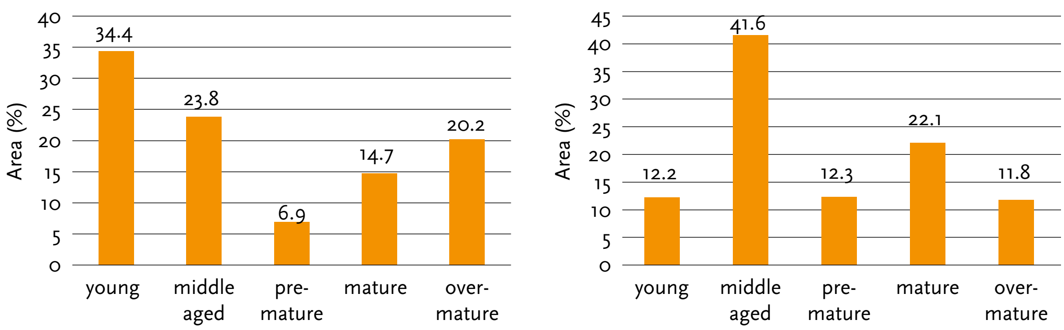

Figure 21. Age structure of coniferous (left) and deciduous (right) forests in Karelia.

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.

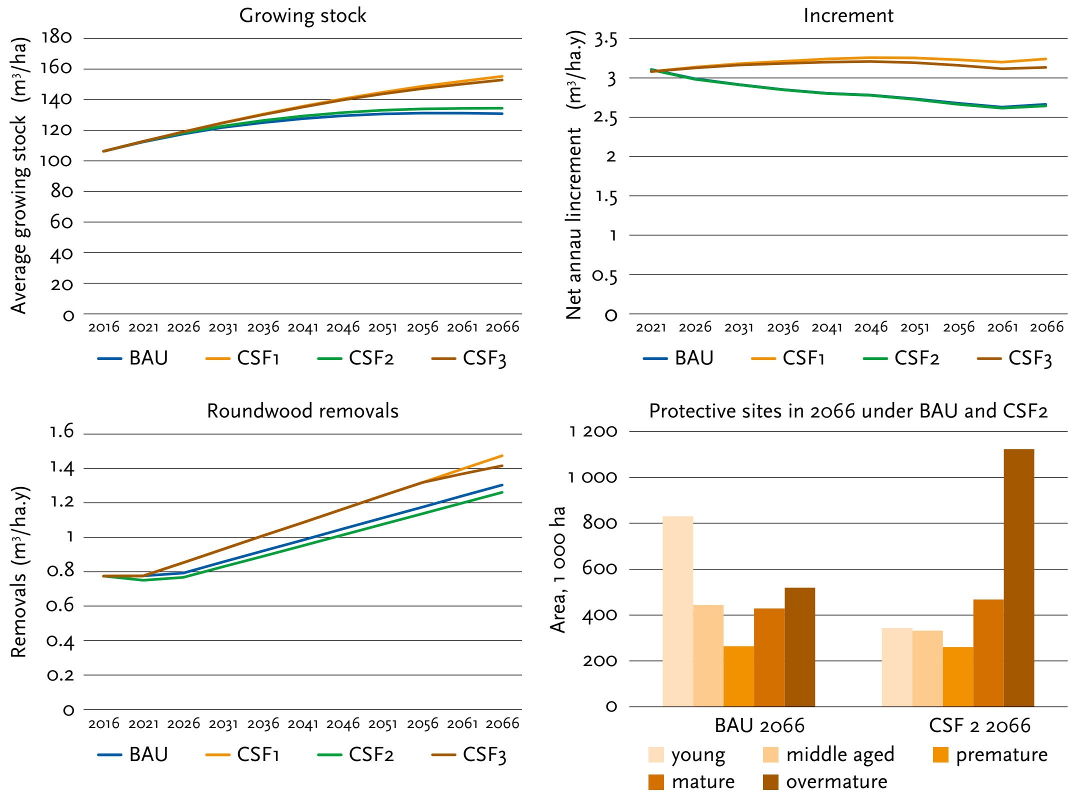

Figure 22. Projected development of (a) growing stock, (b) annual increment and (c) roundwood removals in Karelia under BAU and three alternatives (BAU is similar to CSF2). Furthermore, graph (d) depicts the age distribution in protective sites in 2066 for the BAU and CSF2 scenario.

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. m³/year to 14.4 mill. m³/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.

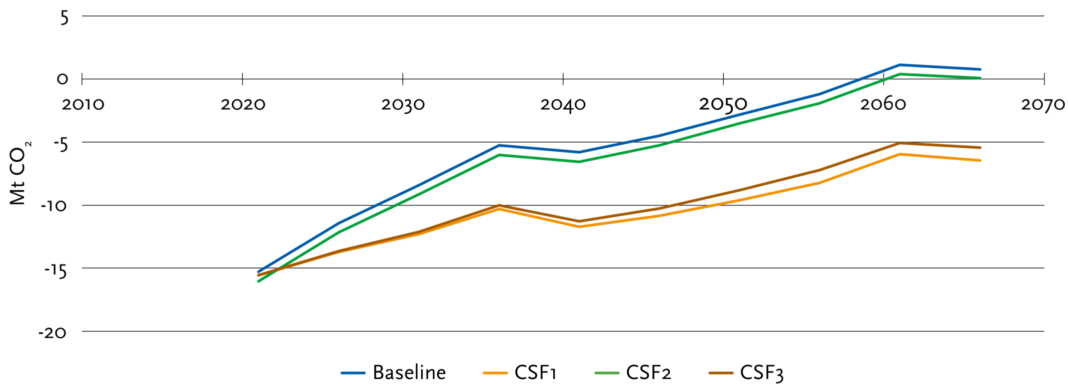

Figure 23. Carbon balance in living biomass for the BAU and the CSF scenarios in Karelia. Positive values are emissions and negative values are removals of CO_2.

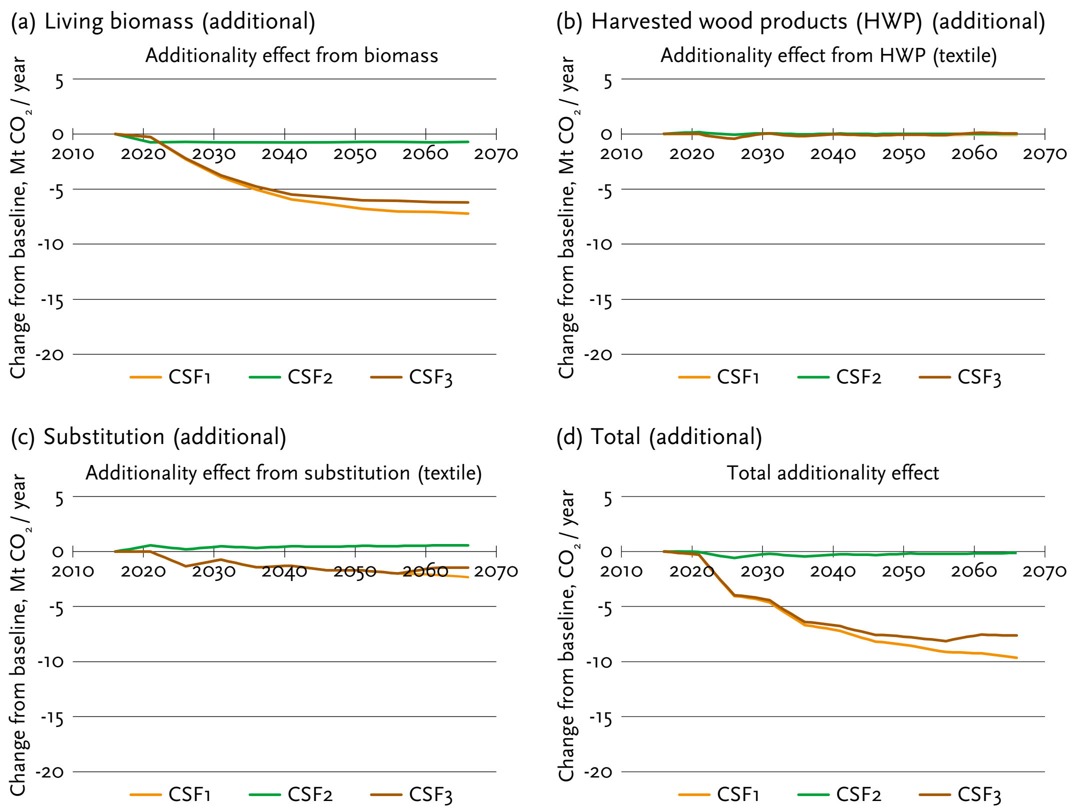

Figure 24. Projected emissions (positive values) and removals (negative values) of CO_2 for the BAU and the CSF scenarios in Karelia. Results show the difference between the CSF and BAU scenarios for additionality effect in forest biomass (a), harvested wood products (HWP) (b), substitution effect (c)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

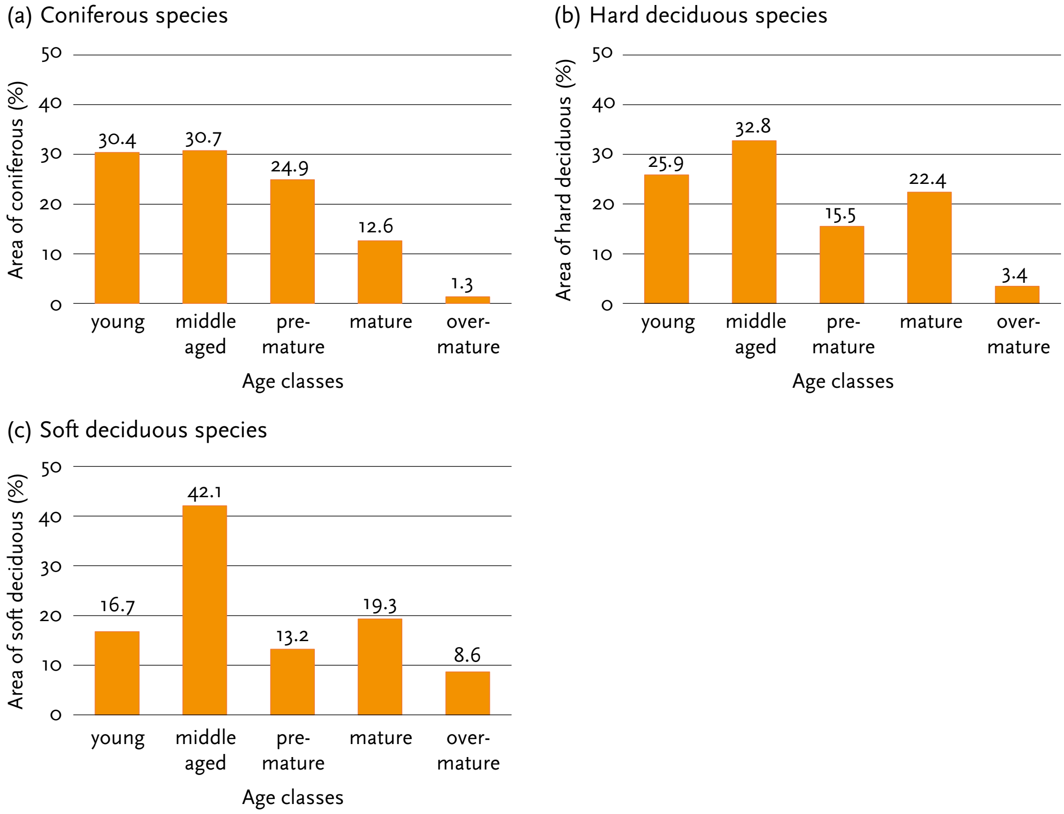

Figure 25. Age structure of (a) coniferous, (b) hard deciduous and (c) soft deciduous tree species in Mari El.

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.

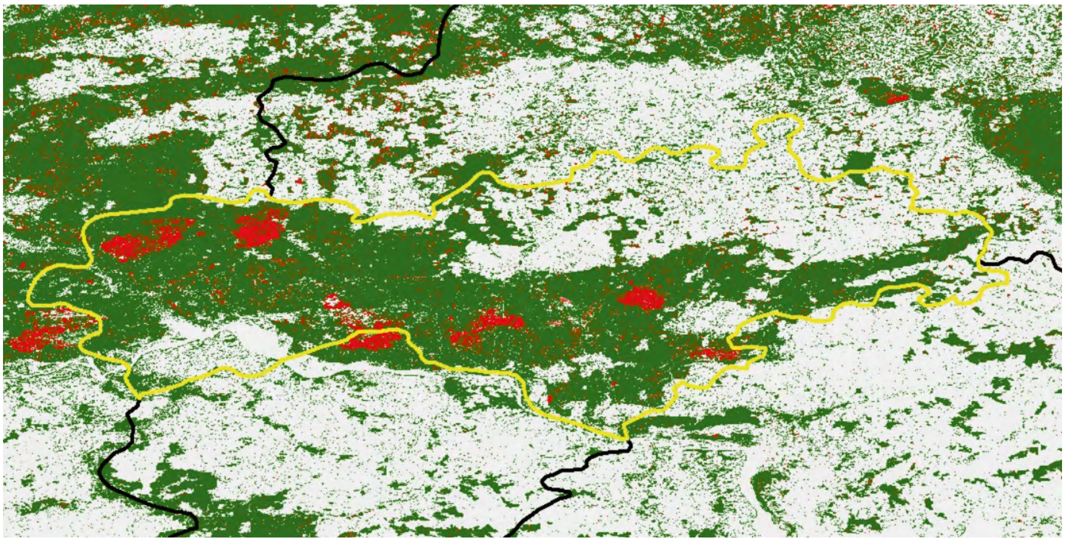

Figure 26. Tree cover changes in the Republic of Mari El over the period 2000–2018. The area is within the yellow line, tree cover is shown in green, tree cover loss, i.e. harvesting and disturbances, is shown in red and the white areas are agricultural lands. Source: Hansen et al., 2013.

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).

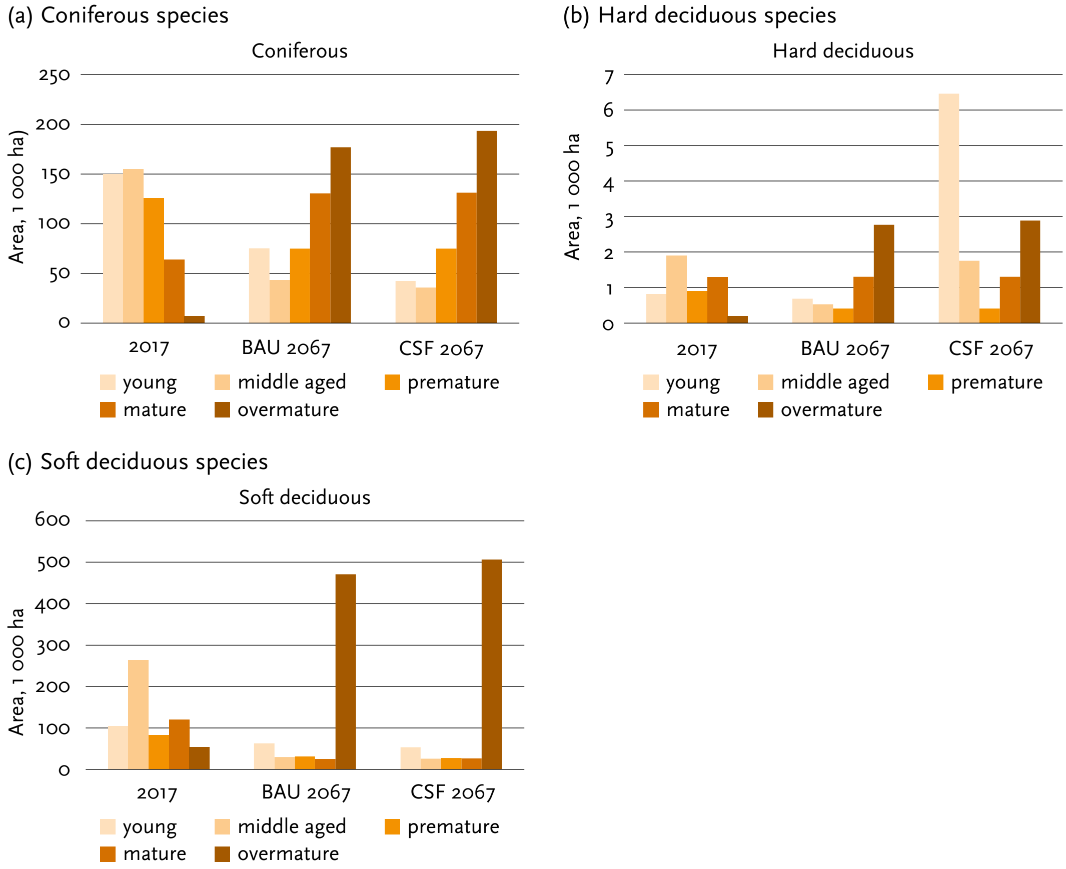

Figure 27. Age distribution of (a) coniferous, (b) hard deciduous and (c) soft deciduous tree species in 2017 and 2067 under BAU and CSF scenarios. N.B.: Age classes for conifers and hardwoods are as follows: young: 1–40 years; middle aged: 41–60 years; premature: 61–80 years; mature: 81–100 years; overmature: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

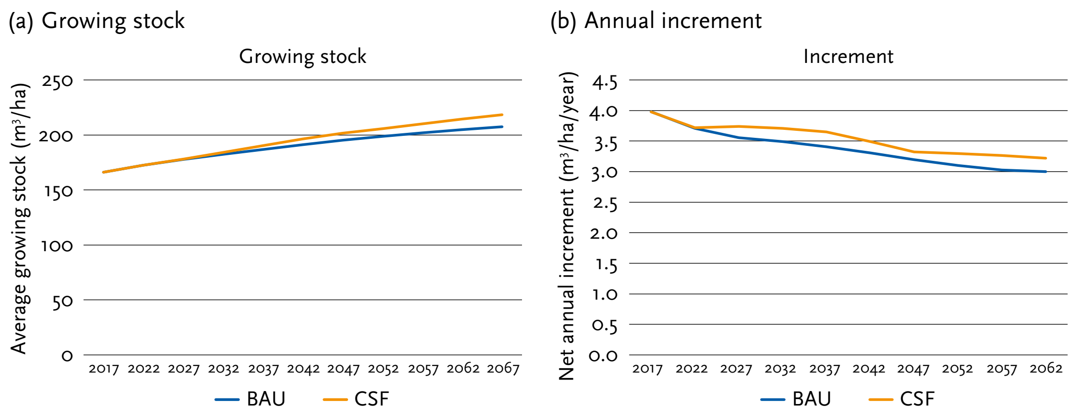

Figure 28. Projected development of (a) growing stock and (b) annual increment (including wood removals) in Mari El.

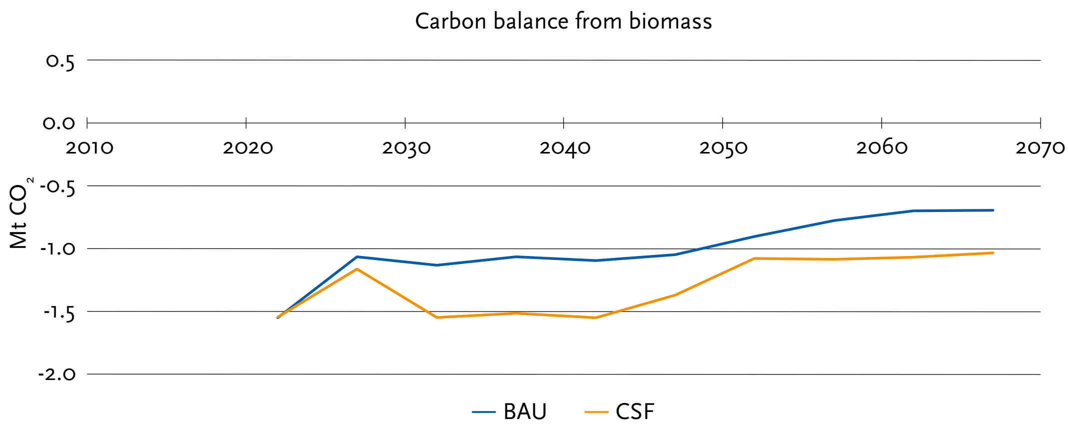

Figure 29. Carbon balance in living biomass for the BAU and the CSF scenario in Mari El. Positive values are emissions and negative values are removals of CO_2.

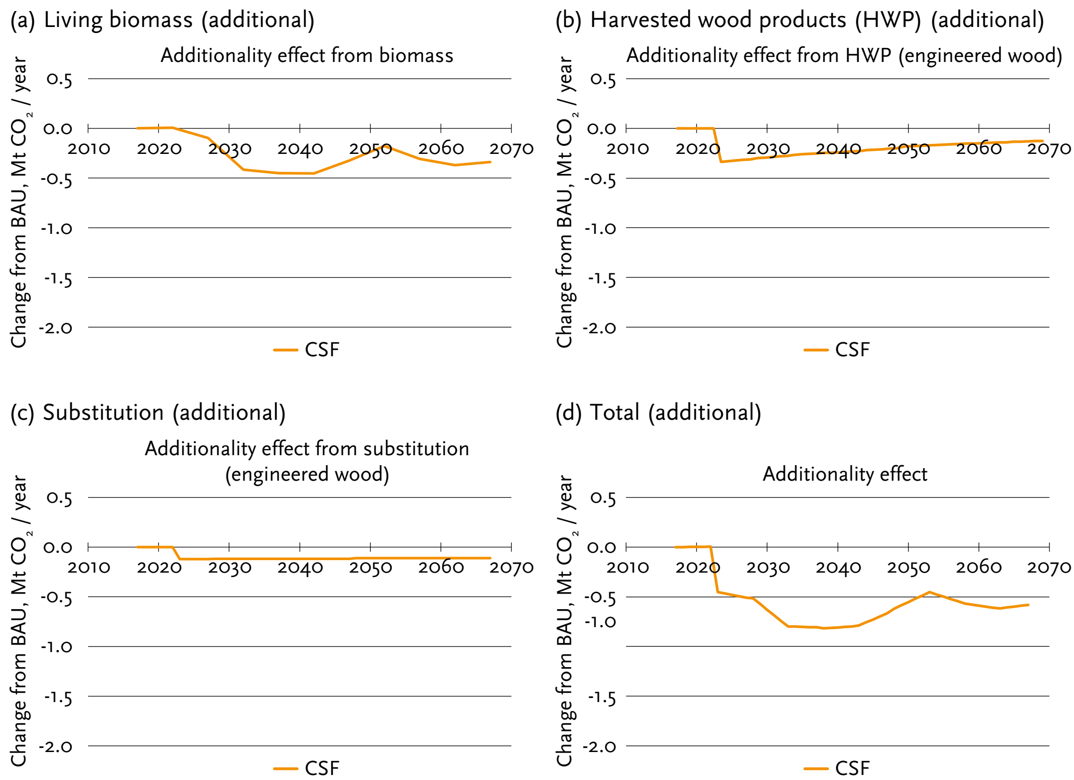

Figure 30. Projected emissions (positive values) and removals (negative values) of CO_2 for the BAU and the CSF scenario in Mari El. Results show the difference between the CSF and BAU scenarios for additionality effect from living forest biomass (a), harvested wood products (HWP) (b), substitution effect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

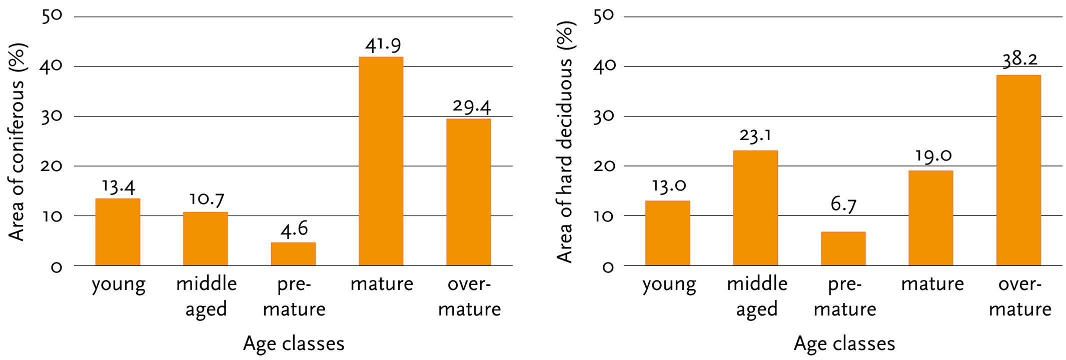

Figure 31. Age structure for coniferous (left) and deciduous (right) species in Angara macro-district, totaling 13.6 mill. ha.

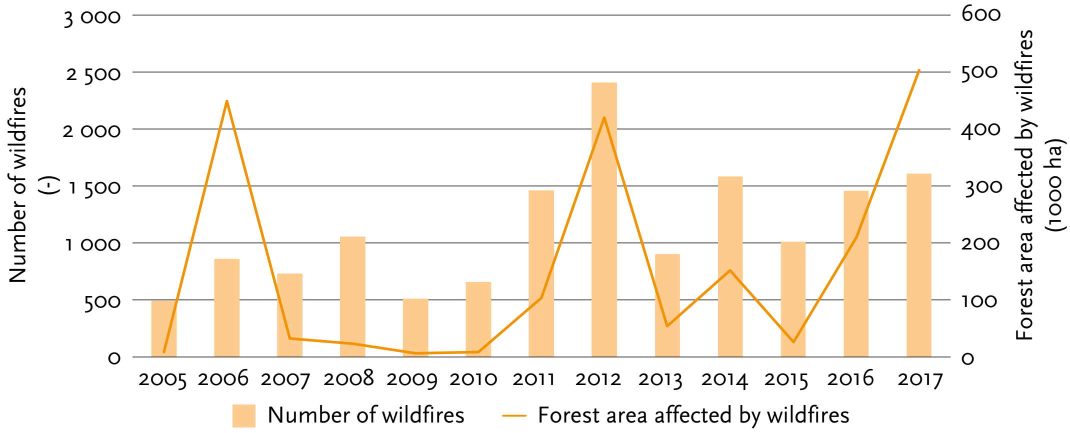

Figure 32. Dynamics of forest fires in the Krasnoyarsk kray for 2005–2017.

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.

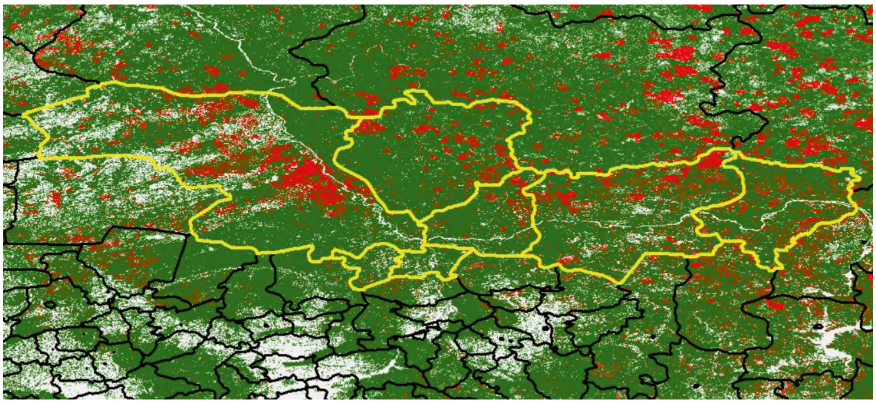

Figure 33. Tree cover changes in the Angara macro-district. The area is within the yellow lines, tree cover is shown in green, tree cover loss, i.e. harvesting and disturbances, is shown in red and the white areas are agricultural lands. Source: Hansen et al., 2013.

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).

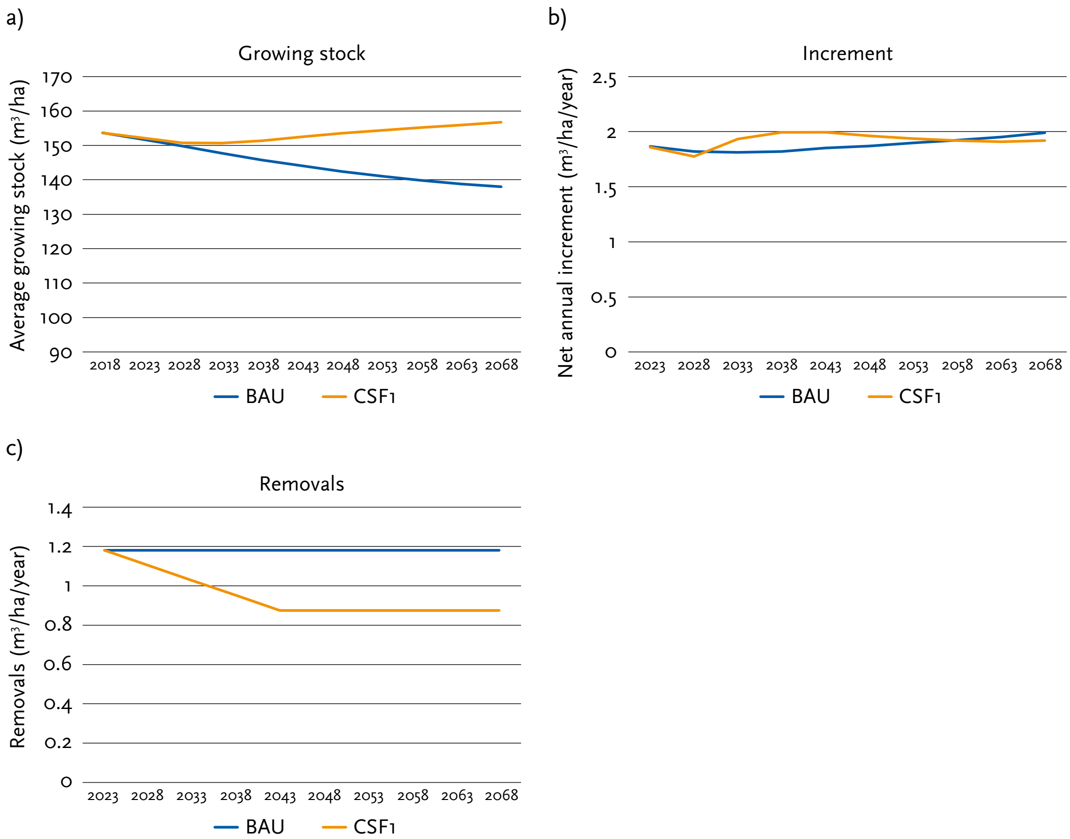

Figure 36. Projected development of a) growing stock, b) annual increment and c) roundwood removals in Angara macro-district under BAU and one alternative.

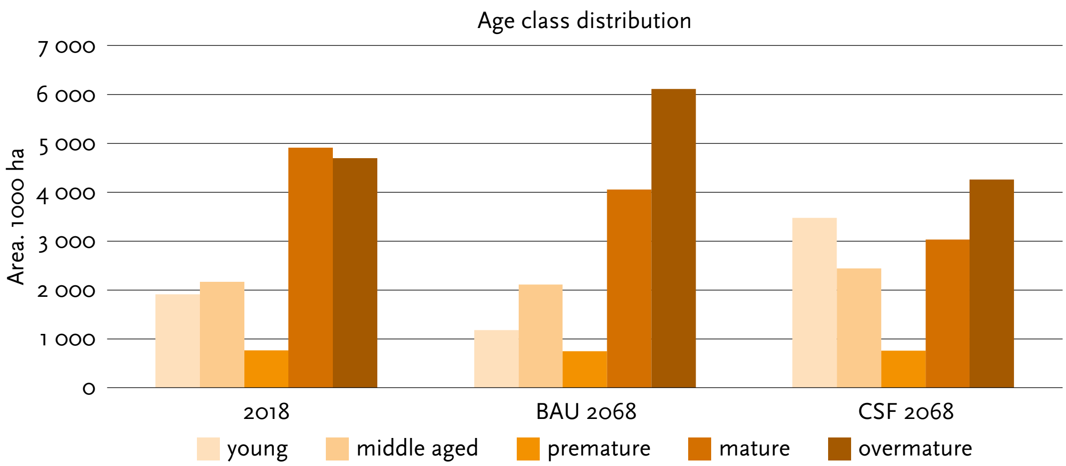

Figure 37. Age distribution for BAU in 2018 and for BAU and CSF after 50 years.

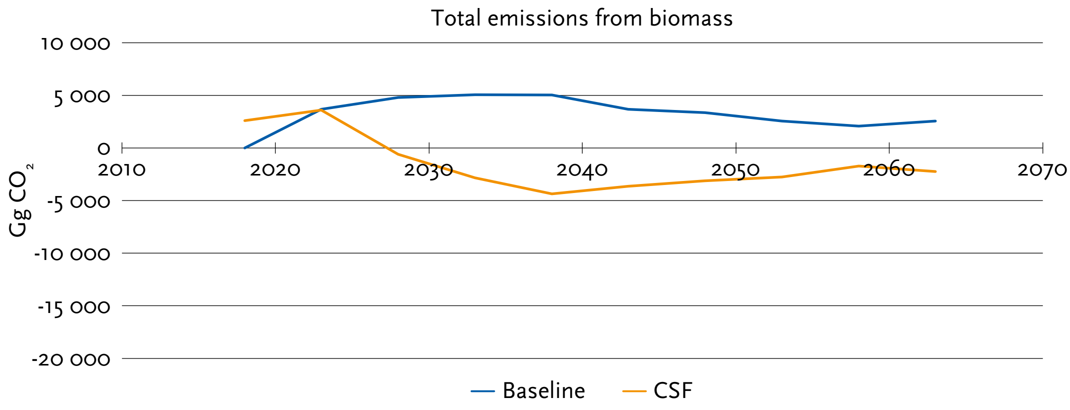

Figure 38. Projected emissions (positive values) and removals (negative values) of CO_2 from living forest biomass in Angara macro-district under BAU and CSF.

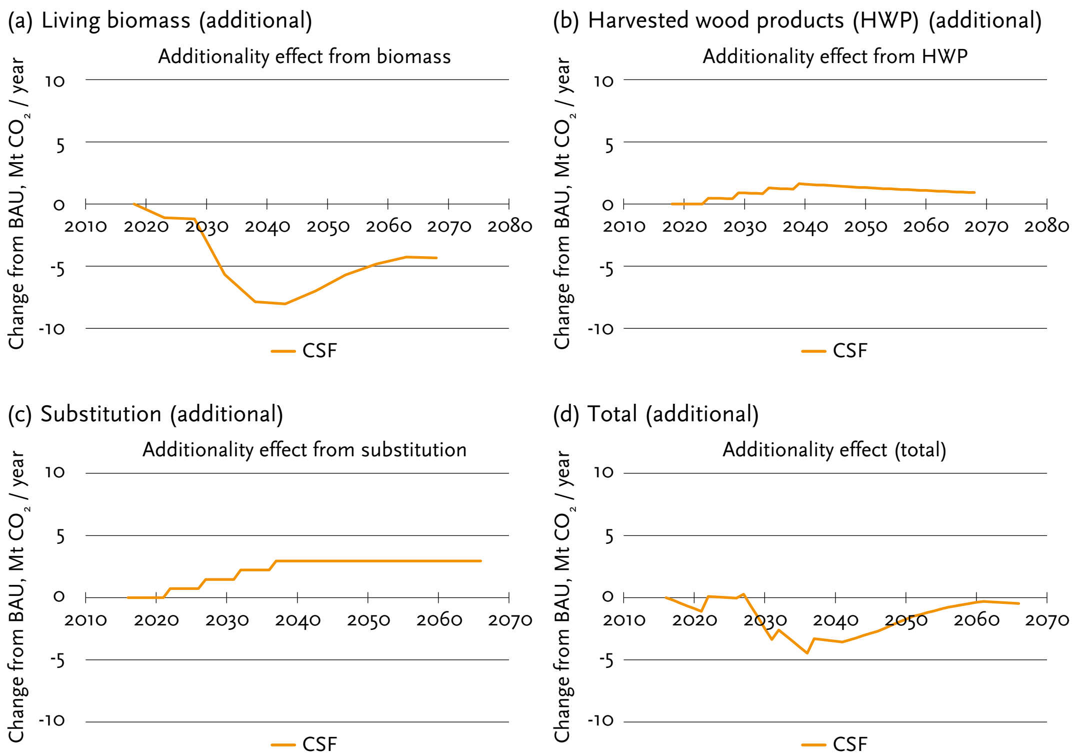

Figure 39. Projected additional emissions (positive values) or removals (negative values) of CO_2 for between the BAU and the CSF scenario in Angara macro-district. Results show the difference between the CSF and BAU scenarios for additionality effect from living forest biomass (a), harvested wood products (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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6.

The role of the bioeconomy in climate change mitigation in Russia

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6.1 Introduction

As discussed in previous chapters, Russian forests represent a vast carbon stock and sink. In addition, there are several ways in which wood-based products can contribute to a net reduction of carbon emissions. Firstly, there is the carbon stored in the products themselves. The more durable the products are, the longer-lasting their carbon storage will be. Secondly, a net carbon reduction could be achieved by replacing fossil-based materials with bio-based, renewable materials. All these components reflect to potential benefits with life-cycle emissions of different products and production systems.

The following chapters will introduce the policy background and current definition of the bioeconomy concept in Russia, the possible contribution of sustainable bioeconomy in reaching the goals of the Paris Agreement, and the possible additional net carbon savings that could be achieved through the upscaling of bio-based industry in Russia.

6.2

The bioeconomy concept in Russia

Since 2010, Russia has been promoting the development of biotechnology and some aspects of the bioeconomy (Osmakova et al., 2017), a concept that currently in Russia is mostly associated with biotechnology. A state programme for developing biotechnology (BIO2020) was created to modernize the country's economy, as Russia was falling behind in the development and implementation of the sector (Government of the Russian Federation, 2012). At that time, the market share in biotechnology products was less than 0.1% and values were negligible for biodegradable materials and biofuels (Vassilieva, 2012). The BIO2020 programme set up targets to be met by 2020 to help foster the development of biotechnology in several areas. Technology platforms gathered public, private, scientific and civil society institutions to collaborate on innovation. Of the first 25 approved Russian technology platforms, several relate to forest-based bioeconomy, for example the Bioenergy Platform and the Russian Forest Technology Platform (Ministry of Economic Development, 2011). The technology platform "Bioindustry and Bioresources" (BioTech2030) was created to implement scientific, technical and innovative policies to spur the development of the bio-based industries. The expected results from these efforts were an increase in the biotechnology sector GDP contribution to a level of about 1% of the GDP by 2020, and to reach at least 3% of the GDP by 2030 (Burghardt et al., 2015). In addition, the Forest Scientific Council of the Russian Academy of Sciences has recently developed a concept of circular forest-based bioeconomy in Russia (see Lukina, 2020 for details).

6.3

The link between bioeconomy and climate change mitigation

6.3.1 Paris Agreement incentives for the Russian bioeconomy

Climate change adaptation and mitigation objectives were adopted by Russia in several high-level political commitments, including the acceptance of the Paris Climate Agreement in September 2019.[4] The UNFCCC Paris Agreement amplified widespread discussions about opportunities for deep decarbonization of the world economy. The term 'decarbonization' refers to a net reduction of carbon emissions, making the balance between carbon-contributing and carbon removing factors. Recent economic modelling studies (SDSN-IDDRI, 2014) confirmed that deep reductions of carbon emissions are feasible in all major economies.

While the Russian economy is heavily dependent on fossil fuels, there is a big untapped potential for energy efficiency improvements and a switch to low or neutral emission energy sources. Forests were considered as one of the key solutions for Russia to reduce carbon emissions by over 80% by 2050 (SDSN-IDDRI, 2014).

Two major objectives are essential for Russian forests to support ambitious mitigation policies:

1) To increase carbon sequestration by forest ecosystems (see Chapter 2.4.5 for details).
2) To increase the consumption of biofuels, wood construction materials and other bio-based products that could substitute fossil fuels and emission-intensive products.

Increasing costs for carbon credits and divestment from carbon intensive sectors brings further encouragement to reaching the latter objective. Averaged over 2019, carbon prices in the EU Emissions Trading Scheme were about €25/tCO2e (US$27/tCO2e), in the California Compliance Offset Programme above 14 USD/t CO_2 and in South Korea around 33 US$/tCO2e (World Bank, 2020). Carbon credit prices are expected to increase considerably over time, which will lower the competitiveness – and attractiveness for investors and consumers – of carbon-intensive sectors. By 2019, already 11 trillion US$ were committed to divestment from fossil fuel companies globally (350.org, 2019). Divestment has become a reality also in Russia since Swedish and Norwegian pension funds sold their stocks of Gazprom and Tatneft in 2018–2019. Low-carbon alternatives dealing with forest carbon sequestration and an expansion of the bioeconomy should therefore be attractive for Russia.

4 Other high-level commitments include: The Climate Doctrine of the Russian Federation (Government of the Russian Federation, 2009); The Presidential Decree on reducing greenhouse gases emissions (Government of the Russian Federation, 2013) and its Implementation Plan (Government of the Russian Federation, 2014); The National Adaptation Plan (2019), and other sectoral and industrial plans and programs

6.3.2 National energy policy context

The national GHG emission target is currently determined as 70–75% of the 1990 level by 2030. The longer-term targets are not officially defined yet, though the low carbon development strategy drafted by the Ministry of Economic Development (in March 2020) proposes similar levels by 2050.

The Russian Energy Strategy towards 2035 (Government, 2020) was adopted by the government in June 2020. The Energy Strategy prospects a stable market segment of 19 mill. tons per year for fuels such as peat and firewood until 2035. This would represent a marginal share of at maximum 3% of the total primary energy production per year by 2035. The policy priorities are clearly set in favour of fossil fuels (petroleum, gas, coal), nuclear and large hydro power plants, while bio-renewables are projected to play a limited role in the current policy framework. At the same time, the Energy Security Doctrine of the Russian Federation (2019) considers as a priority challenge for the national energy security the "expansion of the share of renewable energy sources in global energy balance" (art. 9e), as well as "the international efforts to implementation of climate policy and fast transition to green economy" (art. 10).

In the absence of tangible actions and sufficient budgets at national level, regional and local policies and programmes have been more instrumental in recognising and advancing the potential of sustainable energy initiatives and the accommodation of new developments in existing economic structures (Pristupa et al., 2015).

6.3.3 GHG emission targets

During 1990–2017, Russia's GHG emissions declined by 49%, from 3.1 to 1.6 bill. t CO_2 equivalent. This was mainly influenced by a contraction of industrial activity following the collapse of the USSR in 1991. The total emissions in the energy sector and industries declined by 50%, in agriculture by 54%, carbon sequestration in the LULUCF sector increased almost six-fold (Figure 40). However, the domestic energy consumption is still mostly based on fossil fuels (52% of total energy demand by natural gas, 12% coal, and 35% petroleum). The overall share of renewable sources is below 1% of total primary energy production.

6.3.4 Scenarios for deeply reducing greenhouse gas emissions by 2050

Scenarios for deeply reducing GHG emissions of the Russian economy were analysed using the TIMES-Russia model[5] (SDSN-IDDRI, 2014) based on the socio-economic development indicators from the official strategies (Ministry of Economic Development of the Russian Federation, 2008), reports of international organizations, and industrial

5 TIMES is a partial equilibrium model for representative energy system, developed by the ETSAP program of International Energy Agency. https://iea-etsap.org/index.php/etsap-tools/model-generators/times

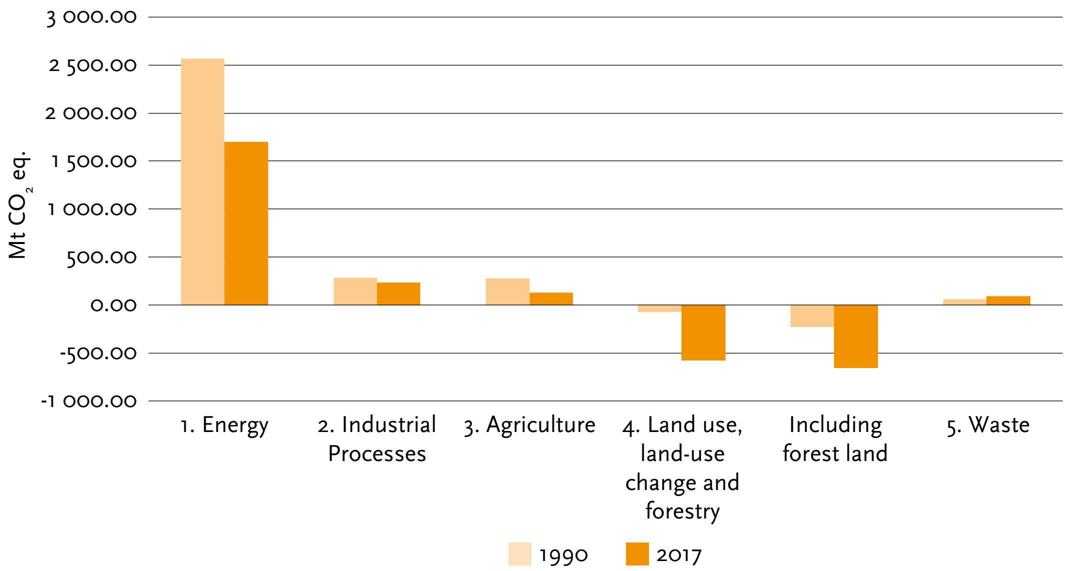

Figure 40. Dynamics of GHG emissions in Russia, 1990–2017 (Mt CO2eq.) Source: Russian National GHG Inventory Submission (United Nations Climate Change, 2019) https://unfccc.int/documents/194822

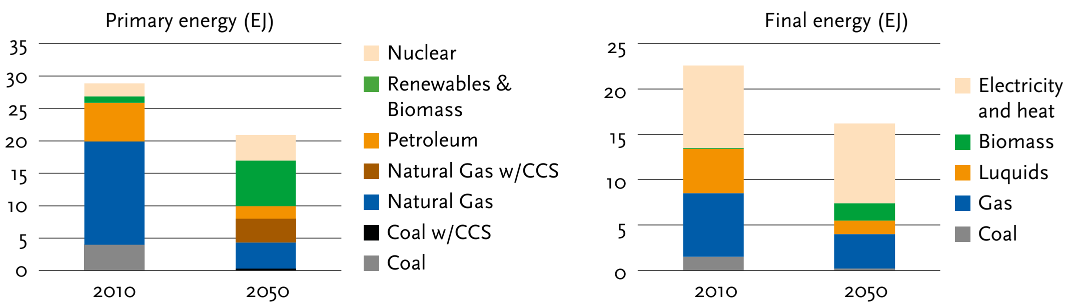

Figure 41. Projected total primary energy supply ("Primary energy") and final energy consumption ("Final energy") in Russia under the deep decarbonization scenario, for the period 2010-2050. One exajoule (EJ) equals 10^{18} joule. Source: SDSN-IDDRI (2014)

expert estimates[6]. The central deep decarbonization scenario aiming at 85% reduction of energy-related CO_2 emissions in Russia during 2010–2050 was modelled with regard to the Paris Agreement target of keeping global warming below 2 °C. Such ambitious GHG emission reduction could be achieved if the total primary energy supply declines by 27% by 2050 with significant changes in the structure of energy production and of final energy consumption (Figure 41).

However, the assumptions about availability of commercially affordable Carbon Capture and Storage (CCS) technology in Russia by 2050, the rise of nuclear power

6 See, for example, WB/IFC (2014) Energy Efficiency in Russia: Untapped Reserves. http://documents.worldbank.org/curated/en/750871468307169609/Energy-efficiency-in-Russia-untapped-reserves

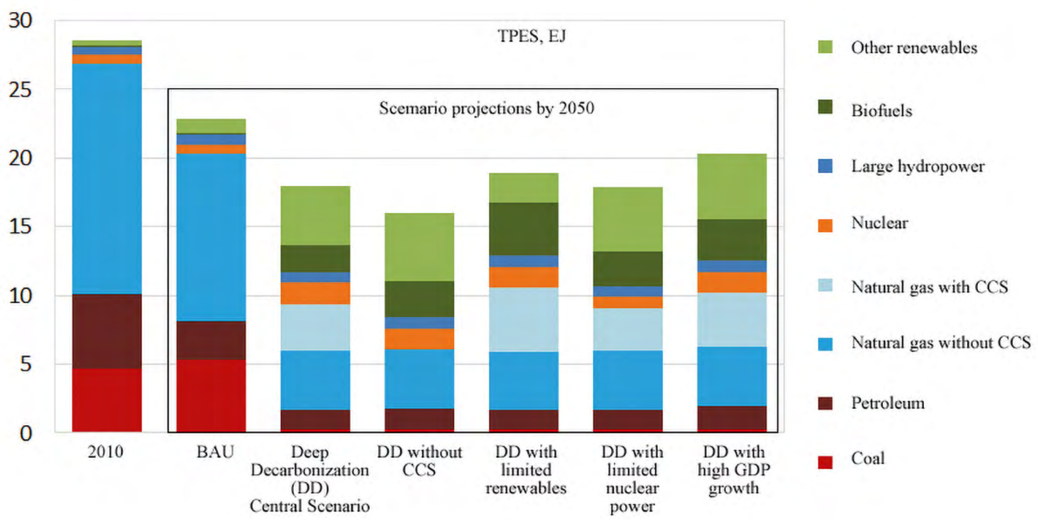

Figure 42. Total primary energy supply (TPES) in alternative scenarios of deep decarbonization in Russia by 2050. Source: Safonov et al., 2016

generation, GDP growth, and some other factors could significantly vary. Several alternative deep decarbonization scenarios were modelled with the general goal of 85% emission reduction target by 2050, while the total primary energy supply varies depending on the scenario assumptions (Figure 42).

In the deep decarbonization scenarios, consumption of liquid fuels for transportation is expected to decline during 2010–2050, and the share of liquid biofuels is expected to increase substantially, from nearly zero in 2010–2020 to 1 EJ/year (or 24 Mt/year) in 2050 (Figure 42). This volume of liquid biofuels can be produced from wood biomass as second-generation biofuels (using pilot technologies as described in the following chapter), as well as from agricultural biomass.

The projected biofuel consumption in all deep decarbonization scenarios is in the range of 3–7 EJ/year (or 72–167 Mt/year). This amount of biofuel can be sourced from the forest sector (wood waste, low grade timber, wood pellets, etc.) and agricultural sector (organic biomass, waste, residues, etc.). By caloric value, the biofuel required for deep decarbonization could be equivalent to 100–200 mill. tons / year of wood biomass.

The potential impacts from the development of the bio-based industries could be addressed more comprehensively in future unified modelling framework assessments, that would look also at impacts from substituting fossil (whether its oil, coal, gas, cement) with bio-based materials in e.g. construction, textiles, plastics and other chemicals.

6.4

State of Russian forest industry and potential for bioeconomy

6.4.1 Production

The dominant branches of the Russian forest industry are logging, pulp and paper, plywood, furniture, biofuels, wooden house construction and non-wood forest products, such as resin and tall oil (Government, 2018). The total revenue of the forest industry in Russia in 2016 amounted to nearly 20 bill. USD, the contribution to the GDP was 0.5%, the share in industrial production was about 4%, and in export, the revenue was 2.4%, the number of employed people was 500 thousand (0.8% of the total) (Government, 2018).

Currently, the contribution of the forest sector to the Russian economy is significantly lower than the estimated potential. This situation was a result from the orientation of domestic producers mainly to low-margin segments – roundwood, sawn wood and plywood (Figure 43), as well as underutilization of export potential (Government, 2018). The forest sector experiences a number of problems, such as lack of skilled workers due to low wages in the sector, lack of legislative mechanisms to stimulate the construction and operation of forest roads, low investment attractiveness of new industries for processing of wood, and e.g. poor consolidation of logging industry (Ernst & Young, 2018). However, after the collapse of the 1990s, the output volume of the main types of forest products has grown steadily for most indicators.

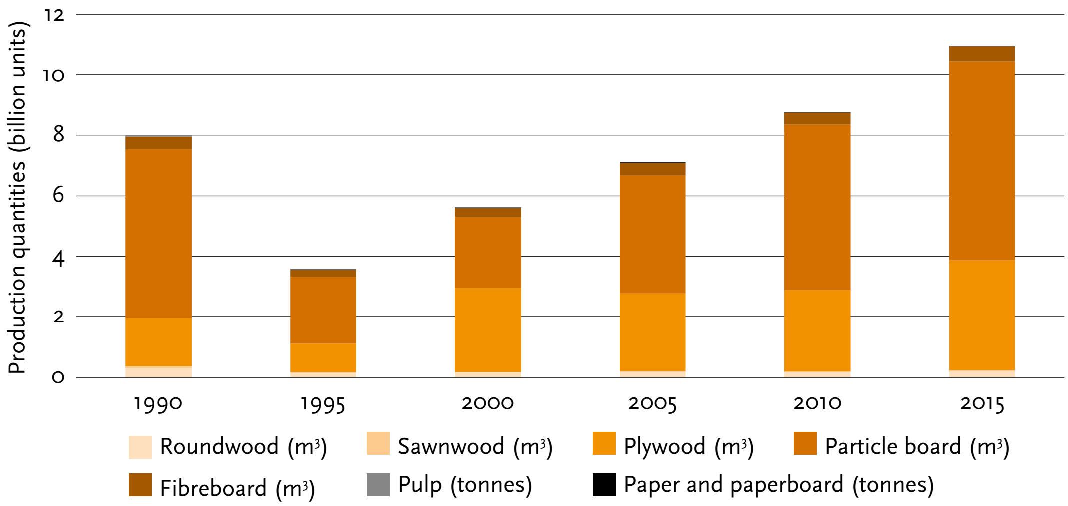

Figure 43. Basic wood products in the Russian Federation, 1990–2015. Sources: Government, 2018; FAO, 2012; IndexBox, 2016.

Domestic demand for many forest products was discouraged by relatively low income and low purchasing power of the general population especially in rural areas (FAO, 2012). As such, the Russian domestic market would be a good starting point for Russian manufacturers, but it is significantly smaller than the markets of the EU, China, and USA, and even with its growth prospects, it is not sufficient to create new high-tech industries (Government, 2018). However, a recent Ernst & Young survey (2018), based on opinion of business circles, has identified the following fast-growing industries in Russia: sawnwood, wood pellets, household and sanitary paper, packaging materials (paper/paperboard), particle board, medium density fibreboard, high density fibreboard and plywood.

The prospect of the forest sector is high on the agenda today and in accordance with the Strategy for the development of the forest complex in Russia until 2030 (Government, 2018), it is planned to significantly increase the contribution of the forest sector to the country's economy. Without referring to biotechnology or bioeconomy, this increase would be mainly through the development of more traditional industries including pulp, cardboard, hygiene products, sawnwood, wood panels, furniture, and wood construction.

6.4.2 Trade

In 2019, Russia exported wood-based products[7] for a total value of 12.8 bill. USD (trademap.org, 2020). The trade balance was clearly positive for a value of 9.2 bill. USD. The top three exported commodities (in trade value) were sawnwood[8] (4.5 bill. USD), plywood[9] (1.1 bill. USD) and wood in the rough[10] (1.1 bill. USD). The main trading partner for sawnwood commodities was China, with a share in the value of Russian exports being 56%. The three main trading partners for plywood were the USA, Egypt and Germany, with a respective share in the value of Russian exports being 14%, 12% and 10%. The three main trading partners for wood in the rough were China, Finland, and Sweden, with a respective share in the value of Russian exports of the commodity being 70%, 22% and 2%.

7 Comprising the commodities in the Harmonized System trade classification, of chapters 44, 47, 48 and 49.
8 'Sawnwood' here included the commodities of the Harmonized System category 4407: "Wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end-jointed, of a thickness exceeding 6 mm."
9 'Plywood' here includes the commodities of the Harmonized System category 4412: "Plywood, veneered panels and similar laminated wood."
10 'Wood in the rough' here includes the commodities of the Harmonized System category 4403: "Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared."

6.5

Sectoral development and outlook

The following chapters presents insights in product and market development for key production sectors in emerging forest-based bioeconomy. Policy enabling factors, current sectoral situation and prospects for development are discussed. Furthermore, to illustrate the potential of climate-change mitigation in two key sectors, wood construction and wood-based textiles, we conducted hypothetical example calculations that take into account so-called product level substitution, or displacement factors and potential volumes that these two product categories could achieve.

6.5.1 Bioenergy

Share of biomass in Russia's energy production

Currently, gas is the main fuel in the Russian energy sector, with a share of 74% of total energy production. The share of solid fuels is 21.5% (mainly coal, and the share of wood and peat is 1–1.6%). The number of solid fuel boiler houses is decreasing in Russia by 3–4% every year, while number of gas boiler houses is increasing every year by 4%. The number of oil boiler houses is decreasing by 11–12% every year, to be substituted by other fuel types. While gas seems the preferred substitute, at least half of the oil volume could be substituted also by biomass – pellets for example. In Russia, the current annual production of pellets is between 1.6–1.9 mill. t, production of briquettes about 0.2–0.3 mill t, and production of wood chips 1.1 Mt (Rosstat, 2019). These outputs are expected to double every ten years (Rakitova, 2020).

Overall, Russia has relatively limited capacity in bioenergy, with some exceptions being Arkhangelsk, Yaroslavl and Tomsk. Figure 44 illustrates the bioenergy utilization in different regions in Russia, which is most developed in the regions of North-West and Central Russia. Biogas projects and pellet boilers are also being implemented in some regions. This type of practices are also developing in Siberia and the Far East, but they are inferior in the number of boilers and capacity.

Solid biofuels: pellets, briquettes, wood chips and bio-charcoal

Pellets have been produced in Russia since 2000 due to the demand from Sweden and Denmark. Rosstat data show that Russian pellet production continues to develop with about 5% per year, while at the same time domestic consumption remains limited. The produced pellets are exported to Europe (90%) and to South Korea (10%) (trademap.org, 2020). Pellet exports are expected to increase, thereby putting pressure on the domestic pellet availability.

The production of briquettes from wood residue is increasing in regions where regional governments penalize companies that leave wood waste unprocessed (Figure 45).

Wood chip production is influenced by several factors such as the harvesting model and Russian laws by which companies burn logging residues. The fuel chip production is estimated to double in size every 10 years (see Figure 45).

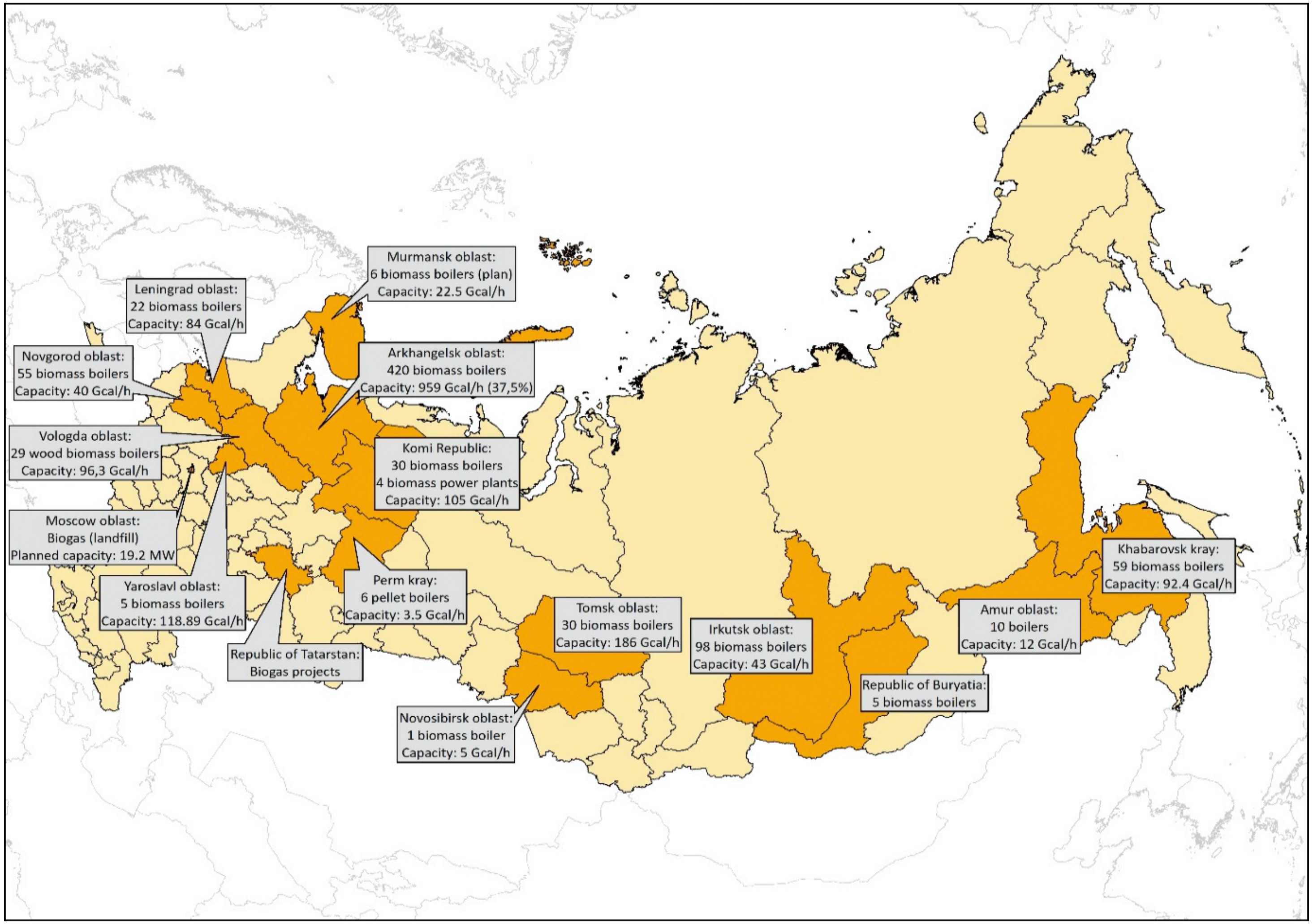

Figure 44. Bioenergy utilization in different regions in Russia – based on the responses to a Ruforclim project survey. The number of biomass boilers varies from 5 to 420, and capacity from 3.5 to 959 Gcal/h . The most developed regions in this respect are the Arkhangelsk oblast and the Komi Republic.

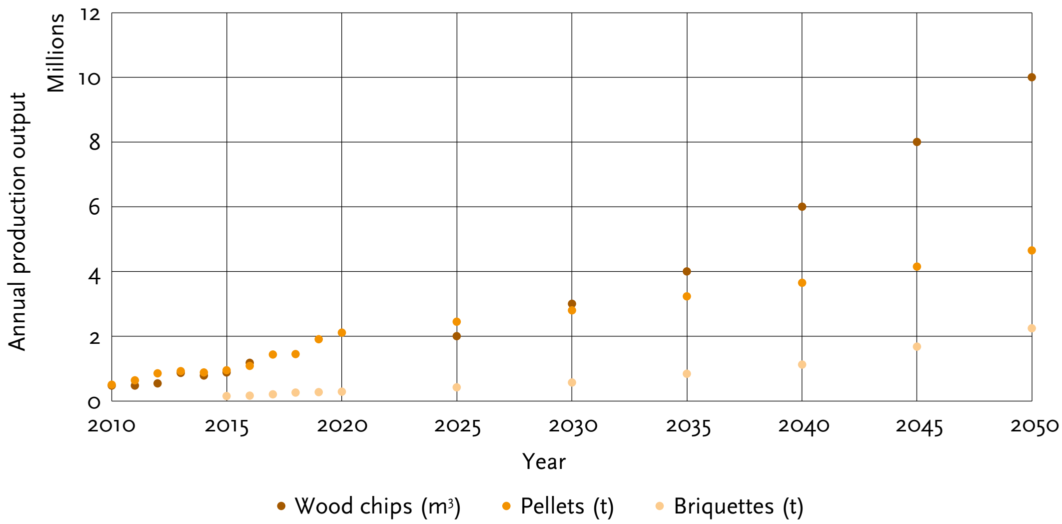

Figure 45. Production of wood chips, pellets, and briquettes in Russia (Rosstat, 2019; The Bioenergy International , 2019; Nikolskaya, 2016), and expert estimation. Data from 2019 onwards are forecast.

The technology for large-scale production of charcoal from wood waste and other organic materials has been developed by several companies in Russia. This can be used at existing coal-fired boiler houses and power plants without any technological changes to substitute for fossil coal. Its caloric value is comparable with fossil coal. The demand for charcoal in Europe, especially in Poland, is high due to the high costs of modernization and fuel switch projects at existing fossil coal power plants.

Second generation liquid biofuels

There are different technologies to produce liquid fuels from alternative raw materials including biomass. The best-known process is Fischer-Tropsch. In addition, domestic Russian know-how is available for liquid biofuel production (e.g. pattern by ZEOSIT Center of the Siberian Branch of the Russian Academy of Sciences).

The local cost of bio-benzene production is estimated at 30–40% of the current price of regular gasoline in Russia. The pilot project initiated in Altai region assumes processing of 450 000 t of wood biomass for the production of 70 000 t of liquid biofuels[11]. There are still many challenges related to implementation of such projects related to high capital costs, supply of raw materials (wood waste), legal status of value-added tax for fuel, absence of premium for "bio"-fuel, etc. However, such technologies can contribute to GHG emission reduction in the future.

11 Estimates from the project documentation of AltaiAgromash company.

6.5.2 Residential construction and perspectives on wooden buildings

Development of residential construction

The Russian government is adopting a series of measures for the increase of construction of e.g. public social housing construction in accordance with the national project "Housing and urban environment" (Government, 2019), through infrastructure development of land plots and through a range of socio-economic measures. Another important project, named "Strategy for developing the building materials industry until 2020 and for following period by 2030" (Government, 2016), supports the development of construction materials production.

Each year about 20 mill. m^2 of housing become outdated, and more than 250 mill. m^2 require replacement or major reconstruction. Due to state support, 40–45 mill. m^2 are commissioned annually, in which the share of wooden housing construction does not exceed 20% (JBI, 2020). In 2018, the total amount of residential construction was 75.7 mill. m^2, of which 42.9% was funded by individuals (Federal State Statistics Service, 2019). Over 80% of housing construction took place in the European part of the Russian Federation.

The annual evolution of residential construction is shown in Figure 7 for low-rise and high-rise buildings. Currently, slightly less than half of residential construction in Russia is low-rise buildings.

Projections of residential construction

According to the Russian Federation Forest Sector Outlook Study (FAO, 2012), the total amount of residential construction in Russia in 2030 could encompass 170 mill. m^2, or over 1 m^2 per person (see Table 8), which corresponds to indexes of developed European countries. The share of low-rise wooden houses would be about 41% of total residential construction by 2030.

Wood-based construction in Russia

Wood-based construction in Russia is characterized by low volumes. The share of buildings with wooden walls is around 10% of the total (Federal State Statistic Service, 2019). As shown in Figure 47, the production of prefabricated wooden buildings in Russia demonstrated steady growth in 2005–2011 and slower growth up to 2017.

Projections for wood-based construction

Table 8 shows four possible scenarios on wood construction in Russia. In the first and second scenario, the wood-based construction as share of total residential construction is based on data in Table 9. First is an extrapolation from 2030 to 2050 of the growth trend as presented in "The Russian Federation forest sector outlook study". In the second scenario, a growth rate of 5% is assumed onwards from the 2030 level of the same outlook study. Third, the same 5% growth rate as in the second scenario was assumed but concerning only prefabricated wood houses (ref. Figure 47).

Projections presented in Table 9 for the year 2050 vary heavily from 36.1 to 183 mill. m^2/year. Such a big variation gives evidence that wood construction is at a turning point and may demonstrate fast growth in the future.

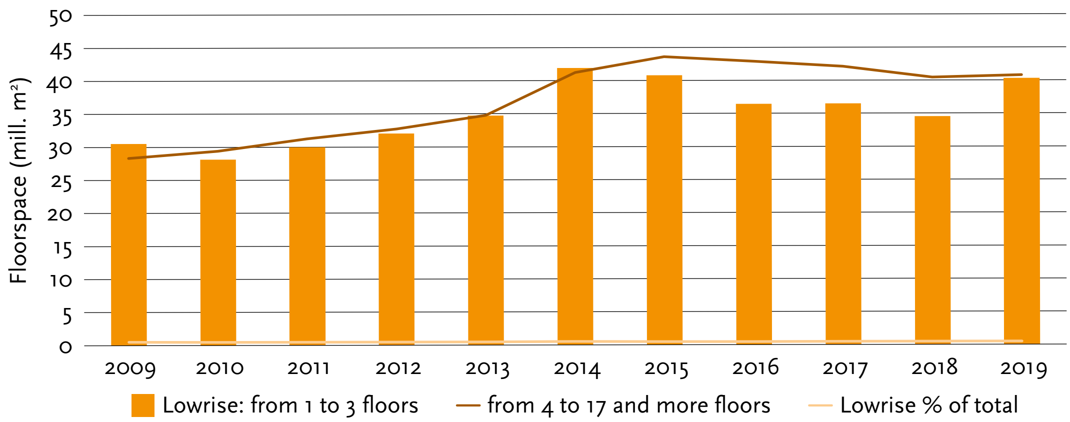

Figure 46. Residential construction according to the number of floors. Source: Federal State Statistic Service, 2019.

Table 8. Housing construction in Russia, projection. Source: FAO 2012.

	2010	2015	2020	2025	2030
Residential construction in total (mill. m²)	58.4	90.3	120.0	145.0	170.0
Low-rise (mill. m²)	25.5	47.0	85.5	95.0	105.0
Low-rise wooden (mill. m²)	8.0	17.8	32.8	50.0	69.0

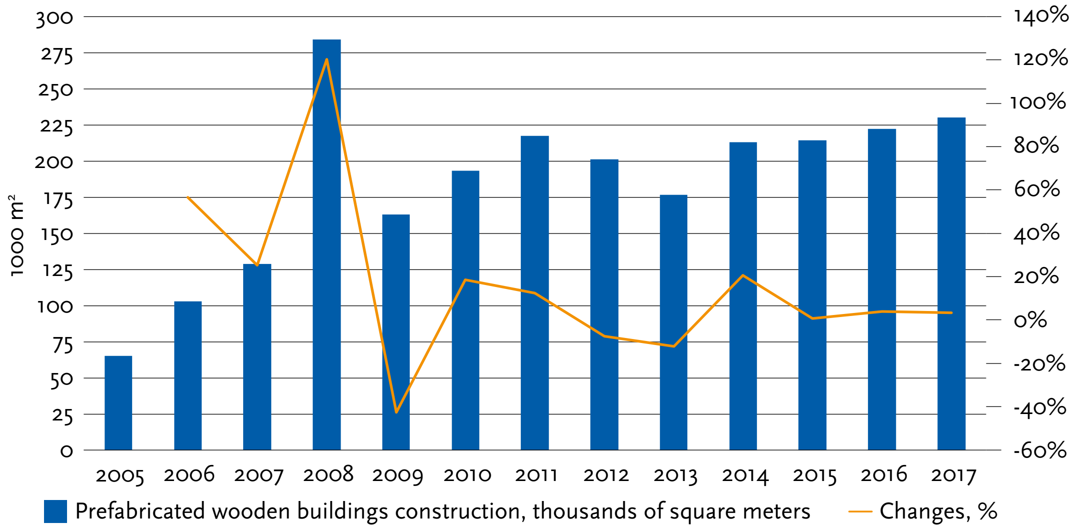

Figure 47. Prefabricated wooden construction. Source: Nikolskaya, 2017.

Table 9. Scenarios for wood construction development by floorspace (mill. m^2 / year) in Russia.

Information source and projection scenario	2030	2050
Wood construction based on Russian Federation forest sector outlook study to 2030, and extrapolation of growth trend by 2050	69.0	128.0
Wood construction based on Russian Federation forest sector outlook study to 2030, and growth after 2030 at the rate 5% per year	69.0	183.1
Prefabricated wooden housing, based on the strategy of forest sector development by 2030, and after 2030 at a growth rate of 5% per year	13.6	36.1

Box 3. Development of multi-storey wood construction in Russia

One of the main challenges in wood construction of high-rise buildings is legal framework related to building permissions and safety regulations. As the development company Etalon planned a multi-storey wooden building in Moscow, they were met with regulations stating that until early 2020, wooden buildings could not be higher than three storeys (Code of rules, 2002). In April 2020, two regulatory documents ("Public buildings with wooden structures. Design rules" (Ministry of construction, 2019a) and "Multicompartment residential buildings with wooden structures. Design rules" (Ministry of construction, 2019b)) were approved, allowing the construction of wooden buildings up to 28-meters high (about 8 storeys).

Etalon works together with the Segezha Group, which is setting up CLT production in the Vologda region. It is expected that the first test CLT panel will be produced during late 2020 and the market entry is planned soon after that. The volume of the investment in new production plant is more than 42 mill. USD, and the capacity is 250 000 m^2 of products per year (Kommersant, 2019).

Climate change mitigation potential of modern wood-based construction

The amount of GHG emissions that would be avoided if a wood-based product was used instead of a similar product made from an alternative material with comparable functionality is measured by so-called displacement factor (DF) (e.g. Leskinen et al. 2018). Essentially, DF is a measure that compares emissions of two alternative production systems based on life cycle assessment (LCA). In what follows, the product level DFs are combined with potential development of wood-construction markets. This makes is possible to produce rough estimates of what could be the climate change mitigation potential at market level, when changing the products from non-wood to wood based. However, it is important to remember that these calculations are illustrative and contain several assumptions and sources of uncertainty.

Using Stora Enso Industrial prefabrication technologies for CLT apartment construction, a 3-person apartment can be constructed using 22 m^3 of CLT for a 80 m^2 flat. Based on the construction material used in a 7-storey residential building in Växjö, Sweden, approximately 28 m^3 of timber were used per apartment of approximately 125 m^2.

Assume housing construction with CLT would be as follows: 38 mill. m^2 floor space; 0.275 m^3 CLT per m^2; roundwood density 0.45 t/m^3; carbon fraction of dry matter 0.5 t C/t d.m. These assumptions would lead to 2.35 mill. t C stored in buildings. Assuming

Table 10. Annual carbon storage and carbon substitution potential, according to varying wood utilization rates (CLT high and CLT low) and different projection scenarios for the annual wood-based housing construction needs for the year 2050.

Information source and projection scenarios	floorspace (mill. m^2)	Carbon in product (mill. t)		Avoided emissions CO_2 equivalent (mill. t)		Industrial Roundwood Equivalent (RWE) required (mill. m^3)	
		CLT high	CLT low	CLT high	CLT low	CLT high	CLT low
Russian Federation forest sector outlook study to 2030, and extrapolation of growing trend by 2050	128.0	9.2	7.9	43.9	37.7	114.7	98.6
Russian Federation forest sector outlook study to 2030, and growth after 2030 at a rate of 5% per year	183.1	13.2	11.3	62.8	54.0	164.0	141.0
Strategy of forest sector development by 2030, and growth after 2030 at a rate of 5% per year for prefabricated wooden housing, i.e. a segment of the wood construction sector	36.1	2.6	2.2	12.4	10.6	32.3	27.8

a substitution factor of 1.3 (i.e. average substitution effect t C/t C for structural construction; see Leskinen et al. (2018)), this would translate into a substitution of 11.20 mill. t CO_2 equivalent by the following assumptions: 2.35 t of carbon in the building; average substitution effect 1.3 t C/t C wood product; 3.664 conversion factor from tons of C to tons of CO_2. In this case, the total amount of required roundwood would be 29 mill. m^3, which is based on the following assumptions: 0.275 m^3 CLT per m^2 floor space; 2.8 m^3 roundwood per m^3 CLT; 38 mill. m^2 floorspace.

The approach described above was applied for different scenarios of wood construction as shown in Chapter 6.4.2. The results are given in Table 10.

6.5.3 Wood-based textiles

Fossil-based fibres such as polyester and nylon are made from non-renewable raw materials which require a lot of energy to produce, cause a lot of GHG emissions during manufacturing and can contribute to water contamination due to the releasing of non-biodegradable microplastics when washed (Muthu, 2017). The conventional production of cotton also causes environmental problems, as it requires large amounts of water, pesticides, fertilizers and energy (Kooistra et al., 2006).

New technologies are being developed to use woodpulp, industrial side streams and agricultural waste as feedstock, as well as to reduce the water consumption during production and the use of harmful chemicals. Most of these new technologies are not yet operationally feasible at a large scale, but they represent more sustainable alternatives to the current textiles production.

The three types of textiles with largest production volumes in Russia are cotton, synthetic fibres and silk (Wittmann, 2017). Even though synthetic fibres like polyester are still preferred by the industry for their price and more uniform characteristics, there is an interest to reintroduce natural fibres to produce textiles. The annual growth rate of natural fibres and yarns consumption in the period of 2012–2017 was around 5%, while for synthetic fibres it was 13–15% (Gerden, 2018a).

In recent years, specialized sectors, such as the technical textiles, were able to meet only 30% of the domestic annual demand, indicating that there is space for growth (Gerden, 2018b). Several companies have been investing in new production plants and a special Industrial Development Fund was created by the Russian government to provide support for the development and implementation of projects to develop the technical textiles industry. Production of textiles in general went up by 6.2% from 2016 to 2017 in Russia and many garments manufacturing companies are planning to start production lines in the country (Wittmann, 2017).

The main issues for the textile industry in Russia are still the outdated production plants, and the shortage of skilled workers and sales partners. Thus, the successful implementation of the Russian government's development program for the textile industry is crucial to overcome these problems (Wittmann, 2017).

When it comes to the production of wood-based textiles, in the 1980s Russia was a leading country in the production of dissolving pulp for viscose (Skripnikov, 2017; Eisenstein and Klepikov, 2018). However, in 2014, Russia produced only 1% of the viscose dissolving pulp manufactured worldwide (Statista, 2014).

As the traditional methods of producing viscose are considered environmentally harmful because of the chemicals used in the production process, and improved technologies for the manufacturing of wood-based fibres are being developed, it would be important for Russia to invest in the production of textiles obtained by more environmentally friendly methods. In addition to improved production technologies related to viscose, there are new technologies such as Spinnova and Ioncell-F. Such new wood-based fibres produce less CO_2 emissions than cotton and synthetic fibres and, among the several options of wood-based products, lead to higher climate substitution benefits (Leskinen et al., 2018).

Bio-based textile fibre and climate change mitigation potential

The current global textile production is estimated at around 93 mill. tons /year, of which around 53 mill. tons of fibre are produced annually for clothing (Ellen MacArthur Foundation, 2017). As it takes about 2.4 m^3 of wood to produce one tonne of textile fibre with the Spinnova technology, 127 mill. m^3 would suffice to meet the global annual clothing fibre demand. At a higher "alternative estimate", it would take about 4 m^3 of wood per ton of fibre, which would result in 212 mill. m^3 to supply annual fibre demand for clothing. The latter is based on an estimate cited by Uusipuu (2017), stating that 10 mill. m^3 would be needed to replace 10% of the global cotton markets, which was estimated at 25 mill. tons (OECD/FAO, 2019).

Perhaps a more realistic estimate would be that around 14% of all fibres would be man-made cellulosic and that these would not replace cotton, which reached a possible global maximum production of around 25 mill. tons in 2015 (Hämmerle, 2011). Therefore, the substitution would be rather for petroleum-based synthetic fibres, for which an average substitution value is 3.4 t CO_2 per ton of fibre.

When combining these assumptions with an outlook for the development of global textile demand, we produced Table 11 to illustrate the substitution potential of the textile industry.

Table 11. Global demand of man-made cellulosic fibres, required industrial roundwood equivalent (RWE), in-product carbon storage potential and CO2 substitution equivalent, based on the wood utilization rates according the Spinnova technology, for 2030 (Hämmerle, 2011) and 2050 (extrapolation of Hömmerle, 2011). Substitution factor based on Shen et al., 2010.

Year	Global demand man-made cellulosic fibres (mill. t)	Industrial RWE (mill. m^3)	Roundwood Mass (mill. t)	Carbon in product (mill. t)	Substitution C (mill. t) [Shen, 2010]	Substitution CO_2 (mill. t) [Shen, 2010]
2030	19	44	20	10	18	65
2050	36	84	38	18	33	122

6.5.4 Wood-based chemicals

The demand for fossil-based products, such as fuels, resins and polymers, has increased in the past decades. Concerns with the GHG emissions, the production of residues and the depletion of fossil resources have promoted the development of new products from bio-based sources. One chemical compound that shows a lot of potential for substituting fossil-based chemicals is lignin. It is the second most abundant natural polymer after cellulose. Despite having a crucial structural function in the composition of wood and being one of the most important chemical components in terms of volume, lignin is still treated as a residue of the pulping process, being mostly used for energy production. Lignin can be broken into building blocks which can be used in the manufacture of several value-added products. Because lignin is a very stable molecule, its fractionation – or division into smaller molecules – can be difficult. Despite that, many advancements have been made in this area in the past few years and the production of lignin as a precursor to several value-added products has become promising. The type of lignin varies according to the feedstock and the production process, the most common one being the lignosulfonates – byproducts from the production of wood pulp using sulfite pulping. The bulk of these commercial lignins is used as plasticizers for concrete, dispersants, binders, and food additives (such as vanillin) (Berlin and Balakshin, 2014). It is estimated that close to 1 mill. tons of lignosulfonates is produced in the world each year (Bajpai, 2018), from roughly 10 mill. m^3 of RWE (Ervasti, 2016).

Lignin as a precursor for chemicals

High-purity lignin is considered a platform chemical, being the precursor for other chemicals such as vanillin, and the aromatics benzene, toluene and xylene (BTX) (University of Bologna and Fraunhofer ISI, 2018). It can also be used in the production of adhesive binders, resins, coatings, films, plastics, polyurethane-based foams, as well as carbon fibres. It can be obtained from the black liquor, i.e. the residue or by-product from the kraft pulping process. The technology readiness level for isolating high-purity lignin is currently 5, but the several applications and the commercial interest may push the development of the technology. By 2022, the global market demand for lignin is expected to grow 4.9% from 2015 values. BTX accounts for roughly 60% of all aromatics, and demand in volume for aromatic applications is expected to grow by 2022 a compound annual growth rate of 5.7% from 2015 values.

The production of lignin is not a foreign concept in Russia (Plaksin et al., 2001). During the Soviet Union, lignin was generated as residue from the ethanol and fodder yeast production processes. It was also a residue from the production of the solvent furfural. This lignin had no commercial use, being discarded in dumpsites. The transformation and use of lignin could be further developed in Russia, since there is already basic knowledge developed for this subject (Abdrakhmanova et al., 2016). The total value of forest-based chemicals produced in Russia, amounted to 2797 mill. roubles (approximately 34.5 mill. euro) in 2016 in accordance with the Strategy of Russian Forest Complex Development until 2030 (Government, 2018).

6.5.5 Bioplastics

Several types of bioplastics have been developed as an effort to reduce soil and water contamination caused by fossil-based plastics. However, not all bioplastics are biodegradable. The industry has been looking for solutions to overcome this issue and some new bio-based products are currently under development and testing. Most bioplastics are currently produced using corn starch, vegetable oils and straw as feedstock. But the technology for producing certain types of wood-based bioplastics is already available at industrial scale.

One successful example is the production of wood-based plastic lining for beverage cartons. It is a substitute for fossil-based plastic but with the advantage of being recycled with cardboard. This type of wood-based plastic can be produced using the tall oil resulting from the pulping process. In 2019, it is estimated that more than 40 million milk and yogurt cartons with bioplastic lining were used in Finland, reducing the need for fossil-based plastics by 180 000 kg per year.

In recent years, many Russian companies have been demonstrating interest in developing and producing biodegradable packaging. However, the bioplastics industry in Russia is still at early stages of development. There are some barriers to the development of the bioplastics industry: the limited paying capacity of companies and potential consumers, the lack of strong regulations to reduce the use of fossil-based materials, and the lack of interest from investors and companies in the development of technologies with long return periods (Volchok et al., 2018).

6.6

Summary and conclusions: Opportunities and challenges for a bioeconomy in Russia

The concept of bioeconomy is relatively new and underutilized in Russia as it is mostly associated with biotechnology. Maximizing the potential of wood-based products in areas such as multi-storey wood construction and wood-based textiles can be important for the Russian economy and bring important additional climate change mitigation benefits.

Additional biomass to supply the forest-based bioeconomy could be gained by increasing the harvesting levels but also by increasing efficiency in forest management and by increasing industrial resource efficiency, including utilisation of industrial side streams. Scenarios for reducing greenhouse gas emissions presented in Chapter 6.2.3, aiming at 85% GHG emission reductions, show that significant efforts are needed in reducing energy consumption and moving the energy production away from the use of fossils. The scenarios do not yet include the potential that would come from bioeconomy development liked e.g. to wood construction or wood-based textiles. Bioenergy and wood-based products cannot solve the challenge alone, but they can significantly contribute to it.

To better understand the sectoral level possibilities of forest bioeconomy, we analysed more closely possibilities of forest bioenergy, wood construction and some emerging products such as wood-based textiles.

According to Chapter 6.4.1, gas is currently the main fuel in the Russian energy sector with a share of 74%. The share of solid fuels is 22%, consisting mainly of fossil coal. The overall share of energy from biomass is low leaving room for increasing its share in the energy mix. Despite producing wood pellets since 2000, most of the production is currently exported, mainly to Europe. Overall, there seems to be a growth potential in pellet production as well as domestic use of it in the energy mix. Similarly, wood-based briquettes show growth potential in production and domestic consumption. Fuel wood chips production is also expected to have growth potential through domestic consumption.

Volumes of residential construction in Russia have declined to some extent since 2015 (see Chapter 6.4.2) and currently the total amount of residential construction is about 76 mill. m^2 per year. The overall volume of wooden construction in Russia is small, and the production of prefabricated wooden buildings has not shown significant increase during recent years. Despite this, the government of Russia has adopted a series of measures to increase overall construction volumes so that the total amount of residential construction in 2030 would reach 170 mill. m^2 per year. This can provide major growth potential for modern wood construction technologies such as CLT. It is expected that a first test batch of CLT elements will be produced in Russia in late 2020, to become fully operational shortly thereafter. According to the optimistic scenario, annual wood-based construction could by 2050 be at level of 183 m^2. When taking into account differences between construction techniques, the roundwood required to achieve this would be up to 164 mill. m^3. The avoided CO_2 emissions would correspond to 63 mill. tons.

New and emerging products that could bring added value to Russia in the future include wood-based textiles. The current textile industry in Russia is mostly based on the production of synthetic fibres, due to the country's large reserves of oil and the well-developed chemical industry. Even though synthetic fibres like polyester are still preferred by the industry for their price and more uniform characteristics, there is an interest to reintroduce certain natural fibres to produce textiles. With respect to wood-based textiles, in the 1980s Russia was a leading country in the production of dissolving pulp for viscose, but nowadays Russia produce only about 1% of the global dissolving pulp. In this context, wood-based textiles would be a major scale opportunity, since global production volumes of textiles for clothing is about 53 mill.t per year, and it is expected to increase significantly. By 2030, global demand for man-made cellulosic fibres may be around 19 mill. t, with a resource efficient production technology requiring about 44 mill. m^3 of roundwood and the amount of avoided CO_2 emissions amounting to around 65 mill. t. By 2050, these numbers would nearly double compared to those for 2030.

We showed that the forest-based bioeconomy has a lot of growth potential that can be important to Russia during the global transition to reduce emissions. Increasing the use of wood in multi-storey construction and textile production can bring significant climate change mitigation benefits when replacing fossil counterparts such as concrete, steel, polyester and nylon.

Such development of bioeconomy would require strong political will, suitable legislation, new investments to forest-based industries, and increased awareness of consumers. In addition, relevant legislation should be preceded by the development of a circular forest bioeconomy strategy adopted by all stakeholders.

Key messages

- Through more efficient forest management, more resource-efficient production processes and increased utilisation of industrial side streams, the Russian Federation has a vast resource potential to develop its forest-based circular bioeconomy and cascading use of biomass.
- The Russian Federation's energy consumption relies mostly on fossil coal and gas. While biomass accounts only a small fraction of the total amount of solid fuels, the phasing out of old oil boiler stations presents a growth opportunity for the production and domestic consumption of bioenergy.
- Wood-based housing construction is now at a turning point and may demonstrate fast growth in the future. Regulation and technology to enable wood-based residential high-rise buildings, have been recently developed. Depending on greatly varying projection scenarios for the annual wood-based housing construction needs by 2050, the avoided emissions from using wood instead of steel or concrete, would be a range between 11 and 63 mill. tons of CO_2 equivalent.
- A world leader in viscose production in the 1980s, the Russian Federation currently produces only 1%of global dissolving pulp. With significant growth expected in global demand for clothing textiles and global cotton production to remain stable or decline, significant growth potential is expected for wood-based textiles. This implies growth opportunities to countries such as Russia.
- Integrating targets for bioenergy, wood construction and wood-based textiles into the Russian level emission reduction scenarios under a unified modelling framework is a topic of future studies.

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7.

Conclusions

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7.1 Forest resources

There is no doubt about the global importance of the Russian Federation's forests in terms of forest area, carbon stock, influence on global climate, potential as a renewable resource, as well as biodiversity preservation. Russia has the largest areas of primary boreal forests in the world and only a relatively small fraction of the total forest resources is utilised economically.

The resource abundance does not mean, however, that the forests are in their optimal state. For example, due to poor management, the average growing stock per hectare is much lower than what would be achievable under sustainable forest management regimes, although the state of the forests varies heavily from region to region. Some areas have high volumes, whereas other regions are understocked as a result of overexploitation or massive fire disturbances. Harvested amounts are much higher in populated regions and there can also be a lack of high value timber in regions of high demand. Because of the clear-cut management system and insufficiency of reforestation efforts, mostly aspen and birch forests regenerate, which are not much used economically. Also hauling distances can become too long rather quickly. Major challenges for the management of the forests are abandoned agricultural land areas and migration of people from rural to urban areas. As the regions are different, there is no one approach that would suit all and regional forest management plans need to be developed further with deeper consideration of region-specific measures.

There is also a need for better forest resources inventory and monitoring systems through better integration of in-situ observations, remote sensing data and model data streams. Trends in observed forest disturbances such as the consequences of wildfires should be better monitored. Accurate data on projected impacts of climate change on forest resources and forest soils is critical in taking into account diverse growth responses from different regions such as potentially improving growth in the North and declining growth in the South, changing species suitability, differences in intensity and frequency of disturbances, etc.

7.2

Climate change impacts, adaptation and mitigation

Climate change is affecting the current and future dynamics of forest growth, mortality and disturbances, and significant increases in number and intensity of wildfires, storms and pests are expected. For example, currently forest area damaged from wildfires fluctuates already between 4 and 7 mill. ha/year expressed as a multi-annual trend. More importantly, even more severe disturbances are expected in absence of enhanced prevention measures. This can have far-reaching consequences for the global climate and more locally for regional ecosystems and human well-being. The melting of permafrost leading to vast emissions of methane is another major risk.

For the sustainability of Russian forests and its forest sector, it is of high importance to mitigate the climate change impacts and the associated forest disturbance risks. Post-disturbance forest restoration should also get increasing attention.

The current Russian forest carbon sink is significant, but it contains also uncertainties, and its future dynamics are even more uncertain. However, when climate change continues, various processes of prolonged growing season and enhanced growth versus losses of permafrost and disturbances might partly outweigh each other. To what degree this would happen and what is the corresponding net balance is unclear, although saturation of the sink seems to be likely.

Climate change and its effects on site productivity, species ranges, and disturbance regimes threaten the forests and its service provision in vast areas. However, disturbances present also a window of opportunity to change practices e.g. by adapting the tree species composition to the changing climate and working towards future site-suitability.

7.3

Forest management

Forests can contribute to climate change mitigation targets and, at the same time, develop a more effective forest utilization. A mix of measures will be needed to achieve the full mitigation potential by forests and the forest sector, which considers both forest ecosystems and wood use simultaneously. Such a mix would include activating management in accessible forests and protecting primary forests and other forests with high biodiversity values.

From the total area of operational forests (approximately 600 mill. ha), only about half is currently accessible. Forest management systems of especially accessible forest areas should be re-considered to achieve actively managed and accessible forests that are managed with long-term goals. The current system of short-term lease contracts and extensive exploitation ("wood mining") without proper forest regeneration leads to degradation of resources, as well as long hauling distances.

Forest management should be improved to mitigate climate change and to adapt to climate change impacts especially in the European part of Russia and the southern zones of the rest of Russia. An important management measure that could provide climate benefits is to increase the share of wood coming from thinning in total wood removals. Increasing the share of wood coming from thinning would allow to better select trees with beneficial properties, reduce the amount of wood needed from final harvests and reduce wildfire risk.

Another important measure would be the selection and better use of high-quality forest genetic resources. Many forests in Russia are nowadays regenerated naturally, but the use of artificial regeneration (or regeneration that combines natural and artificial regeneration) allows to introduce provenances and breeding material that is better adapted to future climatic conditions. Results from breeding in Baltic and Nordic countries also indicate that significant growth gains can be achieved. Investment in tree breeding and in forest regeneration practices could provide benefits for climate change mitigation and adaptation.

Finally, increasing tree species diversity, especially by increasing the share of broadleaved species, is also an important measure to consider. Increasing species diversity contributes to improving the resilience of forests to disturbance risks from wildfires, wind, and pests. To facilitate the implementation of such a measure, it is important to incentivize the development of new value chains and technologies, which stimulate the use of a larger set of tree species.

However, it is important to keep in mind the regional differences of Russian forests. Case-specific Climate Smart Forestry (CSF) example scenarios led in varying results, depending on the baseline management currently implemented in the case studies. In two regions, CSF led to an improved CO_2 balance (additional sink and substitution) of ~0.6 ton CO_2/ha/year. However, in one region where currently overharvesting is taking place, the harvest level had to be reduced for CSF scenarios. This led to an additional mitigation effect in the forest biomass of 0.4 ton CO_2/ha/year, but because of a negative material substitution effect, the total improved net effect was only 0.1 ton CO_2/ha/year.

7.4

Enabling environment for a bioeconomy

Strong, ambitious and effective climate policies and policy instruments are needed and they need to be implemented with urgency in order to implement the Paris Agreement. The full potential of Russian forests can only be unlocked through investments in improved forest management practices, wood mobilization, and industrial development as well as in research, technology development and innovation. Investing in forest management and bioeconomy would start within and between sector innovation cycle, which in turn would allow loop funds back for improving forest management, infrastructure, and ecosystem services including biodiversity protection. Explicit interest in sustainable forest management is essential.

The development of new/emerging bioeconomy markets and investing in new environmentally friendly products based on sustainably produced wood is supported by increased global consumer awareness and readiness, and incentives including government stimulus. If global awareness as well as government policies would lead to implementation of the Paris Agreement targets, industries focusing on fossil-based energy and materials can collapse during next decades due to lack of market demand. Therefore, countries like Russia should urgently start looking for new opportunities for economic development and forest-based bioeconomy can be one option. Prominent areas of new/emerging bioeconomy in terms of environmental, economic and social impacts include:

- Major growth potential exists for new wood-based construction technologies such as CLT: for example, if by 2050 new floor space area build by CLT in Russia would be 128 mill. m^2, this could lead to 43.9 mill. tons of avoided annual CO_2 emissions.
- Major possibilities of wood-based textiles in global textile markets: for example, if global annual demand for man-made cellulosic fibres would be 36 mill. tons by 2050, fulfilling this demand could lead to 122 mill. tons of avoided annual CO_2 emissions. Russia could be important producer of wood-based textiles for global markets in the future.
- Substantial amount of wood waste in Russia could be used to substitute fossil coal in energy production.

7.5

Holistic view

A holistic view in forestry decision making considers the impacts in both ecosystem as well as in technosystem simultaneously. A non-holistic view leads to non-optimal decisions.

Russia has a large potential for the development of a forest-based bioeconomy, assuming that sustainable development of forest resources under climate change would be secured by appropriate adaptation and mitigation measures, which consider also the protection of biodiversity and ecosystem service provisioning. In addition, improved accessibility of forest resources would require investments to improved infrastructure. However, it is also important to remember that regionally overharvesting and large-scale natural forest disturbances are already taking place in some regions.

The increase in frequency and impacts of forest disturbances pose a major challenge to the development of forest resources, and as a consequence, to the potential of sustainable bioeconomy. Investments and improvements in forest management are needed to improve the mitigation potential of Russian forests and its resilience. However, there are also possibilities for efficiency improvements such as more resource-efficient wood sourcing (covering harvesting, storage and transportation of the raw materials), and more efficient production processes e.g. in energy production. These possibilities can lead to a significant increase in the efficiency of utilization of harvested materials. This also concerns an increased utilization of industrial side streams of materials that in the past have been discarded as waste.

7.6

Key messages and next steps

This report synthesizes the current scientific understanding on Russian forests and climate change, and identified the opportunities as well as challenges with respect to adaptation, mitigation and bioeconomy. The key findings and recommendations for the next steps can be summarized as follows:

1) Currently, Russian forests represent a large carbon sink, but there are also large areas in the Northern and Eastern parts of Russia, which act as a carbon source. These areas are typically located either on permafrost or in disturbed forests. However, the several years of large wildfire disturbances with subsequently increased tree mortality may lead to substantial decrease of the Russian forest carbon sink.
2) Future natural disturbance impacts are critical: attention should be paid to preventing of disturbances and enhancing forest restoration/reforestation. Climate change impacts will put the current forest sector severely at risk. The potential to reach the Paris Agreement targets through a significant contribution of the bioeconomy cannot be achieved without active forest management with a strong focus on natural disturbance prevention and enhancing forest resilience.
3) Investments in sustainable and climate-smart forest management are needed and should be aimed at long-term goals rather than short-term lease contracts, as well as to improved infrastructure especially in the accessible forests. Without active, climate-smart forest management, the ambitious bioeconomy goals cannot be achieved. In other words, investing in bioeconomy would enable funding for improved forest management and infrastructure, which could further lead also to protecting biodiversity and ecosystem services.
4) Another important focus is forest restoration since there most likely will be large-scale natural disturbances also in the future. If the aim is to sustain and even enhance the forest sector contribution to climate change mitigation, active support for large scale forest restoration would be needed.
5) Regional differences should be taken into account when developing action plans for implementation.
6) A holistic view is needed for effective climate change mitigation and adaptation as well as biodiversity protection. Climate-smart forestry is proposed to connect mitigation with adaption measures, enhance the resilience of Russian forest resources and ecosystem services, and meet the needs of society.
7) Successful development of bioeconomy markets linked with circular economy can create a new economic foundation instead linear economy based on fossil materials.
8) Implementation of the research results in practice would be the next challenge, and successful utilization of forest resources in the future would strongly depend on the evolution of forest governance. The potential benefits from concepts

such as Climate Smart Forestry requires major changes in policies and management responsibilities. The following topics are suggested for further consideration and for implementation:

- Improving forest policy by taking into account forest-based circular bioeconomy development and effective climate change mitigation and adaptation
- Developing national strategy, and national and regional action plans for forest-based circular bioeconomy development
- Improving national forest inventory and forest monitoring taking into account integration of modern ground-based measurement methods and remote sensing capabilities
- Improving forest management on abandoned agricultural lands for preventing disturbances, and for improved wood production and carbon sequestration
- Considering the possibilities for emerging sectors of bioeconomy such as using wood in construction, textiles, and biofuels production, with respect to economic development and deep decarbonization targets

What Science Can Tell Us

We live in an intricate and changing environment with interrelated feedback between ecosystems, society, economy and the environment. EFI's 'What Science Can Tell Us' series is based on collective scientific expert reviews providing interdisciplinary background information on key and complex forest-related issues for policy and decision makers, citizens and society in general.

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