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A theoretical discussion on the trade-off between, carbon sequestration and biodiversity, and optimal rotation forestry in Norway

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1 Introduction

This chapter introduces various aspects of forests related to biodiversity and climate. It ends with a short outline of the rest of the thesis.

1.1 Anthropogenic impact on the biosphere

The Anthropocene Working Group (AWG) claims that we have now entered the Anthropocene, the epoch where humans have decisive power to control the Earth's condition through collective operations (Zalasiewicz et al., 2017). This term is widely used and accepted. When we talk about global climate and environmental problems, this is often measured in terms of Anthropogenic impacts. By introducing this term, the AWG implicitly argues that humans are perfectly capable of making devastating transformations of the biosphere. But the real test to this hypothesis, is to observe whether humans have the capacity to obtain their long term collective own interest, by rebuilding a safe foundation for a thriving life, a healthy, intact biosphere.

The 2015 Paris Agreement represented a positive shift for global climate ambitions, but nevertheless, global GHG emissions have increased since, to an all-time high in 2019. During the period 2010-2019, annual emissions have increased by 1.1 percent on average, 1.4 percent if one includes estimations emerging from land-use changes (LUC) (United Nations Environment Programme, 2020).

We should see remarkable progress in emission pathways to approach the 2°C target (United Nations Environment Programme, 2020), and yet this achievement would add wide and immense additional damages, compared to a stable 1.5°C scenario (IPCC, 2018). In short, the additional damage attached to the first scenario, involves a substantial sea level increase (IPCC, 2018; IPCC, 2019), a decisive impact on vulnerable ecosystems which local communities depend on (Conference of the Parties to the Convention on Biological Diversity, 2018a; IPCC, 2018), and a dramatic decline in most stocks of terrestrial species (IPCC, 2018; IPBES, 2019), where many of those could lose more than half of its habitats (IPCC, 2018).

The COP of Convention on Biological Diversity (CBD) agreed to establish the Aichi Biodiversity Targets concerning the decade 2011-2020. Although healthy ecosystems are vital to human life and essential parts of the biosphere, the Aichi targets have attracted far less attention than the Paris Agreement. By 2020, not one single of those 20 targets was accomplished, and as many as 13 measures showed no progress (Secretariat of the Convention on Biological Diversity, 2020).

The global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2019 reported that biodiversity had rather declined through all axis, and faster than ever. Without intervention, one fourth of all species could be wiped out in few decades. Climate warming exacerbate many other events, with devastating effect on habitats (IPBES, 2019). Quite many argue that we now face the sixth mass extinction, the first one to be executed single-handed by one specie – the humans (Baumann, 2021; Rockström et al., 2009).

1.2 The collective action problem

The scientific foundations to inform the public on climate and environmental issues are wide and robust. Appropriate guidelines to policymakers about effective measures are distributed frequently, and we know that the price of today's evasive policy will result in accumulated burdens on future generations. Yet, globally coordinated action on these topics appears to me as systematically insufficient and delayed.

If we think of governments as individual rational entities, this above stated narrative fits Elinor Ostrom's description of a collective action problem (2010): when all entities pursue their own interest first and last, the global society receive less net benefit (well-being), compared to the outcome of a well-coordinated behavior.

Ostrom (2010) lists and describes seven structural variables, which all influence the outcome of a collective action scenario. In the appendix, Table 7-a, I directly relate elements from the climate and biodiversity action problem to those variables, with corresponding numbers. I also list remedies that are already introduced to the global process, along with potential remedies, which I assume would be helpful.

Based on assumptions stated in Table 7-a, I conclude that many steps have been taken to deal with this collective action problem. Most importantly, steps taken confirms that parties dedicate time and effort to coordinate action, by participating in the process, and by implementing tangible policy improvements. Throughout this thesis, I even take for granted that the global society have the ability and motivation to incorporate all necessary measures for future progress. I base this thesis on a fundamental assumption that we have entered the Anthropocene.

Based on this overall assumption, I will discuss four interrelated key issues that need extensive Anthropogenic consideration. These are listed in Table 1-a.

Table 1-a: Key issues

Key issues	Section for discussion
Interdependency between biodiversity and climate	**1.3**
Competition for land	**1.4**
Valuation of biodiversity	**1.5**

1.3 Interdependency between biodiversity and climate

Anthropocene damage to our planet cannot be narrowed down to one issue, it can best be described as a predicament. These interdependent challenges entail a holistic approach (Baumann, 2021). We need both declining emission rates and decreasing land conversion rates, by 2030, to stay on the safe side of a tipping point (Dinerstein et al., 2019; IPCC, 2019).

Climate mitigation and safeguarding biodiversity boundaries should be coordinated through science and policy measures (Secretariat of the Convention on Biological Diversity, 2003; Conference of the Parties to the Convention on Biological Diversity, 2018c; 2018d; Dinerstein et al., 2019). Global warming causes biodiversity loss (Secretariat of the Convention on Biological Diversity, 2003). Ecosystems operate as large carbon sinks (IPBES, 2019). Thus, loss of biodiversity will contribute to increased emissions. It is therefore more precise to describe the causal relation between global warming and biodiversity loss as mutually reinforcing (Conference of the Parties to the Convention on Biological Diversity, 2018a; Dasgupta, 2021).

Putting all effort into either climate mitigation or ecosystem conservation, would simply not make sense. Investing all in climate mitigation, would be perverse, as preservation and protection of nature and ecosystem services for long-term human well-being, are main purposes for climate action. On the other hand, safeguarding ecosystems, and analogously accepting global warming, will eventually jeopardize the all-embracing biosphere in the longer run. In economic terminology, the obvious solution to this dilemma, besides increasing the global effort, would be to use an efficient mix of climate and biodiversity actions.

Figure 1.a illustrates in simple manners how this trade-off may proceed. A production possibility frontier ($Forest\ PPF$) defines pareto efficient trade-offs between carbon sequestration and biodiversity “production”. The relative price (MRT') are defined by the utility function ($U(CS, BP)'$) imposed by society and determine how much society will produce of both services. The utility function could hypothetically include all true social costs and benefits but will in in practice be biased due to structural market imperfections. This claim builds on the believe that many external values are not priced, or improperly priced by the market, which skews the utility curve in either direction. I will inspect this further in section 1.5, and I take an economist’s approach on this topic throughout this thesis.

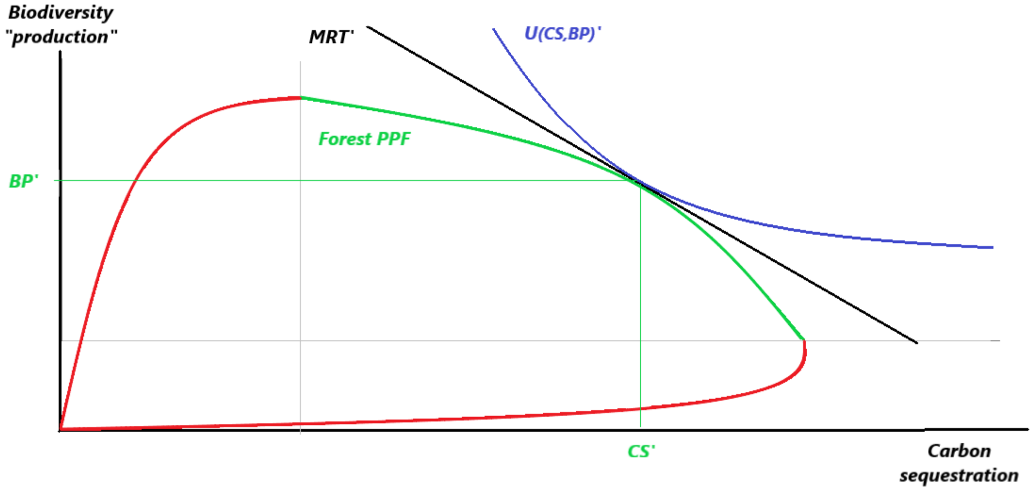


Figure 1.a: Production possibility frontiers between carbon sequestration and biodiversity "production"

In a scenario with a $Forest\ PPF$, the efficient trad-off between carbon sequestration and biodiversity “production” will be located on the green line. Given that the society’s-imposed utility function is equal to $U(CS, BP)'$, the relative price when only considering those two goods, will be equal to MRT'. In this situation, society will produce CS' carbon sequestration and BP' biodiversity “production”.

1.4 Intensifying competition for scarce land

I have briefly mentioned that we should allocate our environmental efforts towards two targets, carbon sequestration and biodiversity “production”. This simplification is useful, but to explain the wider problem of scarce land and intensifying competition, a more complex description is appropriate. Demand for infrastructure, agricultural land, and renewable energy all compete with demand for land that provide carbon capture and storage (CCS) and ecosystem services. If we do not analyze main relevant elements, our conclusions are likely to be biased, and in worst cases irrelevant or misleading.

1.4.1 Demand for agricultural land

The United Nations have projected a global population growth from initially 7.7 billion in 2019, to 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion in 2100. Birth rates have inferior explanatory power compared to current age structures and increasing life expectancy (United Nations, 2019).

About one percent of the world-wide acreage is are now occupied by infrastructure (IPCC, 2019). Densely populated areas have already doubled its proportion since 1992, and more than a third of terrestrial area are now occupied by the agricultural sector (IPBES, 2019). OECD presupposes that food production must increase substantially, to feed the growing population towards 2050, in "Towards Sustainable Land Use" (2020).

Besides population growth, increasing per-capita calorie consumption is an important explanation of the rising food demand in the period 1961-2017. Agriculture, Forestry and Other Land-Use (AFOLU) activities accounts for about one fourth of net emissions. Food production is the main source for the vast part of those emissions, although reduction of carbon sinks through land-use changes contributes substantially (IPCC, 2019).

Policies to cut back joint food waste, and economic and guiding incentives to reduce calorie intake per capita, could ease the demand for agricultural land. Nevertheless, we should presuppose a that inevitable population growth implies fundamental forthcoming increase in demand for agricultural land. (IPCC, 2019).

1.4.2 Demand for carbon capture and storage

Carbon capture and storage (CCS) is a common terminology for processes that remove carbon from the atmosphere, and thus represent a desired counteraction to carbon emission processes. CCS could be processed using advanced new technology, like direct air carbon catch and storage (DACCS), by producing bioenergy with carbon capture and storage (BECCS) from different types of biomasses, or simply by letting natural processes capture carbon in soil and through photosynthetic biomass growth. All sorts of CCS require land, which I will discuss briefly in this section.

Today, forests cover 31 percent of terrestrial areas (FAO, 2020). As little as 15 percent of initial wetlands now remains (IPBES, 2019). Forest degradation and diminishing carbon sinks in peatlands, caused about 4 billion tonnes of CO_2 emissions annually between 2000 and 2009. Climate change will accelerate this process during this century (IPBES, 2018). The last three decades, most of the net loss of forest has occurred in Africa and South America (FAO, 2020). Tropical and subtropical forests, rich on biodiversity have had considerable losses, while boreal forests have slightly increased over the last three decades (IPBES, 2019; FAO, 2020).

Article 5 in the Paris Agreement obliges all nations to conserve and augment carbon pools, and to enhance policy framework to reduce emissions from LUC from initial forest land and elsewhere (UNFCCC, 2015). All pathways established by IPCC to stay well below 2°C requires a turnaround operation, which includes afforestation and reforestation (IPCC, 2019). Except BECCS, land restoration is the only type of carbon removal that does not rely on new technology. Land restoration would in many cases improve ecosystem services, if authorities supervise wisely (IPCC, 2018).

Muri (2018) found that BECCS had limited potential for global cooling effects, and that LUC associated with this, could have adverse impacts. Harper et al. (2018) and Brack & King (2021) supports this conclusion and argues that forest restoration would be a better carbon removal option. Harper et al. (2018) adds that forests also provide valuable ecosystem services which cropland would not. IPCC illustrate how afforestation, reforestation and BECCS all compete with agricultural demand, but that BECCS have potentially large negative effects on desertification and land degradation, contrary to afforestation and reforestation. It is essentially a trade-off between sustainable afforestation-focused land management, and BECCS solutions (2019). OECD (2020) points at the corresponding problems with biofuel production, which is in essence BECCS, but without CCS.

1.4.3 Demand for clean energy

Solar and wind power require far more land than other power sources. Required installations have negative impacts on habitat fragmentation, kills birds and bats, and occupy land. A 100% land based renewable energy production would therefore have an overwhelmingly negative impact on land-use (Saunders, 2020).

For EU, India, Japan, and South Korea, van de Ven et al. (2021) found that solar energy could cover 25-80 percent of the energy volume in 2050, when occupying 0.5-5 percent of total land. They suggest that solar power should not compete for land that have agricultural qualities, but rather blend into urban areas, which would be allocated closer to the end user. This would not only avoid using acreage for power installations, but also remove the need for costly transition lines.

JRC have calculated that EU could cover all energy demand from renewable sources, by letting solar and wind power installations occupy respectively 3 and 15 percent of total terrestrial areas (European Commission, 2019).

1.4.4 Aggregated demand for land

Summing up all implications for land-use, we could expect a global race for land. Modern societies demand substantially more space for infrastructure, food production, CCS, ecosystem services, and renewable energy. In total, this implicates strong and expanding general demand for finite land. Areas convertible to agricultural land is expected to face the strongest increase in demand, as it may be functional for all mentioned segments of demand.

Carbon sequestration through reforestation, afforestation and forestry management strategies are inevitable to both climate mitigation and biodiversity in line with a long-term global solution. That is why I find it reasonable to focus on forest versus non-forest land, even in this land-use context.

Figure 7.a in the appendix illustrate today's proportion of globally aggregated land-use, based on IPCCs special report (2019). In the bottom panel, I have outlined an extended bath-tub model, building on Angelsen's (2010) continuation of von Thünen's work[1], to illustrate in simple manners how aggregated demand evolving from forest land rent and non-forest land rent can explain today's global land-use. Figure 7.a is basically building on the same assumptions, but now focusing purely on net marginal LUC.

1 von Thünen, J. H. (1826). Der isolirte Staat in Beziehung auf Landwirthschaft und Nationalökonomie

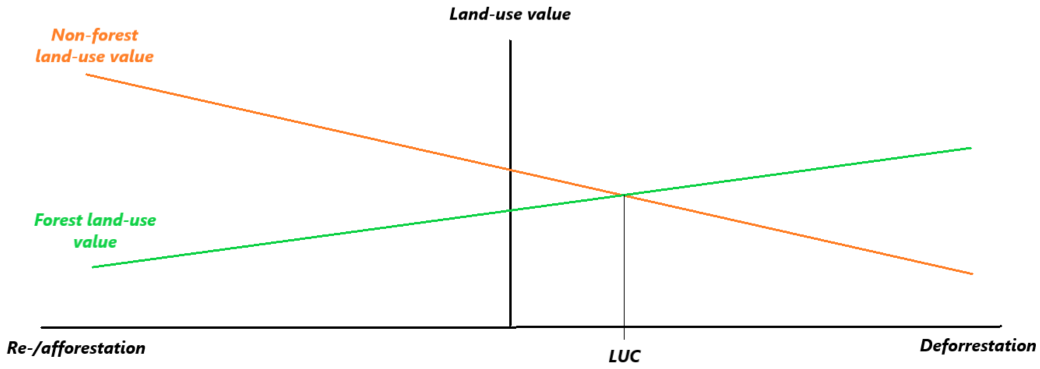


Figure 1.b: Aggregated demand for forest land

The purpose of Figure 1.b is to illustrate how forest land-use values relatively to non-forest land-use values settle the net land-use changes (LUC) with respect to re-/afforestation and deforestation. Both the forest land-use value curve and the non-forest land-use value curve builds on the assumption that such demand could be organized based on input and output variables related to all land-use purposes. The competing demand will define the given LUC equilibrium. In this case we see net deforestation.

Remember that non-internalized costs and benefits, will not influence the landowners' site-use value. If one would like to make land-use markets globally efficient, this would require internalization of globally defined prices on all externalities related to land-use. These conditions seem more like fiction than reality. First, measuring these externalities are close to impossible. Second, and maybe of even greater concern, expecting all nations to accept and pursue free trade in terms of land, does not only seem unrealistic, but it would also launch other major problems, like unwanted internal distributional effects. Yet, I find it reasonable to analyze the aggregated global land-use market as if this were unproblematic. The important lesson from this approach is that we have acquired a tool to analyze forest policy implications on land-use changes.

1.5 The valuation problem

Putting a price tag on species and habitats, is difficult and controversial (TEEB, 2010). Nevertheless, this should be systematically investigated from an ethical and economic perspective (TEEB, 2010). As Figure 1.a illustrates how ecosystem services already face a trade-off between carbon sequestration and biodiversity (amongst other trade-offs). The market has imposed an implicit price on species and habitats through monetization of alternative production on a finite area of land.

OECD (2020) finds such valuation problems to be the main driving force of both inefficient land conversion, and deceptive relative pricing of carbon sequestration and biodiversity "production". Not only are biodiversity and other ecosystem services unpriced or underpriced. Many sources of emissions are unaccounted for, and CCS is poorly rewarded or even disregarded (OECD, 2020).

TEEB (2010) recommends implementing carbon capture payments in forests. Marginal payments are more effective than non-marginal (TEEB, 2010). Dasgupta (2021) concludes that restoration and conservation are of global interest, thus steps should be implemented across borders, and funded through multilateral environmental agreements (MEAs).

Highlighting the missing economic values of the ecosystem can provide a better basis for decision-making for politicians, thereby facilitating rational trade-offs (TEEB, 2010). As explicit pricing of biodiversity may be difficult and controversial, an alternative approach is to use command and control (CAC) regulations, like jurisdictional protection, and other restrictions. Accepting an indisputably inadequate implicit price on biodiversity are ethically more problematic, than seeking to improve the markets valuation.

1.6 Normative guidelines and assumptions

I would like to point at three branches of the distributional problem. In my opinion, distributional problems between sectors, nations, and generations are essential to solve the collective action problem. Any measure that leaves certain sectors or nations behind will not provide the political viability to solve the collective action problem. In my opinion, the Kaldor-Hicks' criteria[2] are not likely to give sufficient credibility to policy measures, in a situation where there is no global governmental institution to force those measures upon nations, nor sectors. Pareto improvement as a standard, will in general avoid conflicts that could potentially harm collective effort.

Even if agricultural in many countries violates many criteria for economic efficiency, it is another story to improve the incentives. I believe this can be ascribed to the agricultural sector being a strong interest group within and across borders, and that it is closely related to the rural identity. OECD (2020) and IPBES (2018; 2019) point to inadequate incentives towards the agricultural sector as a part of their key messages. I believe removing harmful subsidies may not be viable, unless the very same sector is compensated. These considerations are not facts, but simple assumptions that I will refer to later.

Distribution between generations may be the most difficult task to handle. Unlike other collective action problems, the agents (generations) do not have the opportunity to retaliate actions or to implement a reciprocity strategy, simply because they do not live simultaneously. One generations effort determines the net environmental and climate impact on all following generations, but never a former. Dasgupta (2021) argues that, even if households manage to internalize net benefits between generations within their own households, they cannot be expected to internalize net benefits across households. Ethical guiding principles are required to sort this out.

As generations are unable to negotiate with each other, a philosophical experiment could be the only viable solution. John Rawls conceptualizing of the "veil of ignorance" (briefly discussed by Dasgupta (2021) and Perman et al. (2011)) is one tangible ethical approach on this problem. If all agents employ an "original position", unknowingly of what generation they belong to, all agents will presumably be able to discuss in neutral manners, which principles to implement in this society, which they will later inhabit.

Then, all generations could, agree upon one well-informed common principle (in line with Paris' Agreements Article 2 (UNFCCC, 2015)); equal but differentiated responsibility to restrict and stabilize the global warming to a certain degree or pathway established by science. It practices, this means following the IPCCs 1.5°C pathway. By simply adopting this common principle across generations, one could decouple discussion about what the real social cost of carbon should be, what discount rate to apply, and whether it is more cost effective to delay climate efforts. This one principle alone implicates that globally net emission permits for all future periods meet the specifications of

2 An aggregated improvement that could hypothetically have been a pareto improvement, if those who are better off compensated those who are worse off. Based on: Kaldor, N. (1939). Welfare Propositions of Economics and Interpersonal Comparisons of Utility. and Hicks, J. R. (1939). The Foundations of Welfare Economics.

scientifically defined emission pathway. Thus, we now face annual emission constrained profit maximization problems, which moves the focus towards least costly emission reduction and CCS, and trade efficiency.

As the discussion in this chapter has pointed out, the climate crisis and the biodiversity crisis are inseparably intertwined. From a generational perspective, it will not be appropriate to focus solely on a climate target without also safeguarding all other aspects of the ecosystem. Thus, it follows that the biodiversity crisis is simultaneously followed up through well-informed decisions at the global level.

1.7 Forest as part of the essential solution

Rockström et al. (2009) identified nine boundaries for safe supervision of the biosphere's conditions. They suggested that three out of these limits had already been overridden: species loss-rate, nitrogen cycle, and global warming. Mace et al. (2005) stated that the extinction of species was now going on at about 100 times faster then what the paleontologist's estimate as normal frequency. The climate crises are now well-known to all.

The forest ecosystem plays a key role in solving these three crises. In fact, I would argue that these services also make very important contributions to maneuvering within all six other categories as well. In this thesis I focus on the forests relation to what Rockström (2009) and his colleagues referred to as: "Land-System Change" (LUC) as well as "Rate of Biodiversity Loss" and "Climate Crisis".

1.8 Problem statements and thesis structure

As a rational agent, participating to solve the collective action problem in relation to biodiversity and climate crisis, Norway has an independent responsibility. To resolve its part of the issue in the best possible way, Norway should adopt a proactive approach that aligns with the international framework it expects to see in the coming decades.

Moreover, in reference to the Paris Agreement, wealthy countries like Norway have an elevated responsibility for taking on a proportionately greater burden in the fight for climate (UNFCCC, 2015, Article 2). The internal logic of the overall collective action problem described in this chapter, suggests that the country should also follow the same principles in the fight for biodiversity.

Based on the assumptions stated in this chapter, building the presented frameworks, forest economic theory, I will investigate how this affect Norwegian forestry. I will ultimately discuss relevant national and regional measures while waiting for global progress, to expand the Norwegian contribution and potential anthropogenic net benefit.

Even if this thesis takes a Norwegian perspective, the insights gained are likely to hold from many other countries perspective as well.

It should be mentioned that Norway is located on the Northern hemisphere, and thus, the ecosystems are connected to boreal biomes, which gives my expositions some distinct climatic features, that one should be aware of. Moreover, Norway cooperates with the EU on climate policy and frameworks, which delivers both possibilities and policy restrictions unlike many other nations.

This thesis problem statement is:

From a collectively coordinated anthropogenic perspective, what socioeconomic measures can Norway take in the forest sector to help solve the intercorrelated climate and biodiversity crisis?

Table 1.7.b: Thesis structure with brief description of content

Chapter		Content
1	Introduction	Overall description of the global climate and biodiversity crisis in the context of the Anthropocene and as a collective action problem. Discussion on three key issues, and normative guidelines and assumptions.
2	Background	Background information on Norwegian and Boreal biomes. Background information on Norwegian forests and forestry.
3	Theory	Inclusion of CCS in a carbon emission trading scheme. Optimal forestry rotation theory. The production possibility frontier in relation to carbon sequestration and biodiversity "production". The von Thünen approach on demand for forest land versus non-forest land.
4	Discussion	Suggesting potential policy improvements, based on literature review, theoretical discussion, and assessed models and simulations
5	Conclusion	Presenting potential policy improvements. Discussing strengths and limitations, missing links, suggested research topics.

2 Background

Chapter 2 is long, and contains many details about the global forest, the boreal forest, and the forests sector in Norway. Plenty of statistical information is presented with figures, so that the reader should be able to quickly familiarize themselves with the context. Together, this chapter forms the basis for the topics discussed in Chapter 3 and the premises for the argumentation in chapter 4. I suggest reading this section as a compendium.

The overall picture, and its relation to the thesis' problem will be briefly presented in chapter 4

2.1 A general perspective on forests and the boreal biome

2.1.1 The global forest and its ecosystem services

31 percent of global terrestrial areas are categorized as forest, an ecosystem where the vast majority of all amphibians, birds and mammals belong. Insects and pollinators also depend on forests. (FAO & UNEP, 2020). The forest contains almost all biologic diversity on land (EEA, 2016).

Healthy ecosystems are essential for food security on Earth. Biodiversity makes food production more adaptable to climate change and other major changes (FAO, 2019). For billions of people, the forest delivers firewood, food, and fresh water (FAO & UNEP, 2020).

The forests global carbon storage was estimated to 662 gigatons in 2020, which is divided into the following carbon pools: soil (45 percent), living biomass (44 percent), litter (6 percent), dead wood (4 percent) (FAO, 2020).

As trees grow, water and energy are exchanged. Therefore, changes in forest cover will affect the regional climate. Afforestation, contrary to deforestation, will result in colder day temperatures in the summer. The Albedo effect[3], on the other hand, ensures slightly warmer winters in snow-covered areas, such as the boreal zone. Afforestation and other land use changes (LUCs) can affect temperature and rainfall hundreds of kilometers away, and even alter heatwaves (IPCC, 2019).

Forests also have a key role to reduce risk of floods, droughts, landslides, and other natural disasters (Fjellstad & Skrøppa, 2020). Trees can clean the air in urban areas. Trees and vegetation on riverbanks are also important to ensure nutrient supply in freshwater (Lindhjem & Magnussen, 2012).

Worldwide, expanding agricultural acres is the main reason for the extensive fragmentation of forests. When the robust forest, which is home to pollinators and other essential species, is degraded, basic ecosystem services on which we depend, are undermined. One third of the global food production benefit from these pollinators. Thus, nature's ability to feed us is reduced, and in addition, large carbon sinks are released (FAO & UNEP, 2020). Forest edges, grasslands and riverbanks are important for populations of pollinating insects (Lindhjem & Magnussen, 2012).

Biodiversity is particularly vulnerable to fragmentation of ecosystems (EEA, 2016). Today, about 8 percent of plants, 5 percent of the fungi, and 5 percent of animals associated with the forest are listed as critically endangered (FAO & UNEP, 2020). Besides fragmentation and loss of ecosystems, pollution, overuse of species and invasive non-native species are important drivers for loss of biodiversity (IPBES, 2018).

Protection of untouched forests with inherent resilience may limit the loss of biodiversity in other parts of nature (Secretariat of the Convention on Biological Diversity, 2003). Primary forests are particularly valuable, as even small patches can make larger ecosystems more resilient, as it is the

3 Temperature effects resulting from the surfaces relative ability to reflect solar radiation

essential home of some exceptional species (FAO & UNEP, 2020). Approximately 10 percent of the global forests are protected with the objective to preserve biodiversity (FAO, 2020).

Table 2-a provides a decent overview of the forest's many essential and valuable ecosystem services.

Table 2-a: Ecosystem services, categorized and briefly described[4]

Main category	Subcategory	More detailed description
Supportive services	Ecosystem services	Ecological cycle
	Biodiversity	Genetic, species and habitat diversity
Regulatory services	Climate regulations	Carbon sequestration and storage, and regional and local climate mechanisms
	Resistance to natural damages	Protection against floods, storms, landslides and avalanches
	Water flow	Drainage, stabilization, irrigation and replenishment of groundwater
	Biological control	Natural control of pests and disease
	Cleaning capacity	Air and water
	Pollination	Fertilization
Producing services	Edible products	Game meat and meat from grazing animals, freshwater fish, berries, mushrooms, drinking water
	Non-edible products	Timber, bioenergy, feed for game and grazing animals, ornamental green, bio-industry, genetic resources
Cultural services	Recreation and tourism	Everyday recreation, training, recreation in connection with hunting, fishing, and gathering, aesthetic pleasure
	Existential value	Species right to life
	Inspiration for art, design, and culture	Aesthetic inspiration and identity
	Knowledge and information	Education and research
	Cultural and spiritual values, identity and experiences	Cultural identity and values
	Mental and physical health	Stress reduction and well-being

Lindhjem, H. & Magnussen, K.. (2012, p. 18-19). Verdier av økosystemtjenester i skog i Norge. In *NINA rapport*. Norsk institutt for naturforskning. Retrieved 01.08.21 at https://brage.nina.no/nina-xmlui/bitstream/handle/11250/2643062/894.pdf?sequence=2&isAllowed=y

The table provides a comprehensive, but not exhaustive picture of forest-related ecosystem services. It is divided into four main categories, with associated subcategories and brief descriptions of the most obvious and important value contributions.

2.1.2 The boreal forest

The boreal coniferous forest zone covers northern Russia, Canada, Alaska, and Fennoscandia. Together, it constitutes the world's largest contiguous forest area. It consists of coniferous and

4 This table is set up after strong inspiration from Lindhjem & Magnussen (2012, p. 17-19), which in turn credits the TEEB and MEA framework. It also corresponding in large with Secretariat of the Convention on Biological Diversity (2003, p. 1), among others.

deciduous trees. The majority of all the world's wetlands are found in this ecosystem, which contributes to this being the world's largest carbon storage facility in forests (Solheim, 2018).

Weighty snow cover is common during wintertime, which put special requirements on the species that live there. Some mammals go into winter hibernation, while migratory birds fly south. Also, plants and trees enter inactive periods. Some animals specialize in moving on top of the snow, while others make walking systems under the snow (Solheim, 2018)

In a state of natural succession, coniferous trees, and spruce in particular, will outperform deciduous trees as a result of which they tolerate shade better. Thus, there will be natural periods of standing dead trees, which is an important condition for the occurrence of many species of birds and animals. Moose, beaver, brown bear, fox, wolf, wolverine and many bird species live in the boreal zone, both in Eurasia and America. High incidence of woodpeckers is a characteristic sign of natural forests, as they upend dying trees (Solheim, 2018).

The boreal forest is the second largest, and the second least fragmented, by climatic domain, after the tropical forest. It includes 27 percent of the world's forest area (FAO & UNEP, 2020). Yet, FAO & UNEP finds that the level of conservation is deficient, compared to other biomes. While 18 percent of the world's forests are protected, less than 10 percent of the boreal coniferous forest has such protection (FAO & UNEP, 2020).

2.2 Norwegian forests and forestry

2.2.1 Formation of the Norwegian forest

Birch (Betula pubescens) and Scotch Pine (Pinus sylvestris) where among the species to re-establish after the Ice Age, and inhabited higher altitudes than they do today (Fjellstad & Skrøppa, 2020). Norway Spruce (Picea abies) immigrated from Russian plains to Fennoscandia and formed its first forests about 2,500 years ago (Fjellstad & Skrøppa, 2020). A hypothesis that Norway Spruce and Scotch Pine inhabited parts of Norway thousands of years ago are supported by recent DNA studies (Fjellstad & Skrøppa, 2020). Norwegian climate conditions, soil and topography have favored boreal coniferous forest in general, while boreal deciduous forests dominate in higher altitudes and northern parts (Fjellstad & Skrøppa, 2020).

The Norwegian primeval forest has been largely shaped by humans through deforestation and extensive silvicultural measures (Fjellstad & Skrøppa, 2020). After the water saw was introduced in Norway, lumber became an important commodity for Norway from the first half of the 16th century. Timber floating made inland logging areas available for extraction of timber, which could typically be refined and loaded for export on the coast of southern and eastern Norway. During the 19th century, these forests got rather barren. Clearcutting become a widespread method of logging since the first half of the 20th century (Jakobsson & Pedersen, 2020).

In the post-war period, the focus was on planting in new areas and replanting on existing forest areas. 60 million plants annually 1955-1992 have contributed greatly to the current stock with large fractions of trees in their most productive phase. At the same time, annual tree harvest has remained fairly stable. This provides a potential for large timber extractions, and significant CCS (Norwegian Environment Agency, 2019). Standing timber volume has tripled since the 1920s (Bartlett et al., 2020).

Organized planting and even-aged management, changed Norwegian forests, separating older and younger forests. Old-growth forests from before 1945, which is typically located in Southern Norway, contains considerable amounts of deadwood (Jakobsson & Pedersen, 2020), which is important for biodiversity.

2.2.2 Tree species and forest types

Today, two coniferous species, the Norway spruce (Picea abies) and Scotchs pine (Pinus sylvestris) cover about half of the Norwegian forest areas. Together with two birch types (Betula pendula and Betula pubescens) these species form the main forest types (Fjellstad & Skrøppa, 2020). Spruce, pine and birch make up more than 90 percent of total domestic volume (Fjellstad & Skrøppa, 2020).

Picea abies are particularly common in Eastern Norway, in central Norway and in Nordland5. It thrives in deep and nutritious soil and tolerates both cold summers and winters (Fjellstad & Skrøppa, 2020). Usually, it grows between 20 and 30 meters high, but the stem rarely gets more than one meter in diameter. (Aune, 2020). The natural lifespan is 300-500 years (Bartlett et al., 2020).

Pinus sylvestris tolerates cold summers and winters and grows best in medium site qualities. It grows all over Norway. Natural rejuvenations are more common than active regeneration (Skrøppa & Fjellstad, 2020). As the variety is large, it is often divided into subclasses. They can grow to 20-40 meters high, with stems up to one and a half meters in diameter (Sunding, 2019). It can live for 500-700 years (Bartlett et al., 2020).

Birch grows all over Norway. Downy birch (Betula pendula) is more productive than birch (Betula pubescenc) and dwarf birch (Betula nana), and it is also widely used for landscape purposes (Skrøppa & Fjellstad, 2020). These species may live for up to 150 years (Bartlett et al., 2020)

The Norwegian fauna also includes 12 species of Sorbus, eight of which are red-listed, and seven are endemic (Fjellstad & Skrøppa, 2020).

2.2.3 Regional differences

The growing season is only half as long in northern coastal areas, compared to southwestern parts of Norway (Fjellstad & Skrøppa, 2020). The productive forest areas are largely found in Eastern and Southern Norway (Lindhjem & Magnussen, 2012). Northern Norway and Western Norway hold large proportions of the productive broad-leaved forest, while Eastern Norway holds major parts of all other productive forest types (see Figure 2.a). Eastern Norway has 42 percent of total productive areas, while the other four regions have 13-18 percent each (see Figure 7.b) (Statistics Norway, 2021).

5 Nordland is a county located north of Central Norway and south of the northernmost county, Finnmark og Troms.

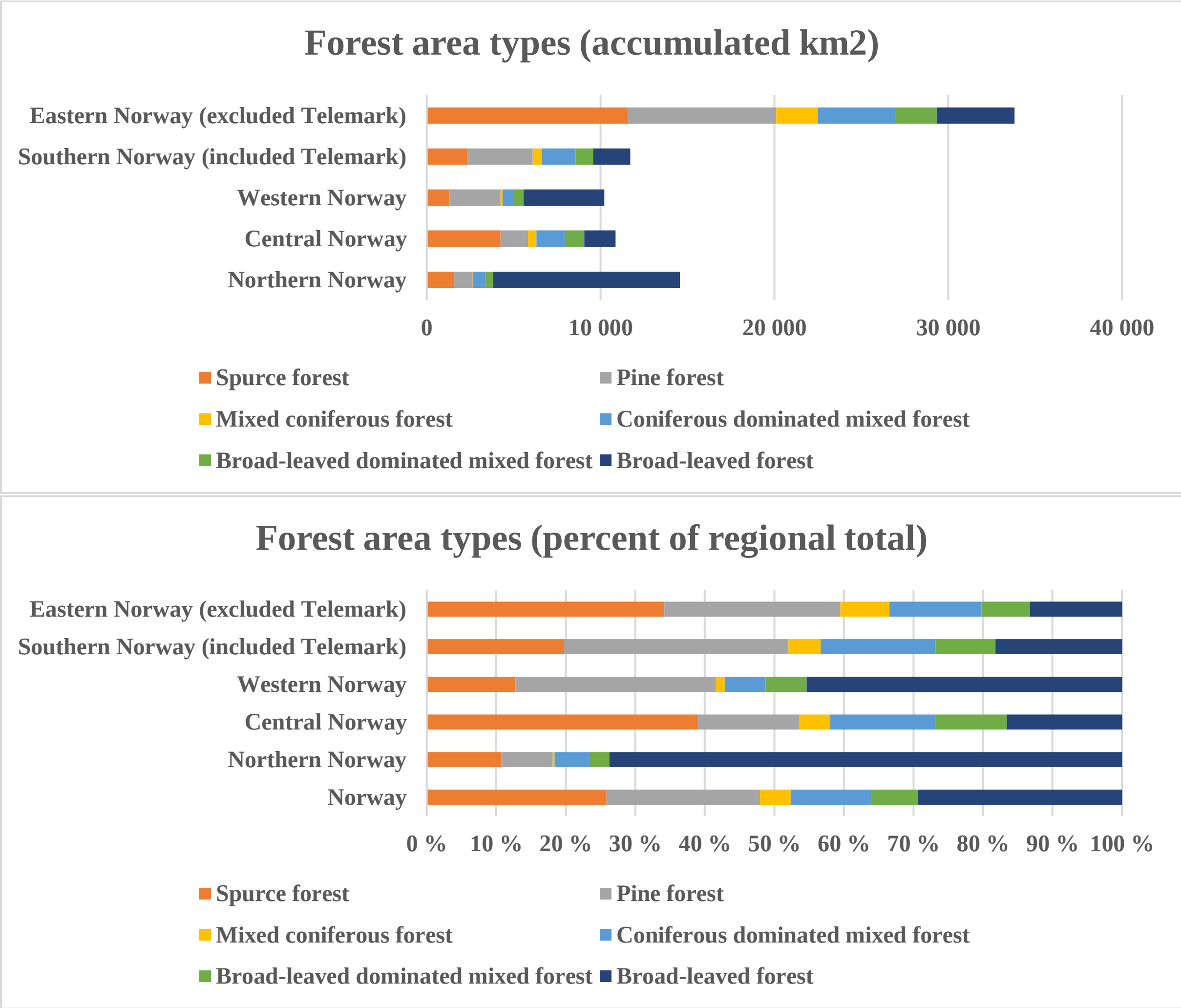


Figure 2.a: ***Regional distribution of forest types***

Statistics Norway. (2021). ***Table 06288: Productive forest area, except area under regeneration, by species of tree and surveyed regions (km2)*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06288/**

Illustration of regional distribution of forest types, considering productive forest areas.

Top panel: accumulated square kilometers per forest type, sorted by region.

Bottom panel: proportionate distribution of forest types, within each region.

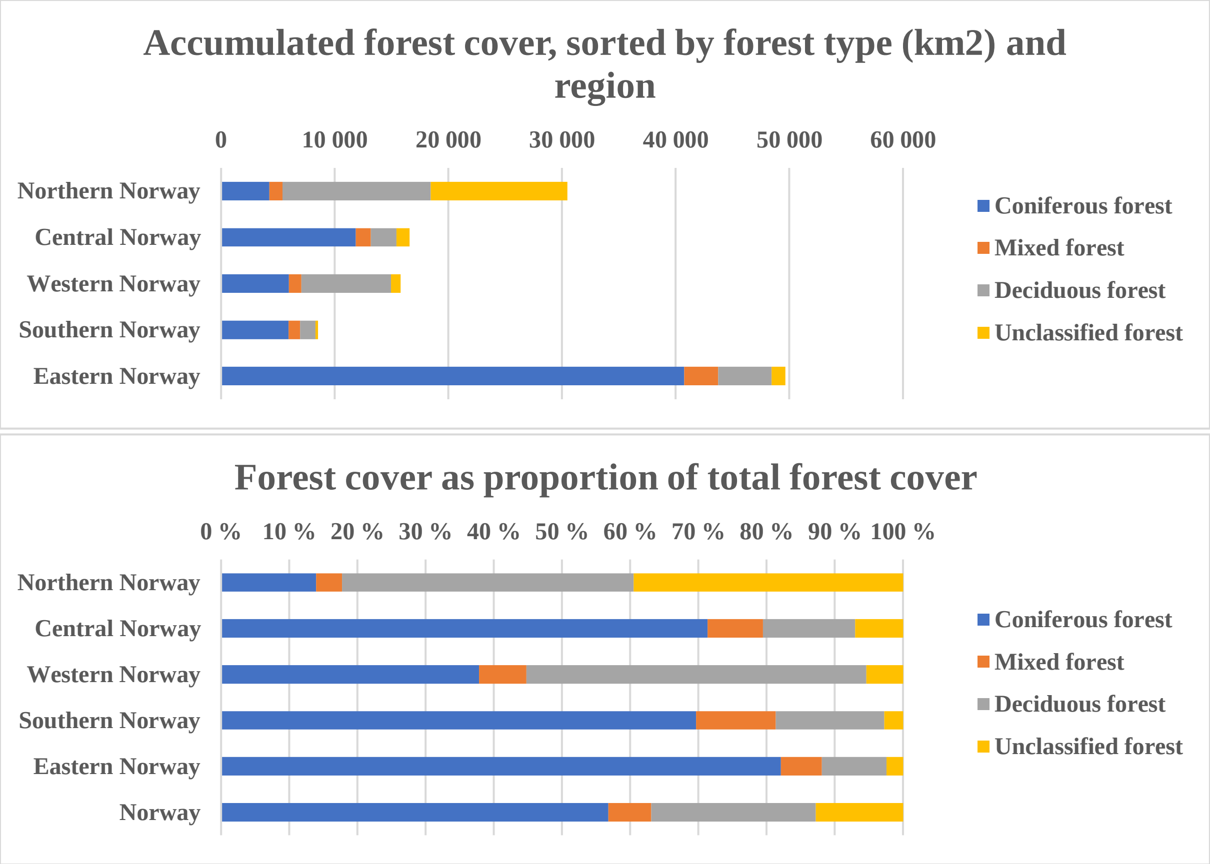


Figure 2.b: Forest cover sorted by forest type, by region, and entire Norway

Statistics Norway. (2021). ***Table 09594: Classes of land use and land cover (km²) (M) (UD) 2011 - 2021*****. Retrieved 07.08.21 at https://www.ssb.no/en/statbank/table/09594/**

Top panel: Accumulated forest cover per forest type, sorted by regions. Most substantial forest type (Coniferous forest) is organized first, and so on.

Bottom panel: Forest types presented as proportions of total internal cover, by regions, and total domestic.

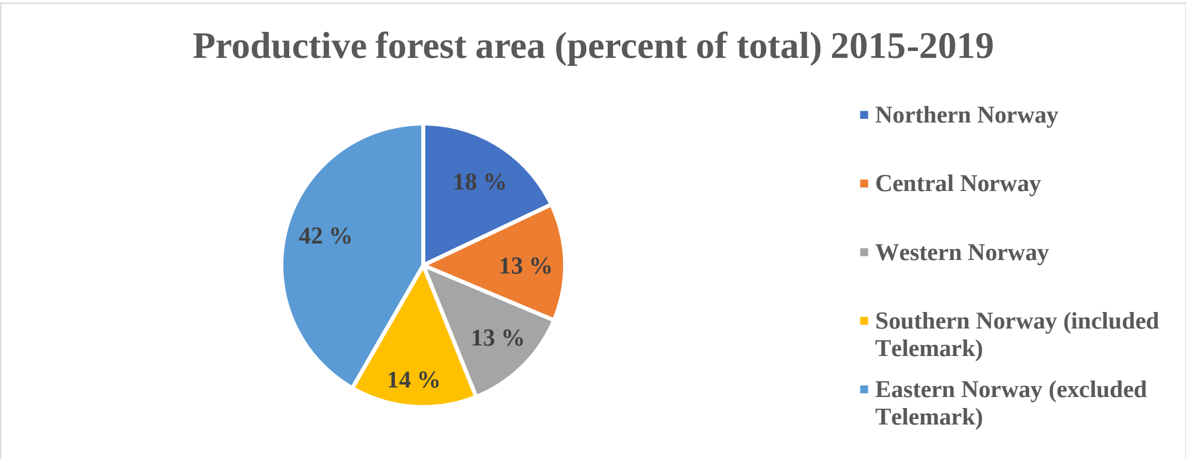


Figure 2.c: Regional distribution of productive forest

Statistics Norway. (2021). ***Table 06288: Productive forest area, except area under regeneration, by species of tree and surveyed regions (km2)*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06288/**

Illustration of distribution of aggregated productive forest per region as share of national total.

As one can read in **Error! Reference source not found.** and see in **Error! Reference source not found.**, Eastern Norway dominates most of the forestry. Central Norway employs a larger share of total employment in the sectors: forestry and logging, wood and wood products, and paper and paper products. In particular, the latter sector has a large share of domestic employment in Central Norway. It is also important to note that 93 percent of all commercial logging from properties larger than 5,000 acres, was produced in Eastern Norway (Statistics Norway, 2021).

2.2.4 Commercial forestry

Figure 2.d illustrates how important the two coniferous species are to Norwegian commercial forestry. Spruce and pine covered about three fourths of total annual increment in the period 2015-2019 (spruce: 53 percent, and pine: 23 percent), and almost all roundwood removal in 2020 (spruce: 70 percent, and pine: 27 percent) (National Statistics, 2021).

As Figure 2.e shows, spruce dominate productive forests, while there are larger volumes of pine and broad-leaved species on other type of land (National Statistics, 2021).

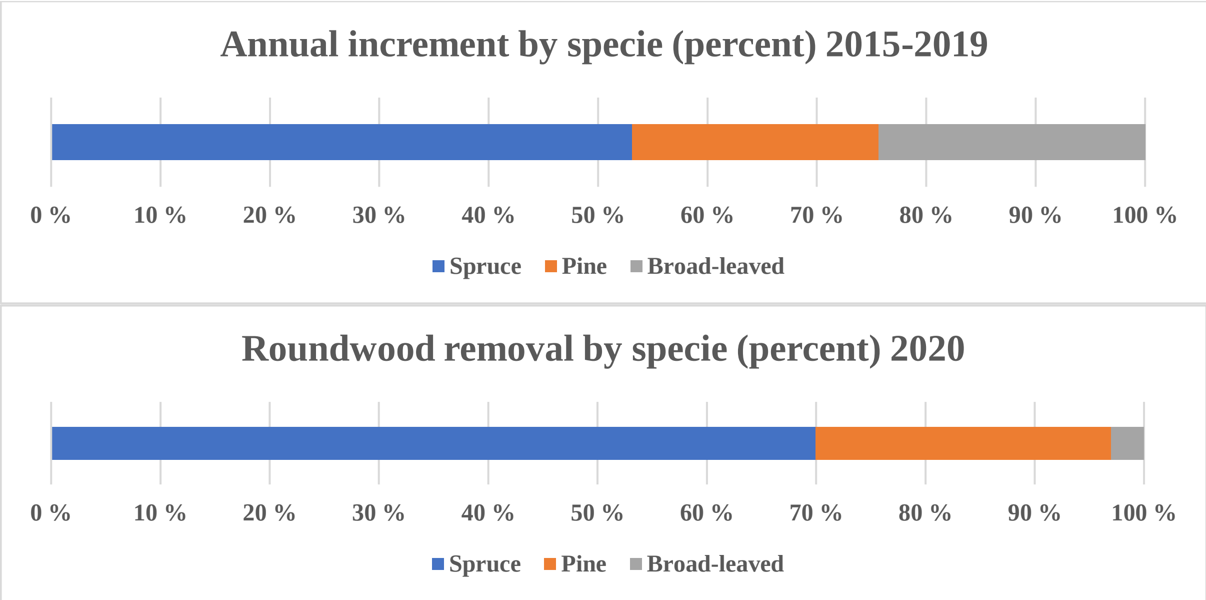


Figure 2.d: Annual increment and roundwood removals, distributed by specie

Left panel: Statistics Norway. (2021). ***Table 06291: Annual increment under bark, by type of land, species of tree and surveyed regions (1 000 m³), 1996-2000 - 2015-2019*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06291/**

Right panel: Statistics Norway. (2021). ***Table 03795: Commercial roundwood removals, by species of tree (m³) (M) 1996 - 2020*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03795/**

Illustration of annual volume distribution of increment (2015-2019) and roundwood removal (2020), sorted by specie.

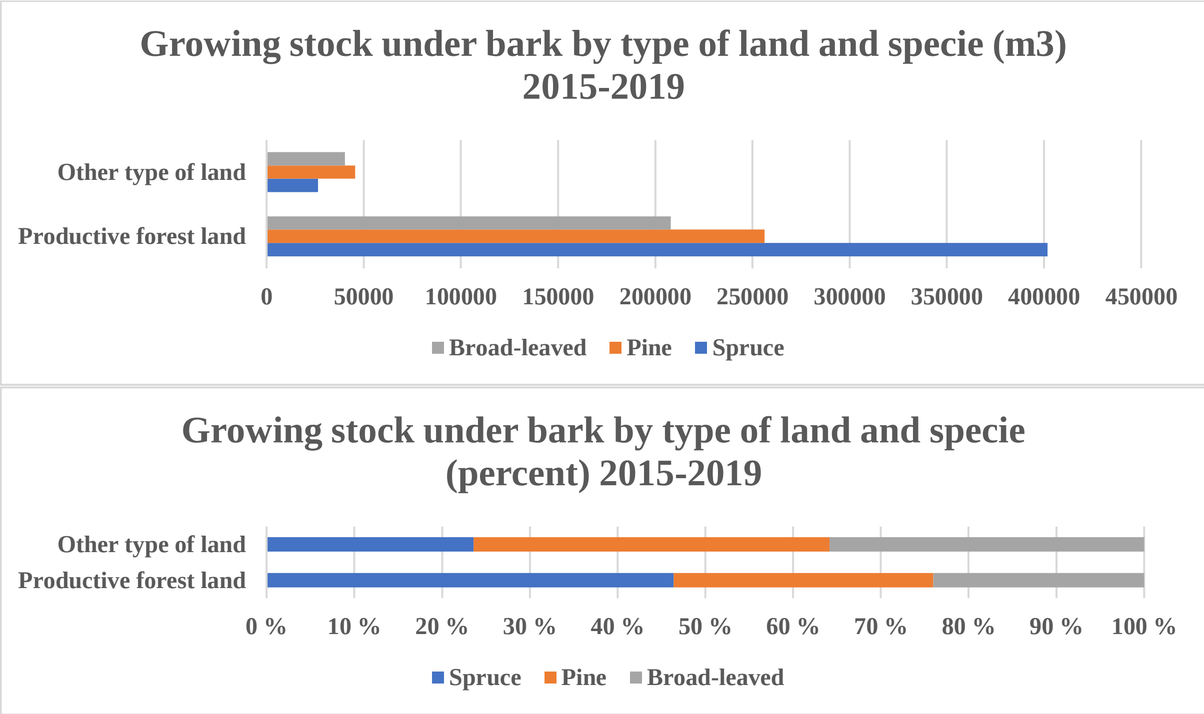


Figure 2.e: Growing stock, distributed by type of land and specie

Statistics Norway. (2021). ***Table 06290: Growing stock under bark, by type of land, species of tree and surveyed regions (1 000 m³) 1996-2000 - 2015-2019*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06290/**

Illustration of growing stock, sorted by specie and land type.

Top panel: volume of stock sorted by specie and land type.

Bottom panel: distributed share of specie, within total stock of each land type.

Improved forest policy, education, afforestation efforts, and shifting from selection cutting to clear-cut logging have transformed the Norwegian forest. Since the first National Forest Inventory in 1932, the growing stock has tripled, while the annual increment has doubled. Deadwood and old forests have increased substantially (Fjellstad & Skrøppa, 2020), from an initial scarce level.

Since 1996, Spruce and Pine have accounted for about 70 percent and 25 percent of annual roundwood removals (see Figure 2.f). Annual average gross value of these removals were about 350 million Euros in the period 1996-2020[6] (see Figure 2.g) (Statistics Norway, 2021). Norway spruce cover 96 percent of all domestic seed sale for traditional forestry. Unlike spruce, Scotch pine is largely regenerated through natural rejuvenation (Fjellstad & Skrøppa, 2020).

6 2020 index and exchange rates (10.7207 NOK/€) according to the central bank of Norway: https://www.norges-bank.no/en/topics/Statistics/exchange_rates/?tab=currency&id=EUR.

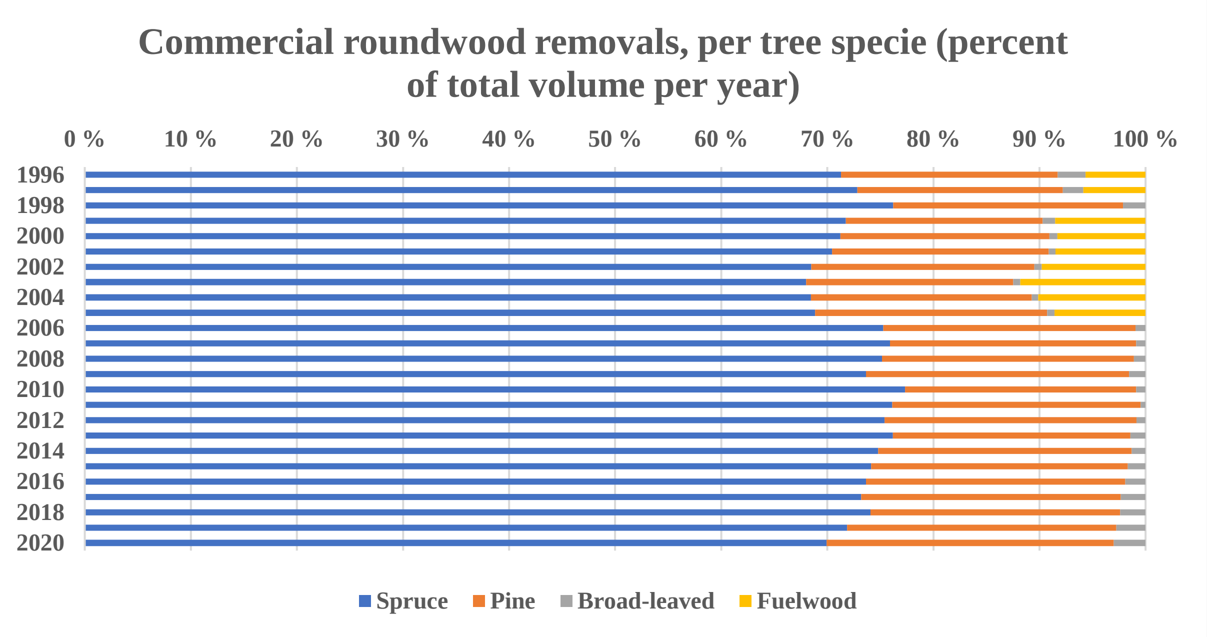


Figure 2.f: Commercial roundwood removals, per tree species and year (1996-2020)

Statistics Norway. (2021). ***Table 03795: Commercial roundwood removals, by species of tree (m³) (M) 1996 – 2020*****.**
Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03795/

Illustration of distributed share of total removal, sorted by specie.

Average gross price of removal has been decreasing from about 50 € per cubic meter in the period 1996-1998 till about 40 € per cubic meter in the period 2002-2020 (see Figure 2.g). Since 2006, the gross price has changed 10 percent or more from one year to another (see Figure 2.h) (Statistics Norway, 2021). Adu & Romstad (2020) have showed how such volatile local timber prices can provide strong incentives, among forest owners who accept risk, to delay harvesting, in anticipation of an expected price increase.

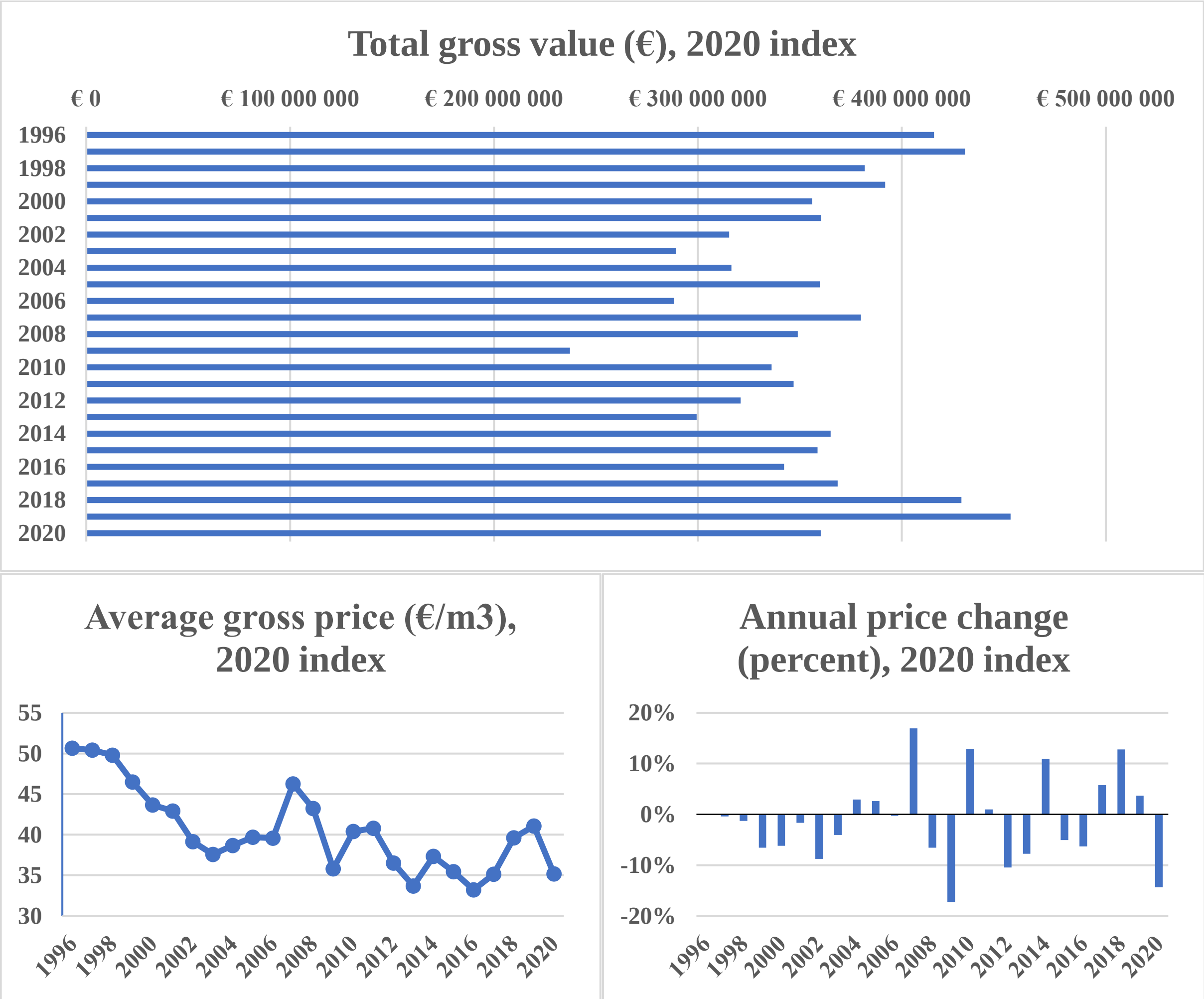


Figure 2.g: Total gross price, average gross price, and annual price changes of roundwood removals (1996-2020)7

Statistics Norway. (2021). *Table 03794: Gross value. Commercial roundwood removals (NOK 1 000) (M) 1996 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03794/

Illustration of price statistics for roundwood removals.

Top panel: total annual gross value of commercial roundwood removal, valuated in Euros, 2020 exchange rates and index.

Bottom left panel: Average gross price per cubic meter of commercial roundwood removals, valuated in Euros, 2020 exchange rates and index.

Bottom right panel: Marginal annual price changes, measured in percent change as a proportion of the initial years price.

We could roughly say that half of the removal are used as saw logs, while the other half end up as pulp wood (see Figure 2.h). The market price for saw logs have on average been almost twice as high as pulp wood (see Figure 2.i) (Statistics Norway, 2021).

7 2020 index values based on Statistics Norway's Inflation calculator: https://www.ssb.no/en/kalkulatorer/priskalkulator

NOK valued in average 2020 exchange rates (10.7207 NOK/€) according to the central bank of Norway: according to the central bank of Norway: https://www.norges-bank.no/en/topics/Statistics/exchange_rates/?tab=currency&id=EUR

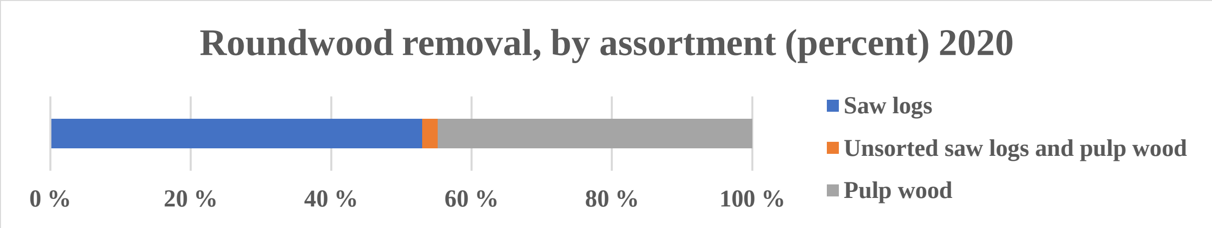


Figure 2.h: Roundwood removals, distributed by assortment (2020)

Statistics Norway. (2021). ***Table 03895: Commercial removals of industrial roundwood, by assortment (m³) (M) 1996 - 2020*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03895/**

Illustration of distribution of assortment (2020). Saw logs account for 53 percent, pulp wood for 45 percent, and 2 percent are unsorted.

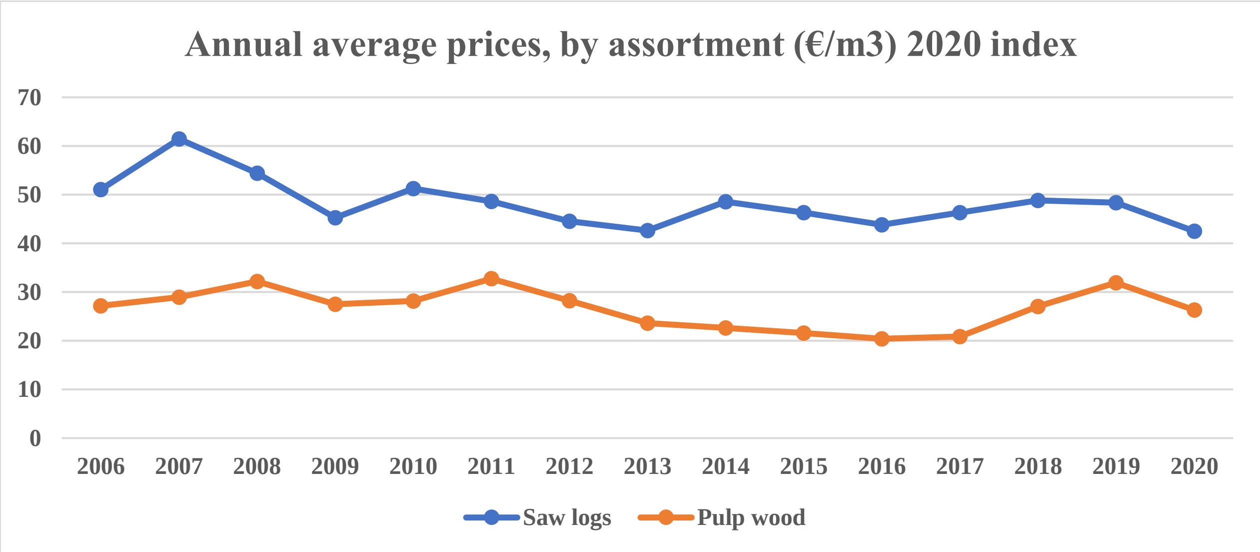


Figure 2.i: Annual average prices, by assortment (2020)8

Statistics Norway. (2021). ***Table 07413: Average price, by assortment (NOK per m³) 2006 - 2020*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/07413/**

Statistics Norway. (2021). ***Table 07410: Commercial roundwood removals, by assortment (1 000 m³) 2006 - 2020*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/07410/**

Illustration of annual average prices of sawlogs and pulp wood in the period 2006-2020, valuated in Euros, 2020 index.

In practice, all commercial forestry relies on a PEFC certification to deliver timber to the most important buyers in the market. In 2018, 75 percent of the productive forest area was associated with this certification (Tomter & Dalen, 2018).

Table 2-b: PEFC Standards for minimum age for logging

8 2020 index values based on Statistics Norway's Inflation calculator: https://www.ssb.no/en/kalkulatorer/priskalkulator

NOK valued in average 2020 exchange rates (10.7207 NOK/€) according to the central bank of Norway: according to the central bank of Norway: https://www.norges-bank.no/en/topics/Statistics/exchange_rates/?tab=currency&id=EUR

Site quality (H40)9	26	23	20	17	14	11	8	6
Minimum cutting age	40	45	50	60	70	80	85	95

PEFC. (2016). PEFC N 02 – Norsk PEFC Skogstandard. Retrieved 20.07.21 at https://pefc.no/vare-standarder/det-norske-pefc-systemet

The National Forest Inventory provides a useful summary of the forest resources. It documents forest cover and tree species, and estimates stand volume, volume increment, plant density and site productivity. In addition, information about the forests health and biological values of is collected. The counting started in 1919 and is constantly updated. Today it provides the basis for Norway's official reporting to UNFCCC (NIBIO, 2021a). Current NFI gather samples every five year from each plot (Fjellstad & Skrøppa, 2020).

Forest owners are offered forest management plans every 10th or 15th year (Fjellstad & Skrøppa, 2020). Half of Norwegian forests have such management plans, which can be said to be a rather useful device to meet the requirements of law (Forest Europe, 2020). This contributes largely to the overall statistical basis related to Norwegian forests and forestry

As Figure 2.j illustrates, the underdeveloped part of the productive forest has almost disappeared in Norway. At the same time, the most mature forest has taken over ever larger areas. The medium-developed populations have also had a size increase in size of acres (Statistics Norway, 2021). Together, this paints a clear picture of a forest that is becoming increasingly mature, compared to the exhausted Norway forest in the early 20th century.

As the top panel in Figure 2.k shows, the productive forest of today is dominated by mature forest. The bottom panel shows that the top site quality accounts for small proportions of the total productive area. Areas with relatively low production capacity make up the majority of the total productive forest (Statistics Norway, 2021).

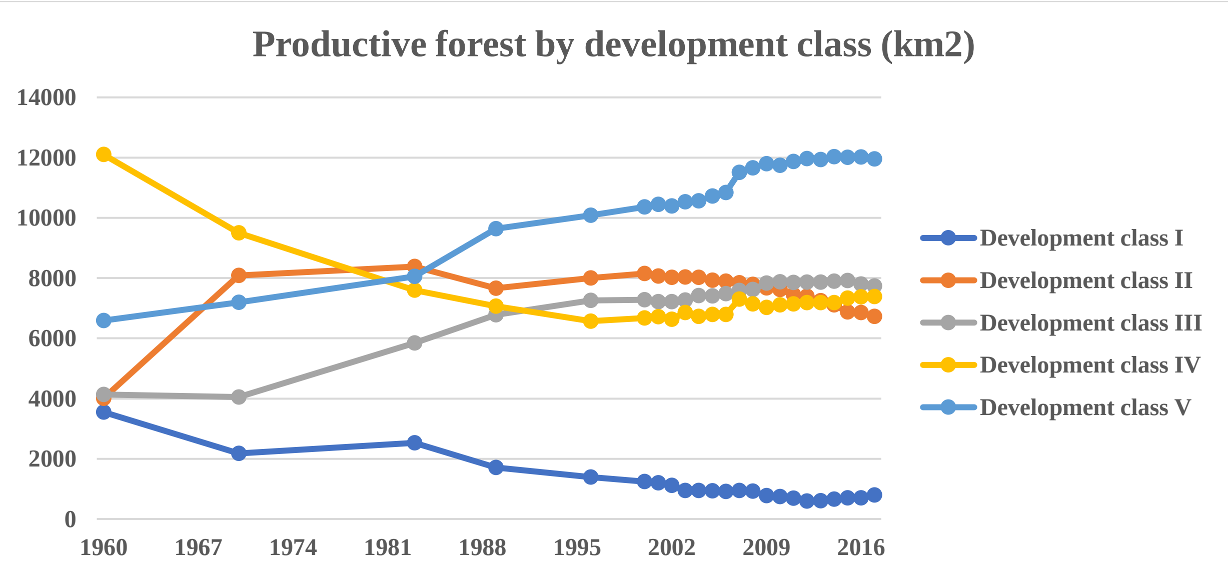


Figure 2.j: Productive forest distributed between development classes

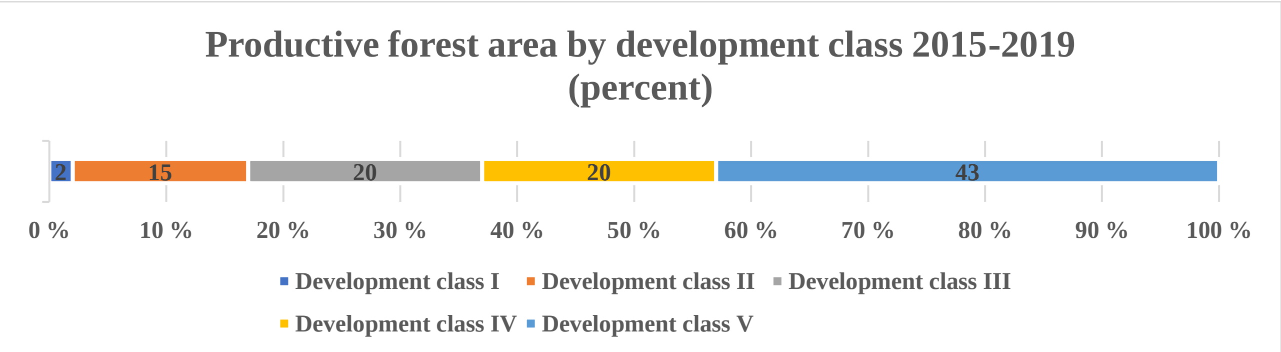
9 According to https://www.ssb.no/en/klass/klassifikasjoner/71/koder, the site quality is classified by the average height of the 100 trees per hectare with the largest stem diameter, measured at chest height, at 40 years of age. The classification system refers to this measured size.

Statistics Norway. (2021). *Table 06286: Productive forest area, by development class*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06286/

According to https://www.ssb.no/en/klass/klassifikasjoner/70, the development classification (I-V) is based on measured age, site quality, and plant density.

Since the census has been carried out with greater frequency in the recent years, there are fewer plots from the 1960s, and gradually denser plots from the 1960s. All plots are stated as square kilometers of forest. Since the forest cover itself has not changed so much over these years, it also reflects the changes in proportions quite well.

Development class I has gone from a significant size in the 1960s, to a smaller fraction of today's productive forest. Development class IV have roughly been halved, while development classes II, III, and V have almost doubled its area. Even if this plot did not measure the forests age itself, the overall picture clearly tells us that the Norwegian productive forest has become much older on average over this time period.



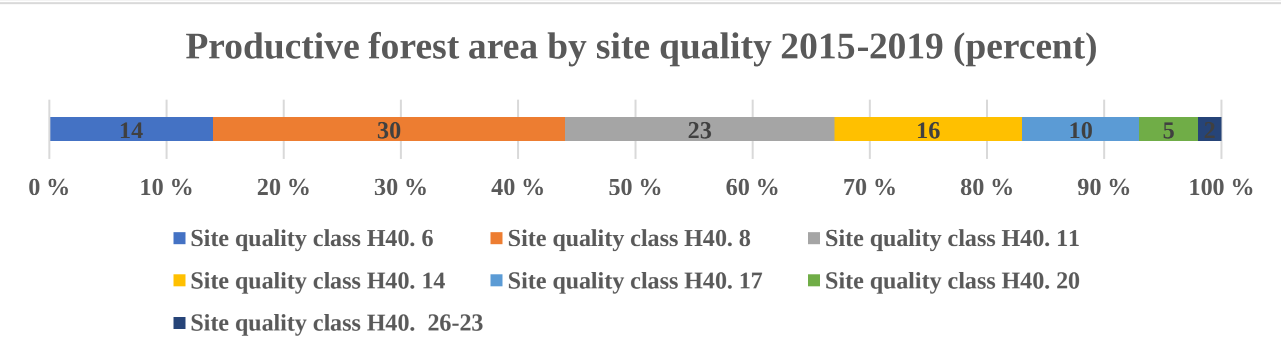


Figure 2.k: Productive forest percentage distribution between development classes and site qualities

Statistics Norway. (2021). *Table 06287: Productive forest area, by development class, site quality and surveyed regions*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06287/

As **Error! Reference source not found.** illustrate, in 2020 the sector wood and wood production (12,962) employ more people than forestry and logging (6,075) and paper and paper products (2,529) together. In the period 2008-2020, the forestry and loggings, and wood production's employment has been fairly stable, while the paper industry in 2020 employed less than half of what it did in 2008 (Statistics Norway, 2021).

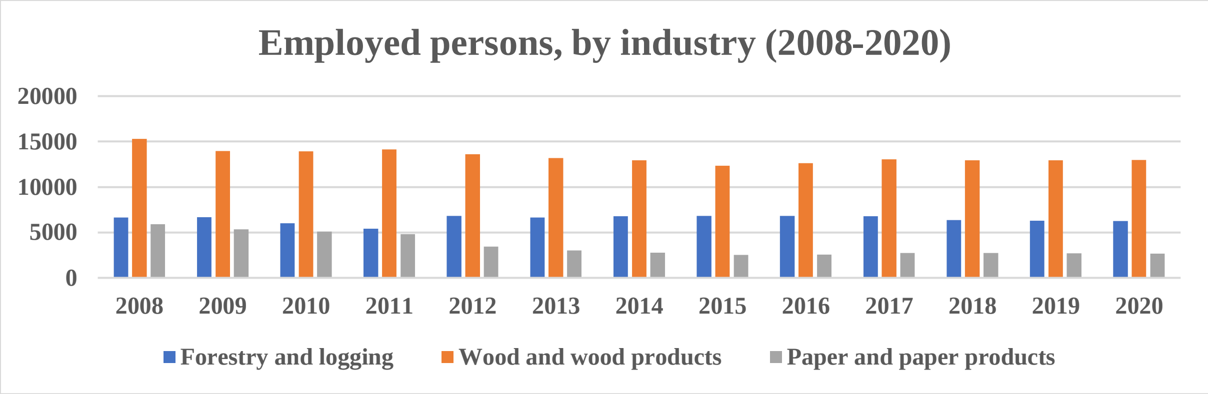


Figure 2.l: Employed persons, by relevant industry (2020)

Statistics Norway. (2021). *Table 08536: Employed persons (aged 15-74), by industry division (88 groups, SIC2007) and sex. 4th quarter (M) 2008 - 2020*. Retrieved 05.08.21 at https://www.ssb.no/en/statbank/table/08536/

Employed persons, sorted by sectors: forestry and logging, wood and wood products, and paper and paper products over the period 2008-2020.

2.2.5 Property structure

Small-scale properties dominate the Norwegian forestry, and combining forestry and agriculture is common (Fjellstad & Skrøppa, 2020). Topographic conditions and varying production opportunities can partially explain this fragmented property structure (Tomter & Dalen, 2018) illustrated by **Figure 2.m**. 96 percent of all forest properties are privately owned, which sums to 83 percent off the total area. Publicly owned properties are on average more than four times the size of an average privately owned forest property. Publicly owned forests tend to be larger and less productive, compared to properties who are privately owned (see **ERROR! REFERENCE SOURCE NOT FOUND.**) (Statistics Norway, 2021).

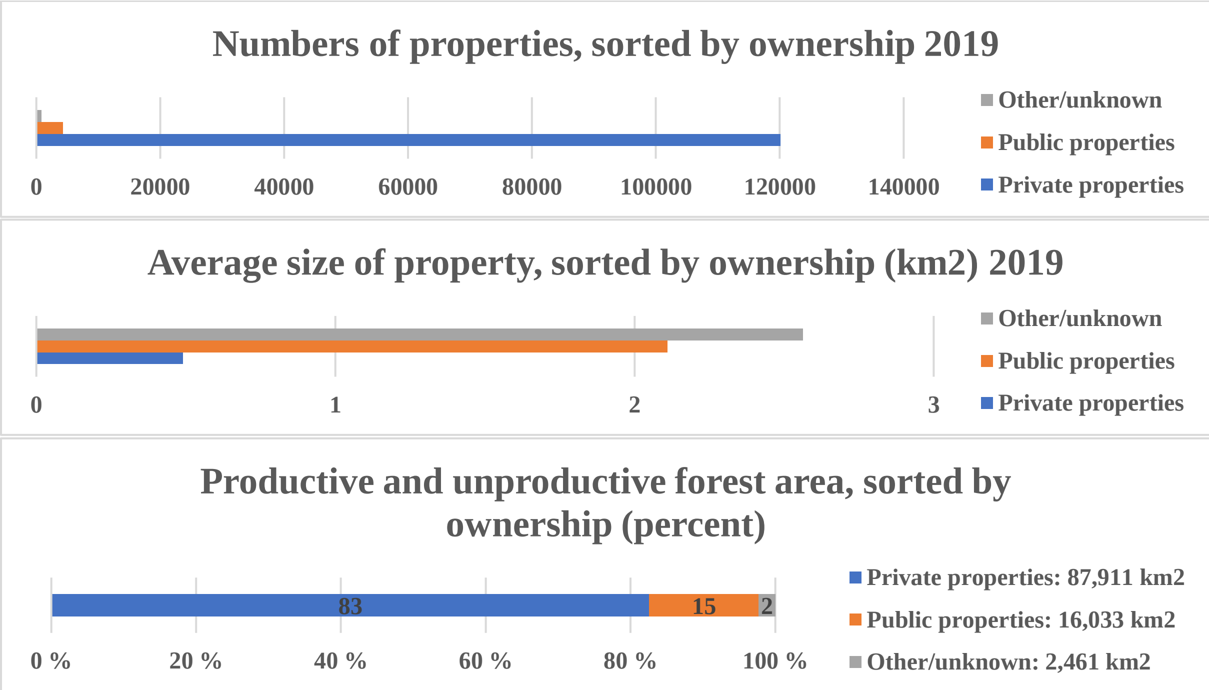


Figure 2.m: Number of properties, average size of properties, and distributions of productive and unproductive forest, sorted by ownership[10]

Statistics Norway. (2021). ***Table 10613: Forest properties and productive forest area, by type of forest owner 2013 - 2019*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/10613/**

Illustration of the distribution of forest properties related to ownership.

Top panel: number of properties, sorted as private property, public property, and other/unknown.

Middle panel: average size of properties, sorted as private property, public property, and other/unknown.

Bottom panel: distributes area of forest properties, sorted as private property, public property, and other/unknown.

2.2.6 Forest-use related to outdoor activities and recreation

Sports and recreational activities in the forest is assumed to improve mental and physical health (Fjellstad & Skrøppa, 2020). The Outdoor Recreations Act protect the public access to outlands in any season (§2), and a general right to considerate harvest of nuts, plants, berries, and mushrooms (§5). Hunting and fishing benefits are on the other hand controlled by the property owner through the Game Act (§27) (see Table 7-d for a short description of laws).

Statistics Norway's survey on sports and outdoor activities shows that the majority of the Norwegian population use the nature for recreational activities. 78 percent of the population goes for shorter trips, and 54 percent for longer trips in the mountains or in the forest annually. Almost half of the population answered that they had had more than 25 hikes over the last year. Fishing trips (37 percent), shorter skiing trips (33 percent), and berry- or mushroom picking (30 percent) are also quite common

10 Private properties consist of categories: individual owners, private owners except individual owners, and properties of persons deceased. Public properties consist of categories: state and local government. Other/unknown consist of categories: other/unknown and common forest not owned by central government.

activities. 6 percent had participated on hunting activities in 2020 (see Figure 2.n) (Statistics Norway, 2020).

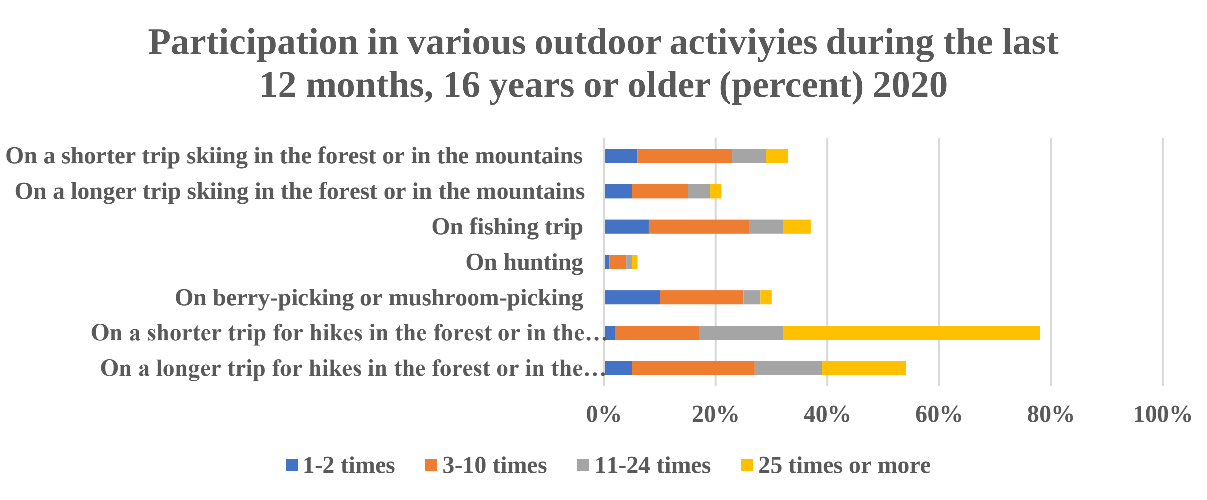


Figure 2.n: Publics participation in outdoor activities during the last 12 months

Statistics Norway. (2021). ***Table 09116: Outdoor activities during the last 12 months, by number of times, sex and age (per cent) 2011 - 2020*****. Retrieved 21.07.21 at** **https://www.ssb.no/en/statbank/table/09116/**

Illustration of Statistics Norway's survey on sports and outdoor activities among adults (16 years or older). For each category of purpose (vertical axis), the population was asked whether they had used the open access over the last 12 months. They could answer 1-2 times (blue), 3-10 times (orange), 11-24 times (grey), 25 times or more (yellow), or 0 times (not displayed). All categories, except "0 times", are accumulated in this illustration.

2.2.7 Forest habitats of special concern

About 40 percent of species that are listed as critically endangered (CR) or endangered (EN) by the Norwegian Biodiversity Information Centre (sine anno), are listed as forest species. As a result of ongoing and expected climate changes, forests may expand into northern and mountain areas. This could threaten certain species and habitats (OECD, 2011).

Valuable habitats are registered and mapped in forest management plans (Fjellstad & Skrøppa, 2020), which is legally binding through the Forestry Act §5 and given specific criterions in Regulations relating to grants for forestry planning with environmental registrations, §6. In practice, Regulations relating to sustainable forestry, §§5 and 6 implements the PEFC criteria's 21-27 as legal standards for commercial forestry's (see **Error! Reference source not found.** for a short description of law and regulations).

As a tool for mapping and measuring biodiversity in Norwegian nature, Norwegian institute for nature research11 (NINA) prepared the Nature index 2020 on behalf of the Norwegian Ministry of Climate and Environment (Jakobsson & Pedersen, 2020). The state of biodiversity for 1990, 2000, 2010, 2014 and 2019 are presented in Figure 2.o. Values on a scale from 0 to 1, where 1 refers to a hypothetical intact condition for each nature type and involve 260 indicators in total.

11 Norwegian name: Norsk institutt for naturforskning (NINA)

Forests (woodland) and open lowlands get considerably lower scores than other categories, even if forests slightly improve in from 2010 (Jakobsson & Pedersen, 2020). The amount of deadwood from broadleaf in succession phase have dropped, and thus contributed to decreased biodiversity index in the forests. Values for small rodents and birds in general also decrease (Jakobsson & Pedersen, 2020).

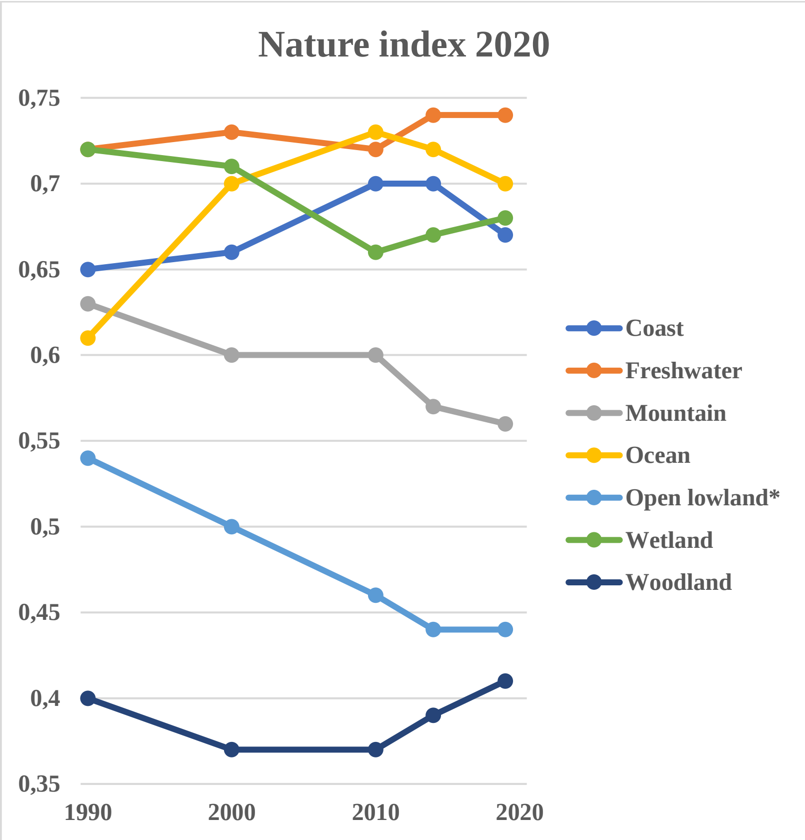


Figure 2.o: Nature index for Norway for 1990, 2000, 2010, 2014, and 2019, with overall score for all seven ecosystem categories12

Norwegian Environment Agency. (sine anno). ***Nature index for Norway*****. Retrieved 01.07.21 from https://www.naturindeks.no/**

As Figure 2.p indicates, the prevalence of biological important life environments within productive forests is generally very low for all registered measures. Although dead, lying wood is recorded in 17 per cent of the deaths. Since we know that these deposits are typically produced in natural forests, where trees can live for hundreds of years, with natural succession and exchange, it is not surprising to find that this development has been rather flat since the first census of 2008-2012.

By taking a closer look at the statistics, we see that all regions score roughly equal to the overall indicators, while the areas surrounding Oslo13 consistently scores half of the national average (Statistics Norway, 2021).

12 Open lowland is referred to as “Open land below the treeline with natural or seminatural vegetation”.

13 Oslo is the capitol of Norway, located in Eastern Norway.

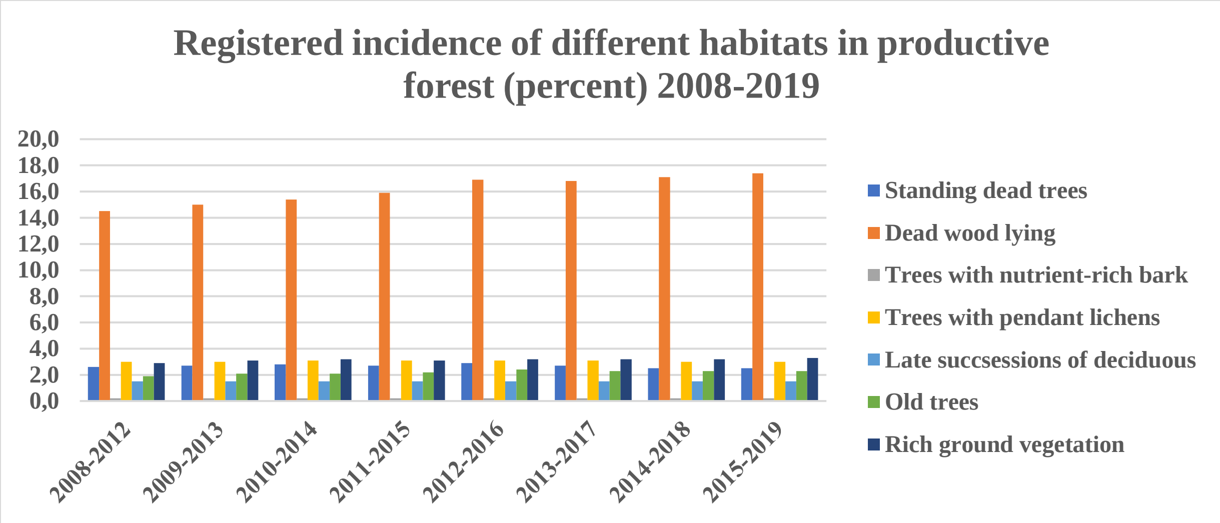


Figure 2.p): Registered incidences of different habitats in productive forests

Statistics Norway. (2021). ***Table 10605: Registered incidence of different habitats in productive forest, by region (per cent) 2008-2012 - 2015-2019*****. Retrieved 12.07.21 at** https://www.ssb.no/en/statbank/table/10605

As seen in Table 2-b, lumber from productive forests can be PEFC certified at harvest after 40-95 years (PEFC, 2016). It is typically recommended to cut Norwegian forests after a rotation period of 60-120 years. In reality, the forest is clear-cut both later and a couple of decades earlier (Stokland, 2021).

In 2016, the Storting14 adopted a target of 10 percent protection each for privately owned properties through a voluntary protection scheme, and public forests (Meld. St. 14 (2015-2016), Vedtak 667).

To enter into an agreement on voluntary protection, the forest owner must first offer his forest land for such purposes. Based on the environmental qualities of the forest, the authorities negotiate with the forest owner to determine the size of the compensation. In 2020 4,420 km2 of coniferous forest, and 510 km2 of broad-leaved forest entered such voluntary protection (Fjellstad & Skrøppa, 2020, p. 39-40).

Five percent of the total forest area are either preserved as national parks or nature reserves (see **ERROR! REFERENCE SOURCE NOT FOUND.** for short description of types of protection (Fjellstad & Skrøppa, 2020, p.38-39). In 2021, Regjeringa.no (2021) wrote that 5.1 percent of all forest, and 3.8 percent of all productive forests, are now protected areas.

2.2.8 Native and non-native tree species

Of alien species, Sitka spruce is the far most widespread in Norway. Alien tree species occur almost exclusively in productive forests, but still make up as little as one percent of the total timber volume (Øyen, 2009 according to Tomter & Dalen, 2018). Sitka spruce (Picea sitchensis) and Lutz spruce (Picea x lutzii) were planted in Western and Northern Norway after the second World War. Today the planting of these species of spruce is controversial, as the natural rejuvenation of native species is displaced (Fjellstad & Skrøppa, 2020).

14 In Norwegian: Stortinget. Stortinget is the supreme legislature of Norway

Simulations showed that Sitka spruce (Picea sitchensis) had a total carbon uptake that was 108 percent higher than Norway spruce (Picea abies) in Northern Norway. In Western Norway, the corresponding measurements were 50 percent (Andreassen, 2019). As lumber for outdoor applications, one can assume that the Sitka spruce has identical durability as other spruce varieties (Gobakken et al., 2014).

The Swedish authorities recommended in 2020 to ensure a greater diversity of trees, and to avoid densely planted monocultures, especially with the fast-growing Sitka spruce, to prevent windfalls, fungi and insect eruptions (Bartlett, 2020). According to the Regulations relating to the release of alien species for forestry purposes, §6 (see **ERROR! REFERENCE SOURCE NOT FOUND.**), planting of non-native tree species requires a permit from the municipality.

Heather moorlands[15], a semi-natural nature type which is listed as endangered (EN) (Norwegian Biodiversity Information Centre, sine anno), are challenged by afforestation and invasive native and alien species (Jakobsson & Pedersen, 2020). This nature type is found on the west coast, and kept in place by traditional farming, grazing, and heather burning until the middle of the 20th century. Sitka spruce was planted here around the same time and is currently considered as a threat to the heather moorland (Hovstad et al., 2018).

2.2.9 Land use and land use changes in the Norwegian context

38 percent of the Norwegian ice-free mainland[16] are categorized as forest, which sums to 121 000km^2. Cropland cover as little as 3.5 percent of the Norwegian mainland (Statistics Norway, 2021) (see Figure 2.q), compared to a global average of 12 percent (IPCC, 2019). Forests have slightly increased its area by 0.08 percent of total area in the period 2011-2021. The net land use change has been modest since 2011. All categories except bare rock, gravel and blockfields have had net gains, while open firm ground has had almost all net losses over the last decade (see Figure 2.r) (Statistics Norway, 2021).

15 In Norwegian: Kystlynghei.

16 Areas permanently covered with snow and glaciers (0.8 percent) are excluded.

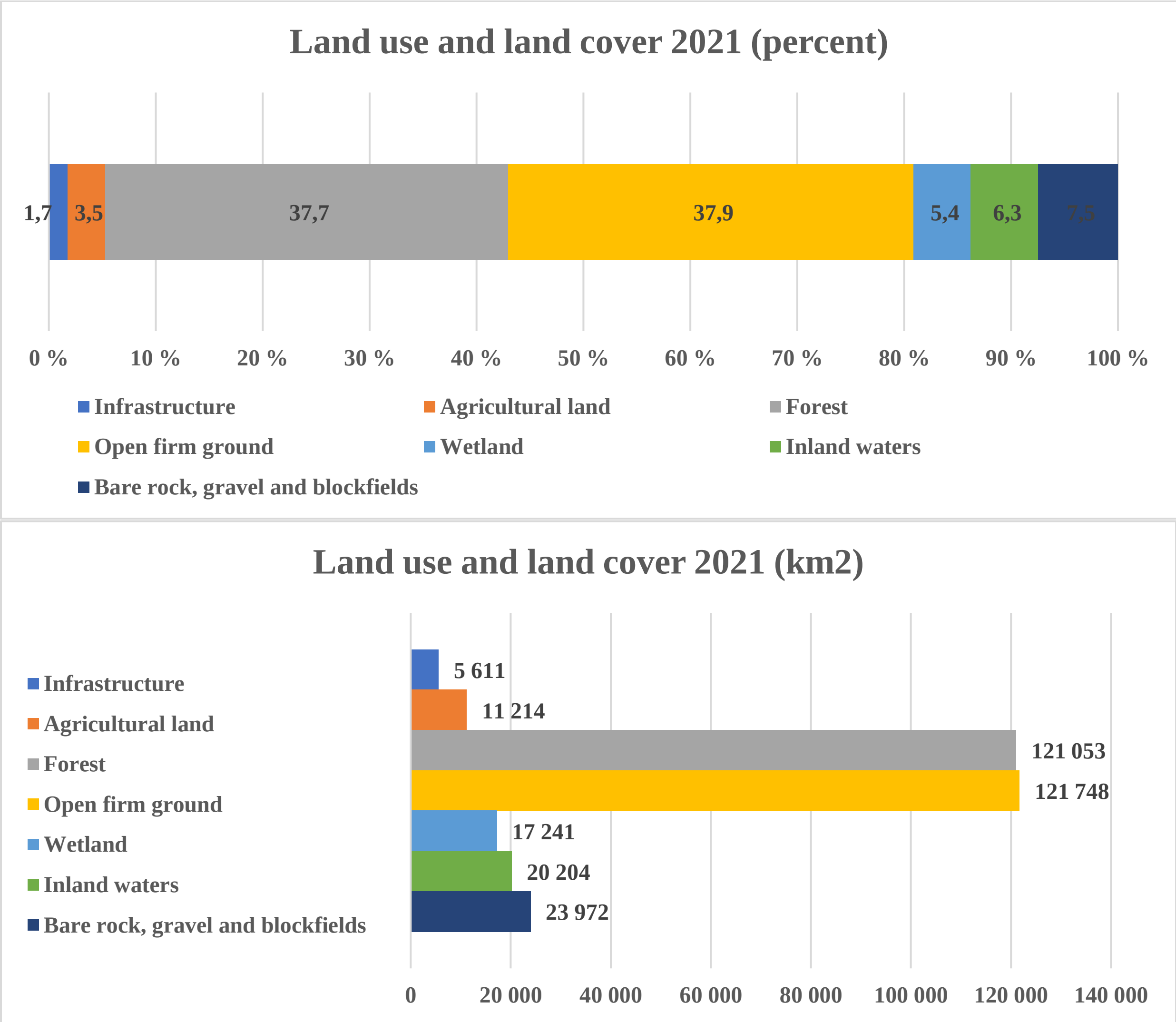


Figure 2.q: Land us and land cover (2021)

Statistics Norway. (2021). *Table 09594: Classes of land use and land cover (km²) (M) (UD) 2011 - 2021*. Retrieved 21.07.21 at https://www.ssb.no/en/statbank/table/09594/

Illustration of land use in Norway as proportions of total ice-free terrestrial area.

Top panel: land use categories a proportion of total land in2021.

Bottom panel: land use categories in square kilometers in 2021.

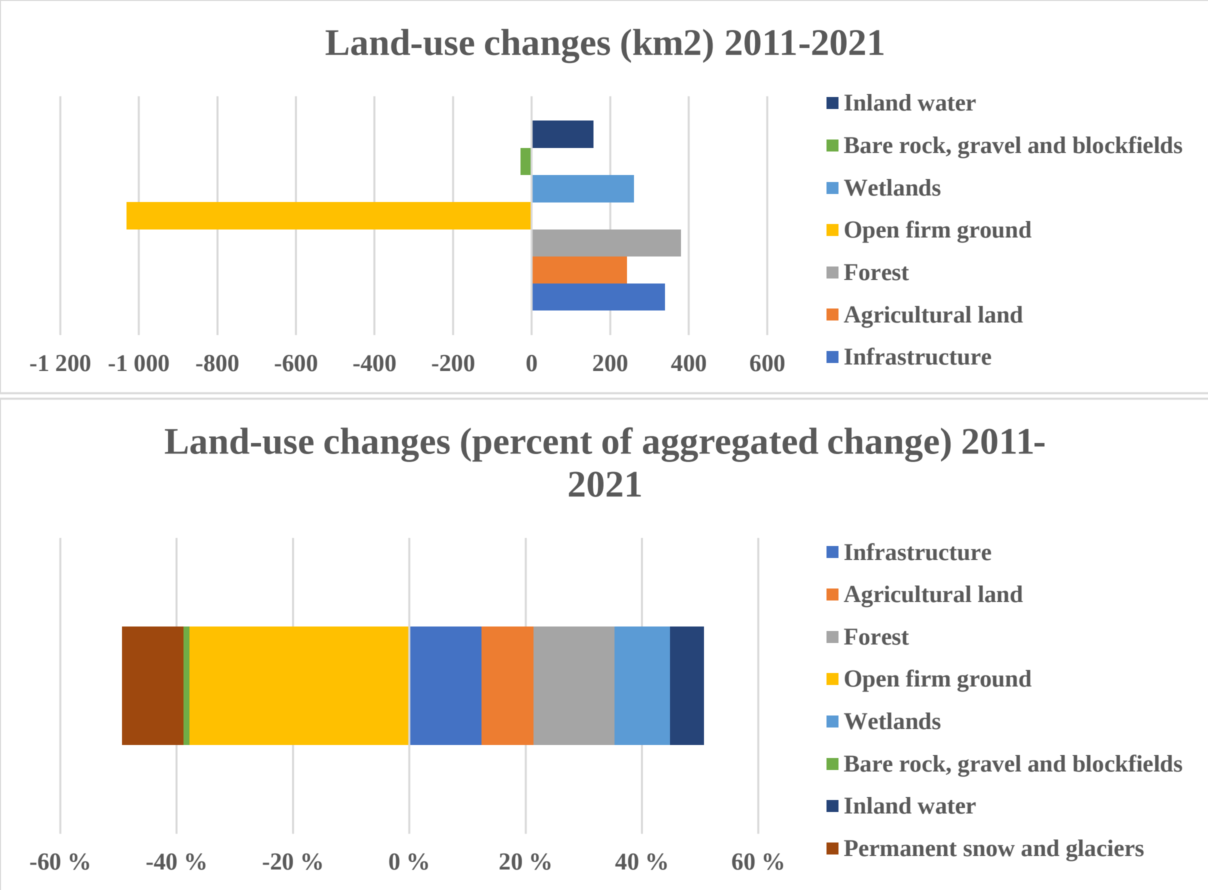


Figure 2.r: Land-use changes (2011-2021)

Statistics Norway. (2021). *Table 09594: Classes of land use and land cover (km²) (M) (UD) 2011 - 2021*. Retrieved 21.07.21 at https://www.ssb.no/en/statbank/table/09594/

Illustration of land use changes in the period 2011-2021 in Norway, as proportions of total ice-free terrestrial area.

Top panel: Categories of land-use changes over the period 2011-2021, expressed in square kilometers.

Bottom panel: Categories of lands proportion of the changes in the period 2011-2021.

In the period 2008-2019, based on a statistical sample, degraded land was estimated to 540 km2, in Norway. 40 percent is linked to residential construction. This originated from forest (42 percent), agricultural land (17 percent), and wetlands (2 percent), which are all associated with negative climate impacts. Construction of residents and cottages accounted for most of the degradation (Rørholt & Steinnes, 2020).

Figure 2.s is based on predictions provided by Søgaard et al. (2019b). The categories differentiate slightly from what Statistics Norway and IPCC had used for their land-use estimations. Nevertheless, the main picture appears clearly. The establishment of new infrastructure will dominate the land-use changes in Norway throughout this century. Interestingly, agricultural areas and pastureland is also predicted to increase its acres in this period, on the expense of all other land use categories.

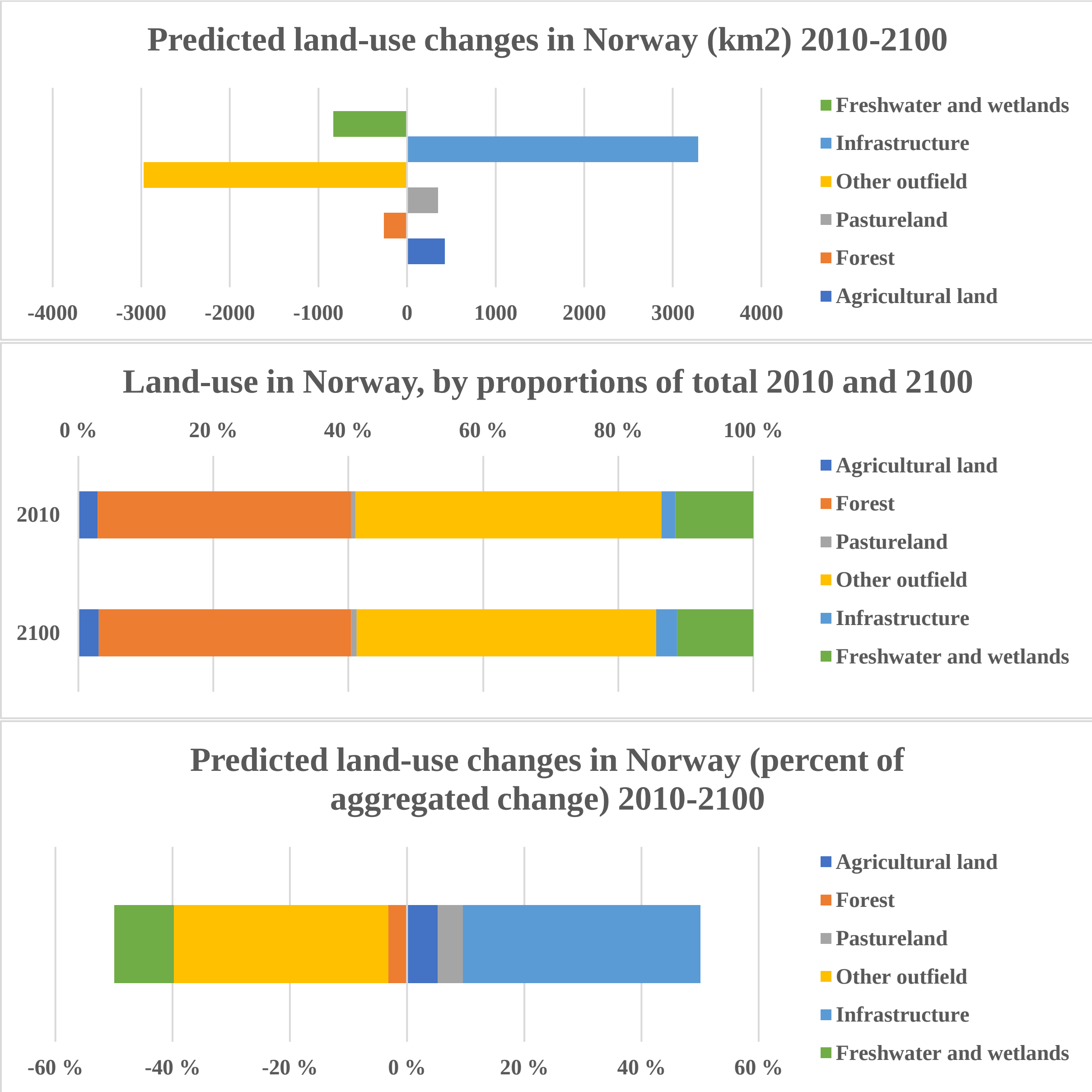


Figure 2.s: Predicted land-use changes in Norway (2010-2100)

Søgaard, G., Mohr, C. W., Antón-Fernández, C., Alfredsen, G., Astrup, R. A., Breidenbach, J., Eriksen, R., Granhus, A. & Smith, A. (2019b). *Framskrivninger for arealbrukssektoren – under FNs klimakonvensjon, Kyotoprotokollen og EUs rammeverk*. In *NIBIO Rapport*. NIBIO. Retrieved 02.08.21 at https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2633736

Top panel: Shows the predicted land-use changes in the period 2010-2100, in square kilometers, sorted by categories.

Middle panel: Land-use categories in 2010 based on statistics, and 2100 based on predictions, presented as proportions of total terrestrial land.

Bottom panel: Predicted land-use changes in the period 2010-2100, by categories, presented as proportions of total change.

In the 2021 National Inventory Report, Norwegian net emissions from the LULUCF sector accounts for -19.6, -21.0, and -24.3 million tonnes CO_2-ekvivalents in respectively 2000, 2005 and 2010, compared to -18.6 million tonnes CO_2-ekvivalents in 2019 (based on estimates from Statistics Norway/Norwegian Environment Agency/Norwegian Institute of Bioeconomy Research) (Norwegian Environment Agency, 2021)

2.2.10 Carbon catch and storage in the forest

Norway reported to the UN that total emissions for 2019 summed to 50.3 million tonnes of CO_2-equivalents (Norwegian Environment Agency, 2021). The LULUCF sector removed 18.6 million tonnes CO_2-equivalents, which are not officially accountable according to the Kyoto Protocol. Average annual removal from this sector was estimated to 19.1 million tonnes CO in the period 1990-2019. Most of these removals' origins from forests (Norwegian Environment Agency, 2021)

Afforestation/reforestation, deforestation, and forest management accounted for net removals of more than 20 million tonnes CO_2-equivalents in 2019 (Norwegian Environment Agency, 2021). In addition, net input to the harvested wood products (HWP) pool removed almost half a million tonnes CO_2 (Norwegian Environment Agency, 2021). On average removals due to forest management (Reported as B1, Forest Management to UNFCCC) counteracts 37 percent of emissions to air in the period 2013-2020 (Due to Statistics Norway's accounting) (see Figure 2.t) (Statistics Norway 2021; United Nations Framework on Climate Change, 2021).

Subsidies for regeneration and monitoring that forest owners' replants according to Forestry Acts time schedule (see Forestry Acts §6 in Table A.2.1.a), have been important for the authorities' climate policy in the forestry sector (Fjellstad & Skrøppa, 2020).

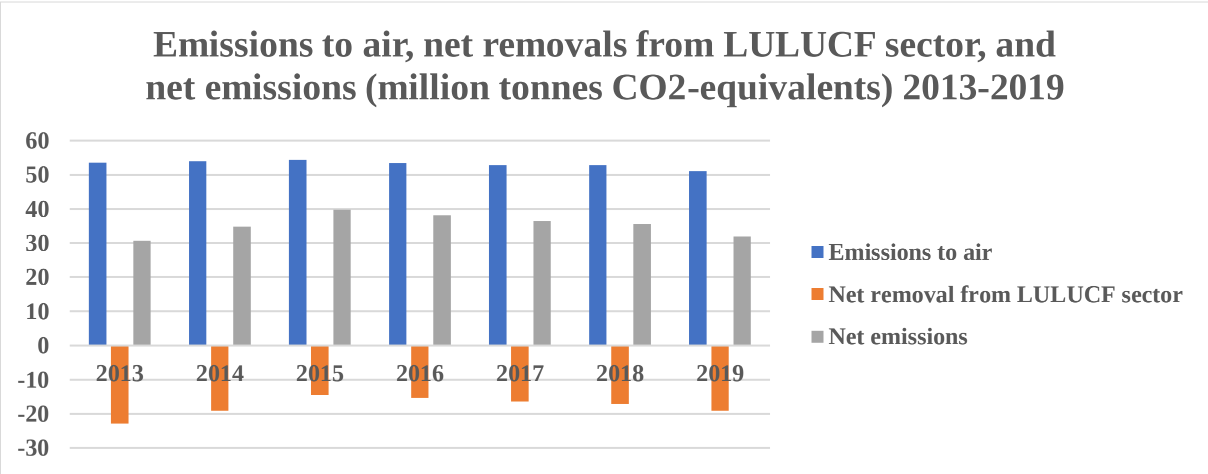


Figure 2.t: Emissions to air, LULUCF-removals, and net emission (2013-2019)

Statistics Norway. (2021). Table *08940: Greenhouse gases, by source, energy product and pollutant 1990 - 2020.* Retrieved 21.07.21 at https://www.ssb.no/en/statbank/table/08940

Removals due to forest management (B1): United Nations Framework Convention on Climate Change. (2021). Norway. 2021 Common Reporting Format (CRF) Table. Retrieved 31.07.21 at https://unfccc.int/documents/273426

Illustration of forest managements unaccounted impact on net carbon emissions in Norway in the period 2013-2019. Emissions to air, due to Statistics Norway's accounting (blue columns) and removals from LULUCF sector according to Norway's official 2021 report to the UNFCCC (red columns) are merged to net emissions (grey columns).

Carbon sequestration from forests does not only occur through growing biomass. Several other pools contribute as well. Figure 2.u illustrates how different pools contribute to the carbon removal from forest sector. The 2021 National Inventory Report for 2019 stated provided the following figures for the various carbon pools for 2019: organic soil (671 kt CO_2), mineral soil (-174 kt CO_2), living biomass (-17,784 kt CO_2), dead wood (-919 kt CO_2), litter (-4,546 kt CO_2) (Norwegian Environment Agency, 2021).

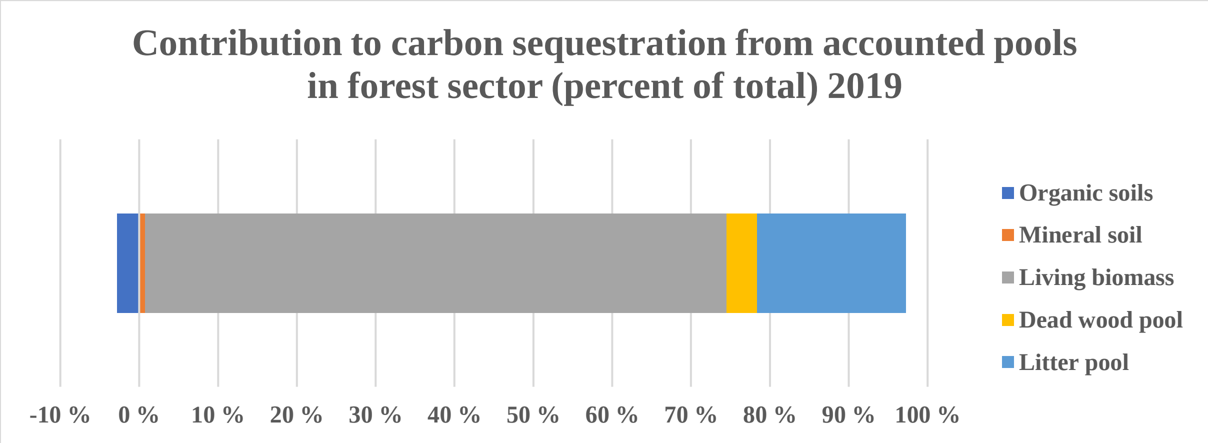


Figure 2.u: Percentage contributions to carbon sequestration, by carbon pools (2019)

Norwegian Environment Agency. (2021). Greenhouse Gas Emissions 1990-2019 – National Inventory Report. Retrieved 01.08.21 at https://unfccc.int/documents/273425

Illustration of contributions from different carbon pools in Norwegian forestry 2019. Organic soil contributes with positive emissions (-3%), while all other pools contribute with negative emissions – mineral soil (1%), living biomass (78%), dead wood (4%), litter (20%).

2.2.11 OECDs review of Norwegian performance

As an EEA member, Norway have effectively implemented the EU climate and environmental policy. The air and water quality are relatively good, and the number of threatened species are relatively low. Norway is described as a leader in climate and marine and chemicals cooperation. It is recommended that Norway agree upon ambitious climate targets and implement cost-effective policy to get there. Increased protection of areas, sustainable aquaculture and removing environmentally harming subsidies are other concerns (OECD, 2011)

3 Theory

This chapter assess three models/frameworks: the Faustmann's equation, the production possibility frontier, and the von Thünen model.

This chapter describes and utilize Faustmann's basic model for optimal rotation lengths in forestry, which internalizes non-timber values in accordance with Perman et al. (2011).

3.1 Optimal rotation theory

3.1.1 The benefits of the forest

In Table 3-a ecosystem services that are beneficial to us was presented. When analyzing optimal forestry from a societal perspective, it is useful to sort the benefits by internal and external values, as this also provides some indications for policy.

The basic assumption is that the forester intends to optimize the internal benefits, which accrues him/herself. Externalities, on the other hand, should be internalized by the forest owner. To make sure the forester accounts for external values, he/she must be exposed to economic incentives or direct regulations.

In Table 3-a I have listed the most important benefits from forests. As the scope of this work is limited, I will only analyze three out of those (timber, carbon sequestration in growing biomass, and biodiversity). Other benefits listed in Table 3-a are essential and will therefore be subject to discussion in other sections.

Table 3-a: Benefits of the forest

Internal benefits	**External benefits**		
Private benefits	**Climate benefits**	**Environmental benefits**	**Other benefits**
Timber	**Carbon sequestration in growing biomass**	**Biodiversity**	Drinking water, berries, mushrooms, and other food
Firewood and input for biofuel	Carbon storage in soil	Clean air, clean water	Habitats for humans
Hunting benefits	Carbon storage in forest products - HWP	Pollination	Recreational facilities
		Ecosystem resilience	Aesthetic amenities

3.1.2 The assessed data

The assessed data is based on a plot of unknown origin, size of acres, and forest type, provided by Perman et al. (2011) as a supplement to their textbook: Natural Resource and Environmental Economics. The data have been modified with simple means to make the proportions of the growth figures resemble with what I expect from conventional even-aged single stand of Norwegian spruce forest.

Carbon sequestration is assumed to be 0.2 t CO_2/m3 of the total volume increment that is assumed to be twice as large as timber volume increment (including bark and residues), in accordance with Hoel et al., (2014). The carbon price assessed corresponds to the EU ETS carbon price from 05.08.21 (55.98 €/t CO_2), according to Ember (https://ember-climate.org/data/carbon-price-viewer/).

As the price on biodiversity are unknown (as discussed in section 1.5), the assessed growth function and price rests solely on a fictious function based on my own intuition and a pragmatic approach to the programming behind the numbers. As I have stated earlier, it is better to put some value to biodiversity, than to leave it unpriced and over-exploited. Even if the numbers are highly speculative, this could at least serve as a base for discussions.

The growth curve of the biomass, measured in cubic meters ($B(t)$) per area of unit of this sample are illustrated in **Error! Reference source not found.**. We are looking at an even-aged stand, which I use as a base throughout all analysis related to optimal rotation of forestry.

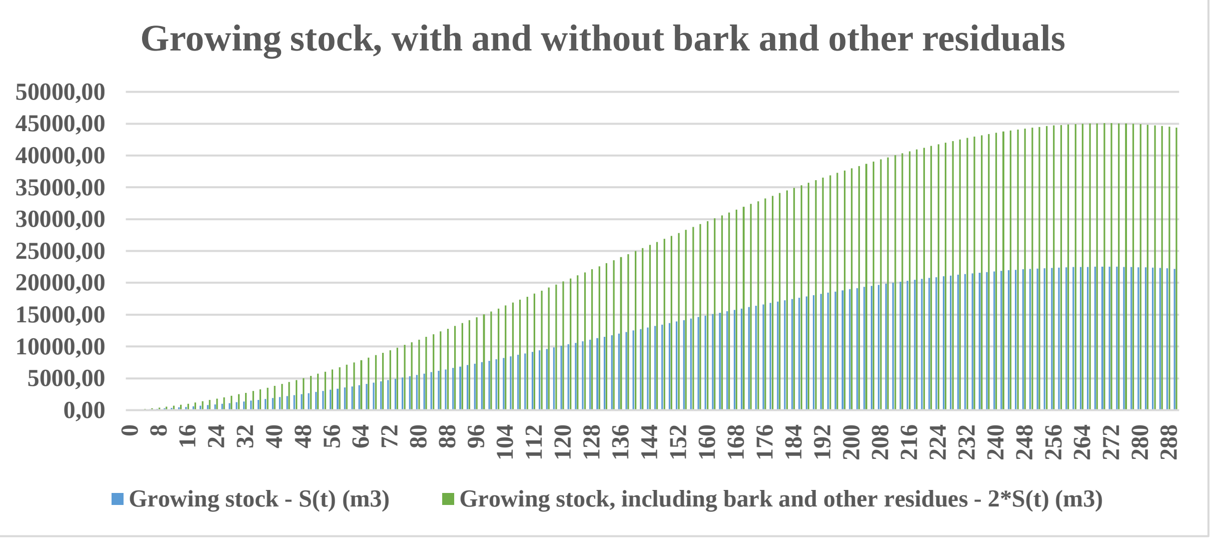


Figure 3.a: Example of a single stand growing stock over a rotation period of 290 years

Perman, R., Ma, Y., Common, D., Maddison & McGilvrey, J. (sine anno). Additional materials: 4th edition. Natural Resource and Environmental Economics. Chapter 18: Forest Resources. http://personal.strath.ac.uk/r.perman/mats18.htm

Illustration of growing stock in a rotation period of 288 years, based on Perman et al. (sine anno), and modified as described above. In this context, it is assumed that the initial data: Growing stock – S(t) (m3) is excluded bark and residues which is often left on ground after harvest. It is also assumed that can be extracted as timber will only include half of the total biomass. Therefore, an additional growth function: Growing stock, including bark and other residues – 2*S(t) (m3), twice as large as the initial function are included to supplement the picture.

3.1.3 Private optimal rotation

Maximizing forest owners' private profit alone, can be quite complicated. Understanding when to harvest, and how to calculate expected net present value of the investments made over the cycle, rests on knowledge across different fields of science.

A rotation period, the time span from planting till harvest, can in Boreal forests, most common in Norway, be 40-150 years. In such long time spans many parameters essential for investment decisions are unknown and potentially unstable. The demand for property and land-use might change dramatically. Future interest rates, timber prices, and forest policy (local, domestic, and international) are very uncertain. On top of that, the financial planning naturally involves next generation, and thus distribution of wealth. The forest owner planting a tree will in many cases be departed when that very same tree is harvested.

3.1.4 Single rotation model

A forest provides many vital benefits which is external to any private owner of the site. Costs like planting, thinning, harvesting, maintenance and construction of forest roads and other operating costs, on the other hand, are primarily allocated to the forest owner alone. In the initial model we will include planting costs (k). The rest of the costs are represented as marginal harvesting costs (c). One can consider this as an aggregate value of all forest managing costs. In practice, represents a fixed proportion of the gross income (P) of harvest. The net income will therefore be $p = P - c$. Timber available at the optimal harvest time (T unlike t) is denoted S_T. The discount rate is given by i. The foresters discounted net profit (π) can thus be presented as:

$$(P - c)S_T e^{-iT} - k = pS_T e^{-iT} - k \quad [1.1]$$

By solving for the i, we can express the relation between the discount rate (i), and the biomasses proportionate rate of growth ($\frac{\dot{S(t)}}{S(t)}$) in time:

$$i = \frac{\frac{dS}{dT}}{S_T} = \frac{\dot{S(t)}}{S(t)} \quad [1.2]$$

This growth rate relation is of particular interest to a forest owner who would like to maximize his/hers profit. If values grow faster in the financial market, it would be more profitable to harvest, exchange the timber values into money, and let these grow further in the financial markets.

I let the discount rate be $i = 0.03$, which is rather low in other markets, but quite common to assess long term decision problems, like in forestry17. An alternative rate of 0.05 is also presented. In **Error! Reference source not found.**, the biomasses proportionate growth rate ($\frac{\dot{S(t)}}{S(t)}$) crosses the alternative discount rate after 60 years, and the lower discount rate after 100 years. So, lesson learned from this, is that lower discount rates incentivize longer rotation periods, i.e., postponed harvest.

17 An interest rate of 3% corresponds to the expected returns of the Norwegian sovereign fund and to the risk adjusted rate of return requirements for projects with a life span of 40-75 years (Det kongelige finansdepartement, 2021) based on a 2016 NOU.

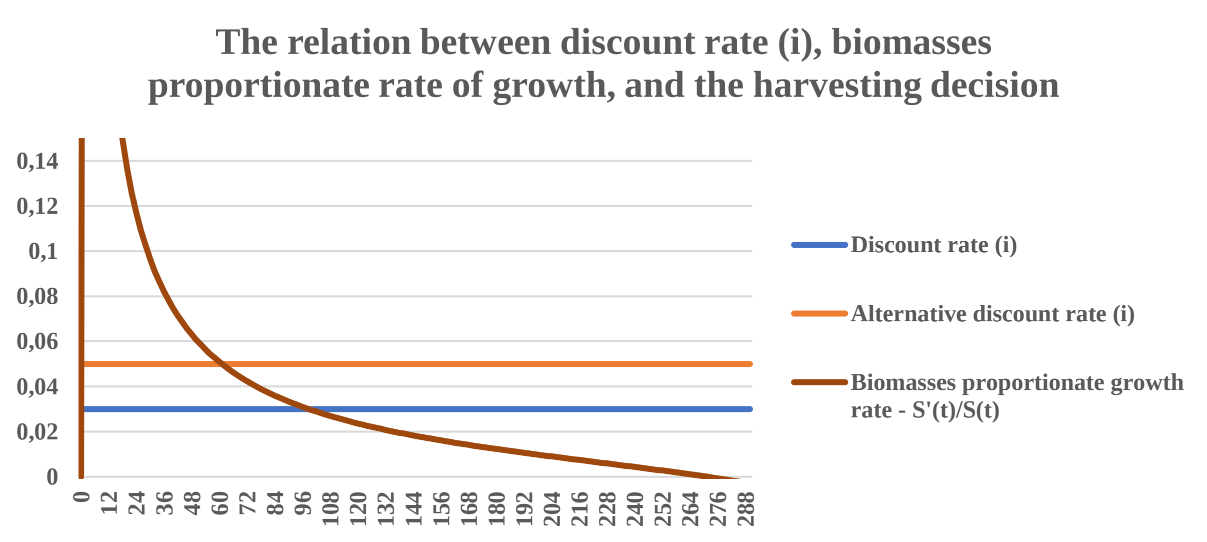


Figure 3.b: The relationship between discount rate, biomasses proportionate growth, and harvesting the decision

Illustration of the relationship between the preferred discount rate, the proportionate growth rate of the biomass stock, and optimal time optimal harvest (in a single rotation perspective). Where the proportionate growth rate crosses the foresters discount rate, it is time to clear-cut this even-age stand.

3.1.5 Infinite-rotation model

So far, we have looked at a single rotation model, where the next rotation period is not considered. From a purely rational agents' perspective, profits from upcoming rotation periods are "discounted away" in his/her model for decision-making, when the next rotation income is decades ahead. I will therefore not dwell more on Martin Faustmann's 1849 versions of a model for infinite rotation periods, which accounts for regeneration (Perman et al., 2011, p. 619):

$$\frac{p\dot{S}}{pS_T - k} = \frac{i}{1 - e^{-iT}} \quad [2.1]$$

$$p\dot{S} = ipS_T + ip\Pi \quad [2.2]$$

The profit function would then be:

$$\Pi = \frac{pS_T e^{-iT} - k}{1 - e^{-iT}} \quad [2.3]$$

When comparing the solution of a single rotation model, [1.1], we now see that the planting cost (k) plays a part in the solution to a multiple-rotation solution of [2.1], and that the opportunity cost of interest from values tied to the land site (Π) is a part of [2.2].

For the analysis in this thesis, I will impose planting costs: $k = 0$, for simplicity reasons. I expect the impact of this modification to have limited effects on the final projections.

By comparing equation with [1.2] we can see that [2.1] have two differences, except that they are inverted. The latter contains two new elements, planting cost (k) on the left-hand side, and ($\frac{1}{1-e^{-iT}}$) on the right. As the latter expression is expected to have the larger impact, we expect the infinite-rotation approach to launch shorter rotation ages. This is confirmed by the simulation showed in **Error!**

Reference source not found.. Whereas optimal harvest was allocated to 60 ($i = 0.05$) and 100 ($i = 0.03$) years, this model approach shows it is 60 ($i = 0.05$) and 98 ($i = 0.03$) years.

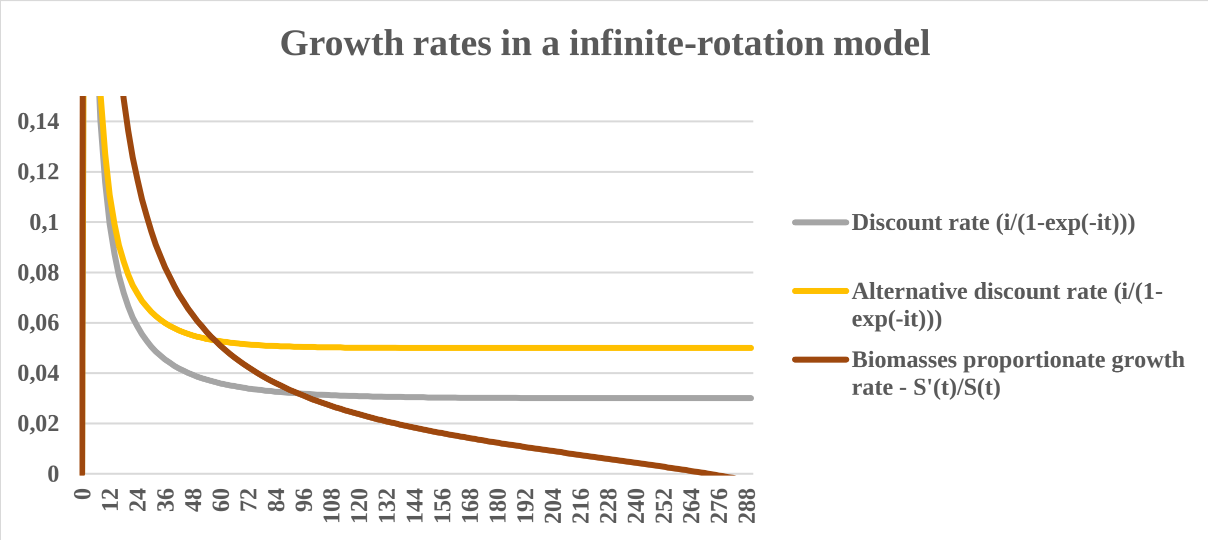


Figure 3.c: Growth rates in an infinite-rotation model

Illustration of the relation between discount rates, the proportionate growth rate of biomass, and the optimal harvest level, when imposing an infinite-rotation harvest model (see equation [2.1]) on the same plot sample as used in Error! Reference source not found.. **We now see that the rotation**

I now add a value to this biomass, by assessing the Norwegian 2020 average gross price of timber (35.17 €/m3, according to Statistics Norway (2021)). I also make the assumption that the harvesting cost accounts for 35 percent of the gross income, while net price accounts for 65 percent of it ($c = 0.35P$, $p = 0.65P$). It shows that the forest will get a discounted profit of 38,706 €, and a gross income of 59,548 €, when assuming that the forester owner has a discount rate of 3 percent, and thus harvest after 98 years. An illustration of this is presented in **Error! Reference source not found.**.

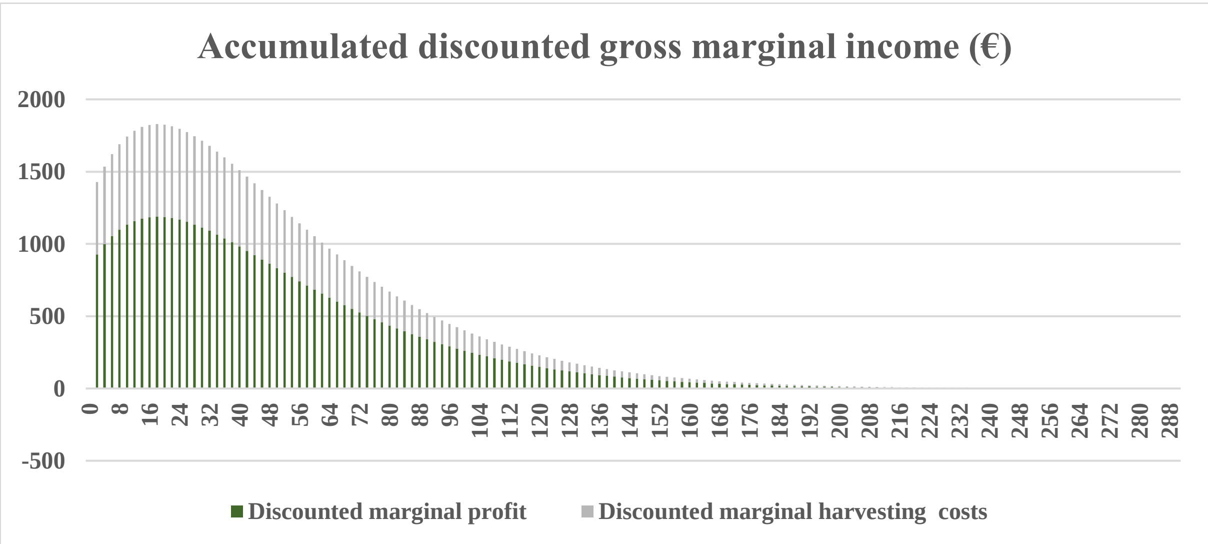


Figure 3.d: Discounted gross marginal income

Illustration of potential gross marginal income from the stand. Based on assumptions, the harvesting makes 35 percent of the discounted marginal gross income, while 65 percent is profit for the forester.

From equation [2.1] we can see that the left-hand side will not be affected by a change in net price (p) as long as planting costs are assumed to be $k = 0$. And we could deduce that, if k was positive, a decrease in the gross price p (as a result of increased harvest costs) would marginally increase the optimal rotation age.

3.1.6 Optimal rotation with respect to carbon sequestration

We would now like to include the values of carbon removal. I denote these additional benefits R_T, with the carbon price p^C, and insert it into the present value function for the first rotation:

$$PV_1 = (pS - k)e^{-iT} - k + p^C R_T \quad [3.1]$$

This leads us to the first-order condition for maximization:

$$p\frac{dS}{dT^C} + p^C R_{T^C} = ipS_{T^C} + i\Pi^C \quad [3.2]$$

Equation [3.2], can be solved for i and Π^C:

$$i = \frac{p\frac{dS}{dT^C} + p^C\frac{dR}{dT^C}}{pS_{T^C} + \Pi^C} \quad [3.3]$$

$$\Pi^C = \frac{p\frac{dS}{dT^C} + p^C\frac{dR}{dT^C}}{i} - pS_{T^C} \quad [3.4]$$

As Perman et al. (2011) points at, the single-rotation case [3.1] mislead us to think that any positive non-timber value we might put into this model, the rotation age will increase. This can represent a warning of how precise we should be when investigating this further.

In [3.2] we now introduce the socially optimal rotation age (T^C) and socially optimal profit (Π^C). A positive carbon removal value ($R_{T^C} > 0$) will, in this wealth-maximizing scenario, increase the rotation length (T^C) through $\frac{dS}{dT^*}$, and at the same time decrease the rotation length through increased site value ($\pi^* > \pi$). Which effect is dominating depends on the relationship between the timber-growth function ($S(t)$) and the carbon-removal-growth function ($R(t)$). Relatively greater impact from carbon removal in early stages of the period tend to decrease the optimal rotation age (T^C) and vice versa. If the flow from carbon removal is constant, which is very unlikely, the optimal rotation length will be unaffected.

Results, as presented in the top panel of **Error! Reference source not found.**, added external value from carbon sequestration suggest that it is socially optimal to postpone harvest until year 144. The bottom panel of **Error! Reference source not found.** shows how the added value from carbon sequestration is added on top of forest owner gross income from the forest.

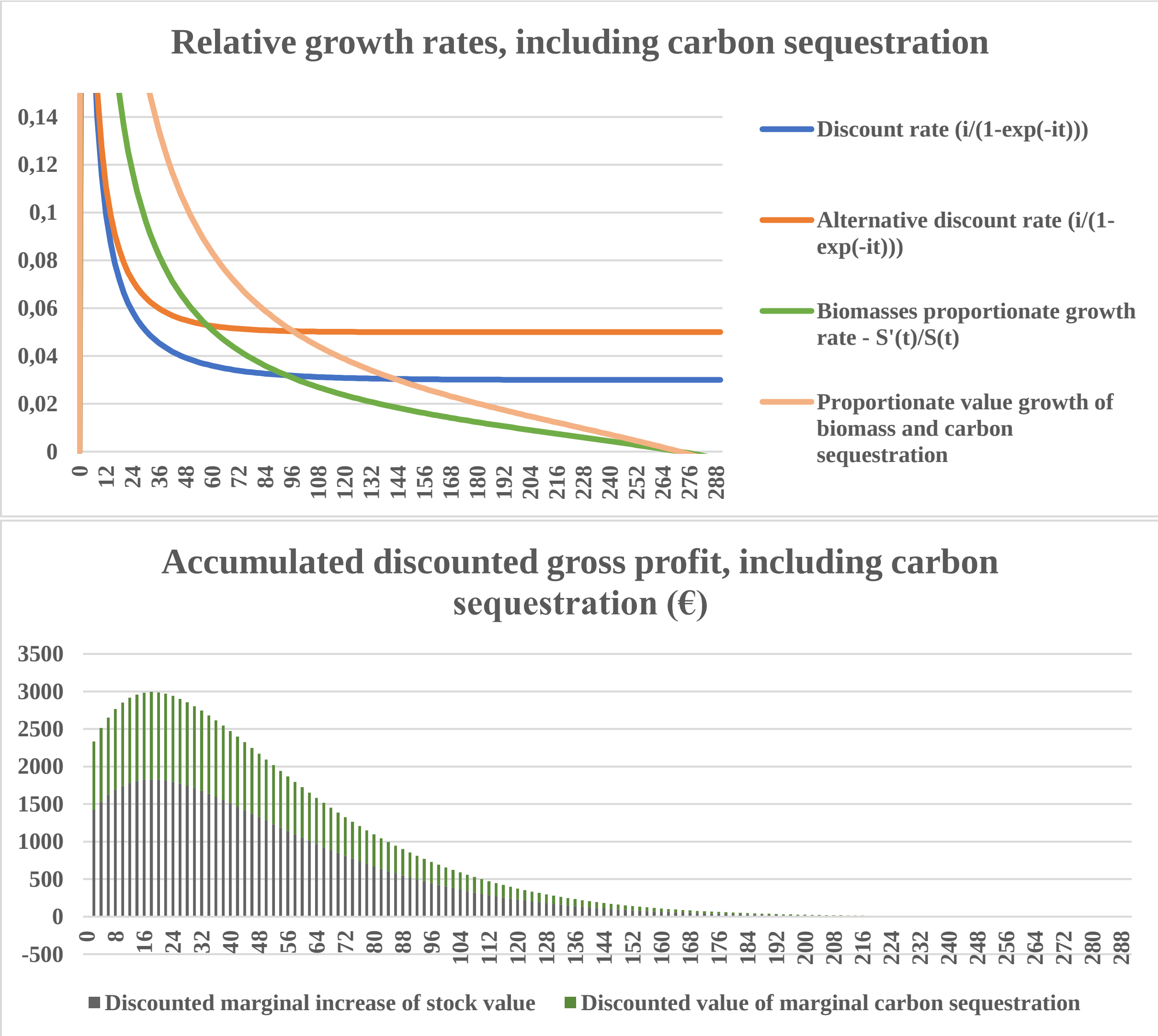


Figure 3.e: Simulation of inclusion of carbon sequestration values

Top panel: illustration of impact from internalizing values from carbon sequestration into the forest owners' preferences. The forest owner with 3 percent discount rate would initially prefer to harvest after 98 years, where the green and blue curves cross. If values from carbon sequestration was added, he/she would harvest after 144 years, where the yellow curve crosses the blue.

Bottom panel: illustration of accumulated discounted gross profit, when internalizing carbon sequestration.

If authorities would like to incentivize the forest owner to postpone harvest to this social optimum, it does not necessitate a full compensation. It suffices to compensate the forest owner such that the increased rotation age becomes more profitable. Alternatively, the authorities could tax earlier harvest than the socially optimal rotation age.

For convenience, we assume that forest owner's discount rate is equal to society's discount rate, which is 3 percent. By paying the forester for carbon sequestration values after 98 years, where it is expected that harvest would have happened, we can incentivize an extension of the rotation period, from 98 to 145 years (see **Error! Reference source not found.**).

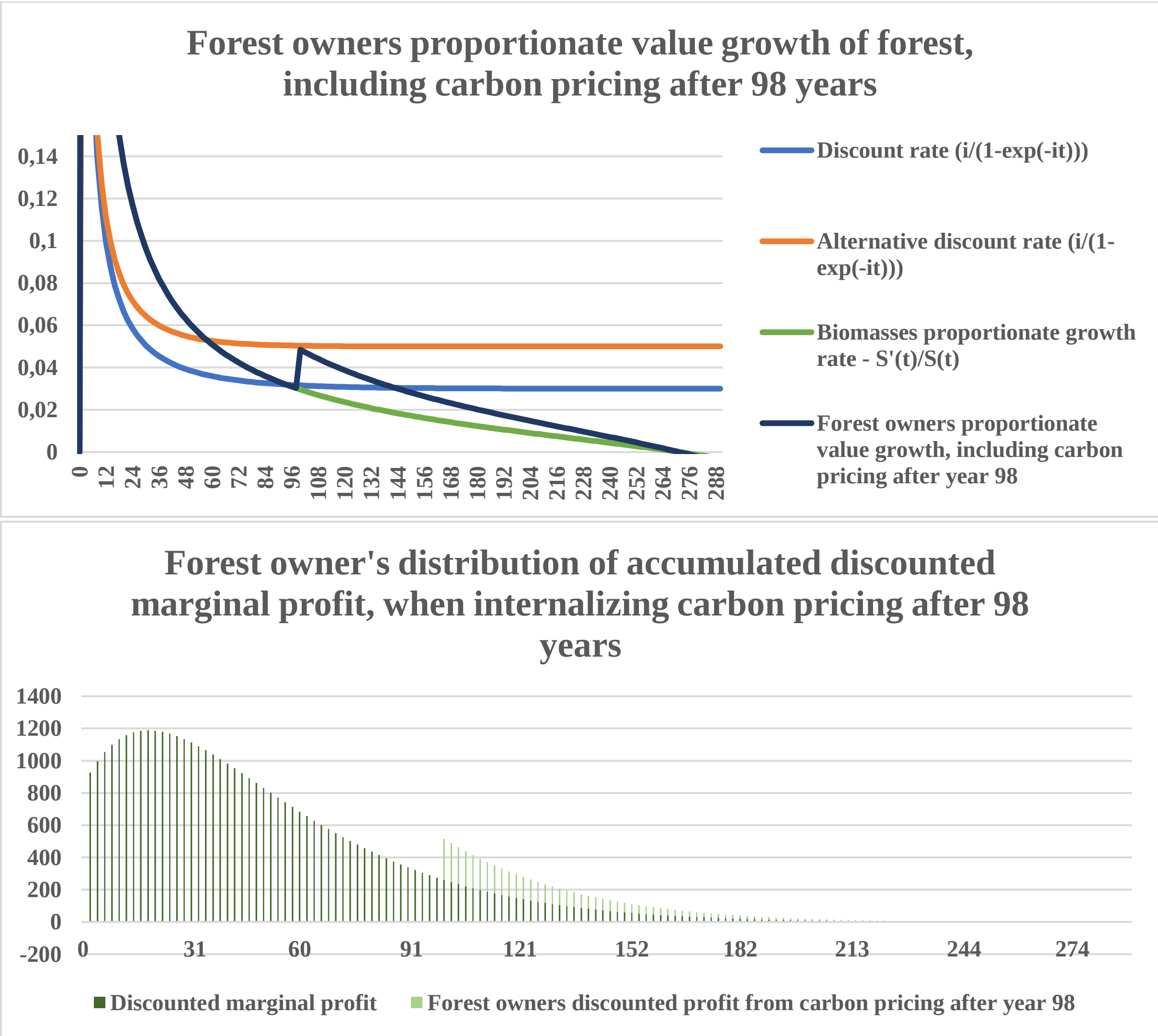


Figure 3.f: Inclusion of carbon sequestration incentives

Top panel: illustration of forest owners shifting proportionate value curve, resulting from internalized carbon pricing after year 98.

Bottom panel: illustration of forest owner distribution of net income, provided that he/she are credited the value of the carbon sequestration after 98 years

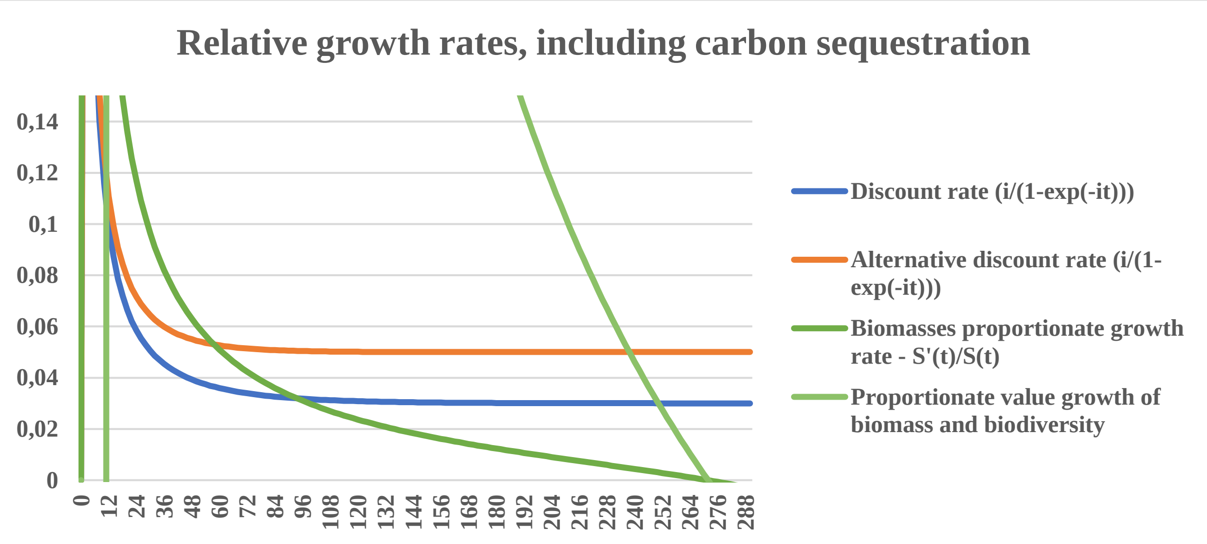
3.1.7 Optimal rotation with respect to biodiversity

I now include rather biodiversity values. The operation is exactly the same as for carbon sequestration. We simply switch $p^C R_T$ with the price of biodiversity (p^B) and the stock of biodiversity (B_{T^B}):

$$i = \frac{p\frac{dS}{dT^B} + p^B\frac{dR}{dT^B}}{pS_{T^B} + \Pi^B} \quad [4.1]$$

$$\Pi^B = \frac{p\frac{dS}{dT^B} + p^B\frac{dR}{dT^B}}{i} - pS_{T^B} \quad [4.2]$$

Simulations presented in the top panel of **Error! Reference source not found.** shows that added external value from growing biodiversity stock indicates that social optimal harvest should be executed after 250 years. The bottom panel illustrates the accumulated marginal values from forest owners' profit and stock of biodiversity. As clearcutting removes the essential habitat for biodiversity, negative values related to this have been allocated to the first period, until the tree stand is about 11 years old, in each rotation. After this, biodiversity values start increasing substantially.



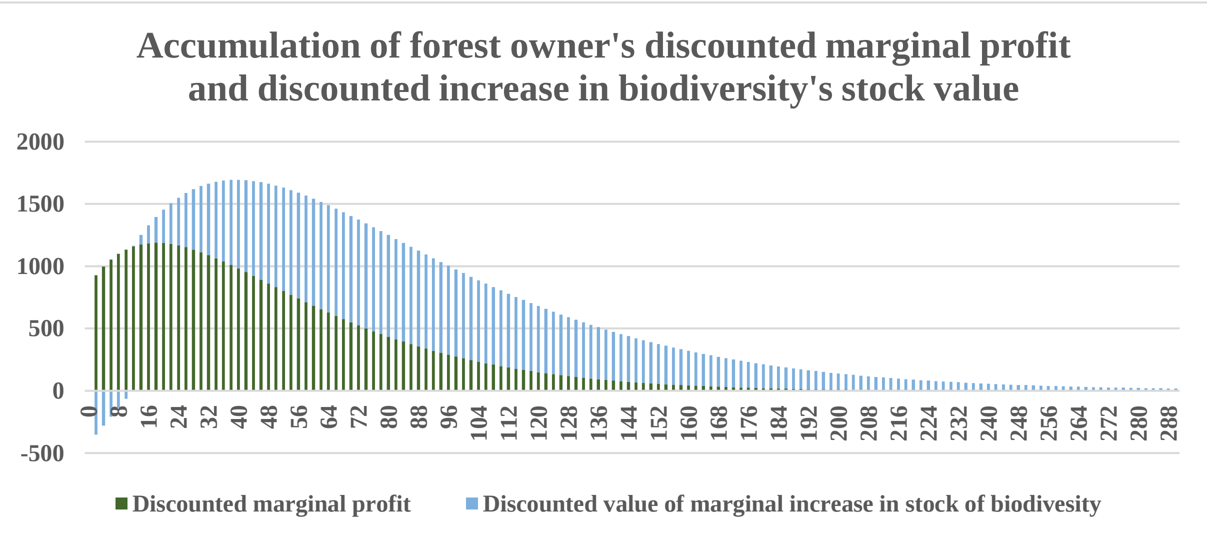


Figure 3.g: Inclusion of biodiversity values

Top panel: illustration of impact from internalizing values from the growing stock of biodiversity into the forest owners' preferences. The forest owner with 3 percent discount rate would initially prefer to harvest after 98 years, where the light green and blue curves cross. If biodiversity values were internalized, he/she would harvest after 250 years, where the dark green curve crosses the blue.

Bottom panel: illustration of accumulated discounted gross profit, when internalizing biodiversity values.

Authorities could incentivize this by paying the forester to facilitate for biodiversity from year 98 till year 250 (see **Error! Reference source not found.**, top panel). From **Error! Reference source not**

found. quickly draw the conclusion that the forest owner would need a relatively small compensation compared to the value of biodiversity to postpone harvest in accordance to the social optimum. And as in the case of carbon sequestration, taxing harvest could be an alternative measure.

The value of the stock of biodiversity could be very different from one property site to another. Differences in the quality of forests as habitat can be due in part to forest type, climatic conditions, the quality of, and distance to surrounding ecosystems. Thus, each properties biodiversity value should be considered separately, much like what the Norwegian authorities have done to proceed protection.

The authorities could also classify the quality of the properties as habitats and call for tender competitions to preserve the most valuable areas at the lowest transaction cost. Adu & Romstad (2020) have investigated these N+1 price forest biodiversity auctions in relationship to uncertain timber prices.

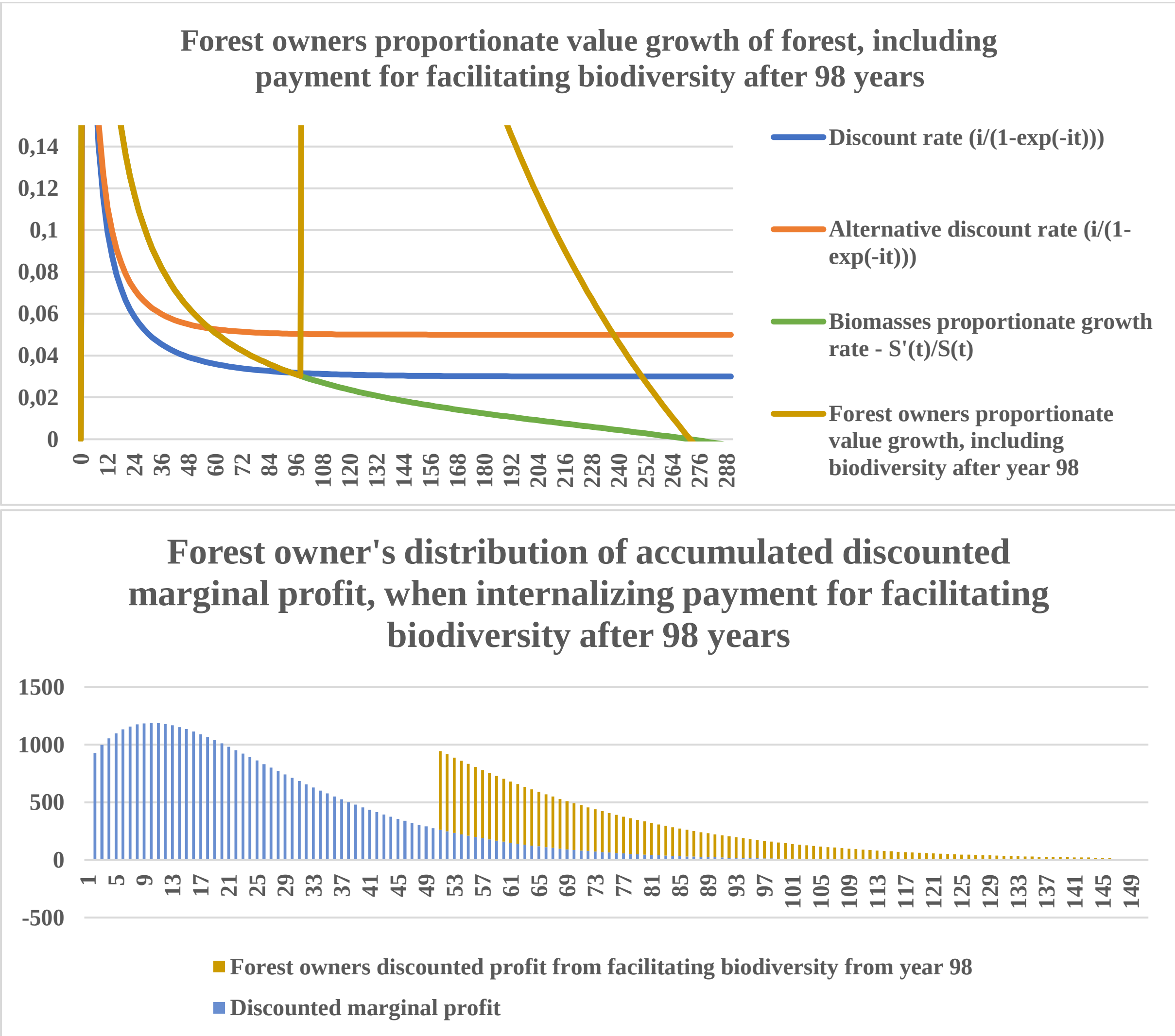
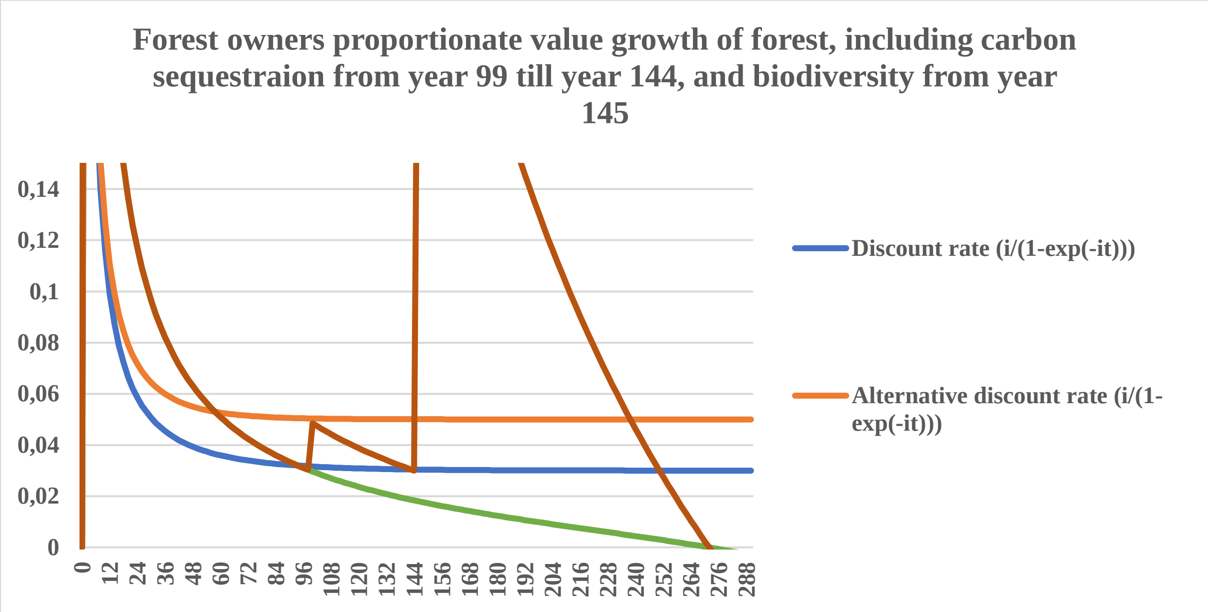


Figure 3.h: Inclusion of incentives for facilitating biodiversity

Top panel: illustration of forest owners shifting proportionate value curve, resulting from internalized biodiversity values after year 98.

Bottom panel: illustration of forest owner distribution of net income, provided that he/she are credited the value of the growing stock of biodiversity after 98 years.

Another approach could be to first incentivize carbon sequestration, then the facilitation of biodiversity. **Error! Reference source not found.** shows how this setup affect the forest owner's relative growth rates and expected income. The advantage of setting up the framework in this order is that all agents meet similar incentives in the "interim period" (year 99 till 145), and that the authorities do not have to commit to the conservation of biodiversity to areas that lose their value or turn out to be less valuable than first assumed.



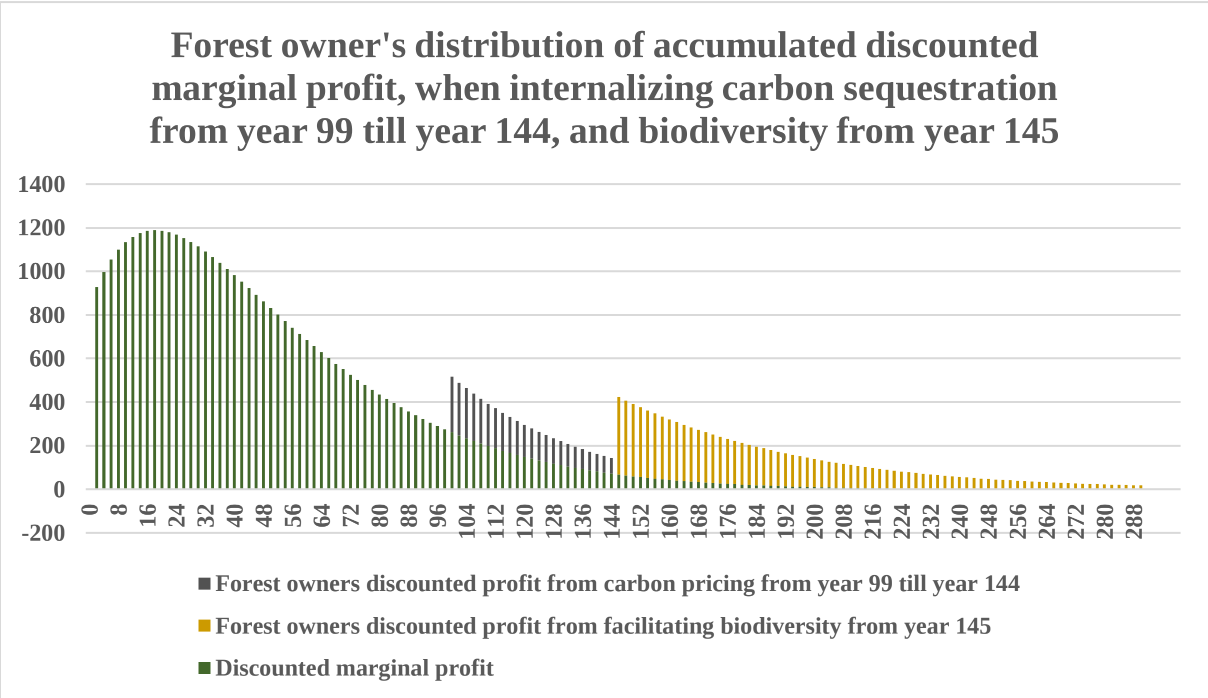


Figure 3.i: internalizing values from carbon sequestration from year 99 till 144, and biodiversity from year 145

Top panel: illustration of forest owners shifting proportionate value curve, resulting from internalized carbon sequestration values from year 99 till year 144, and biodiversity values after year 145.

Bottom panel: illustration of forest owner distribution of net income, provided that he/she are credited the value of the carbon sequestration from year 99 till 144, and the growing stock of biodiversity after 145 years.

3.2 The trade-off between biodiversity and carbon sequestration

3.2.1 The price of ecosystem services

In a normal trade situation, goods are exchanged for monetary values, given the aggregated valuation of the supply and demand chain. This is essentially two parties making trade-offs between cost and benefits associated with the traded good, evaluated on a monetary scale. I would argue that all other trade-offs have the same characteristic, except that the monetary value may not be explicitly expressed.

While many ecosystem services do not carry an explicit price tag that is recognized by global markets, ecosystems deliver invaluable economic value to us (Secretariat of the Convention on Biological Diversity, 2003; NOU 2013: 10). When certain ecosystem services are emphasized more than others, a trade-off is made, consciously or without knowledge, but with real long-term effects (Conference of the Parties to the Convention on Biological Diversity, 2018). When focusing solely on developing certain parts of nature's services, such as timber production, the entire ecosystem deteriorates (EEA, 2016).

In any situation where an agent makes a provable decision (which may also be to postpone clearcutting) the agent has made a genuine valuation of costs and benefits, although it does not necessarily involve monetary values. By nature, such prices are not observable in the market, and are often referred to as shadow prices when trying to estimate these.

If one believes that extinction of species, global warming, and extensive global deforestation is not tolerable, this is what economists call a market failure. To re-establish the balance in these integrated markets, one must try to find the shadow price associated with exploitation of forest resources and introduce genuine countermeasures.

We should highlight the real costs of lost nature, even if it does not have to be measured in monetary terms, as it is particularly relevant for cost-benefit analysis. Trade-offs between climate measures and their effects on biodiversity must be considered (NOU 2013: 10).

3.2.2 The production possibility frontier in an aggregated market

As illustrated in chapter 1 (**Error! Reference source not found.** is equal Figure 1.a), the trade-off can be illustrated by the production possibility frontier (PPF). We now consider the forest to be a production unit that can only produce two goods (carbon sequestration (CS), and biodiversity "production" (BP)). When both carbon sequestration and biodiversity are positively valued, the optimal allocation of the two goods (services) is located somewhere on the negatively sloped segment of the PPF. This corresponds to the green portion of the PPF in **Error! Reference source not found.**.

Society's relative preferences for CS and BP defines the blue curve ($U(CS, BP)'$). Considering a situation where the production is efficiently allocated, the marginal rate of transformation (MRT')18 is tied to both these curves. MRT' defines the production sides optimal trade-off ration between the two goods, the relative price of each good.

If we put a price on CS, we have implicitly put a price on BP. If we did not put a price on neither of those, there are other forest benefits with relative trade-offs that we did put a price on, like timber. No matter how much anyone insists that biodiversity is priceless, biodiversity has a relative value to other goods and services that society prizes.

Dasgupta (2021) argues that proper valuation of biodiversity is difficult due to measurement problems and the unknown impacts on human well-being if an ecosystem is degraded or collapses. Dasgupta (2021) refers to the latter as accounting prices.

Carbon sequestration and biodiversity are contingent on each other. At some point decreasing carbon sequestration (fewer trees) will necessarily also involve a decreasing stock of biodiversity. On the other hand, decreasing stock of biodiversity will also decrease the biomass production. These boundaries are illustrated by the red curves, which cannot be considered to be technically efficient, and therefore not a part of the defined PPF.

Error! Reference source not found.: Theoretically illustration of an optimal allocation of the two relevant goods.

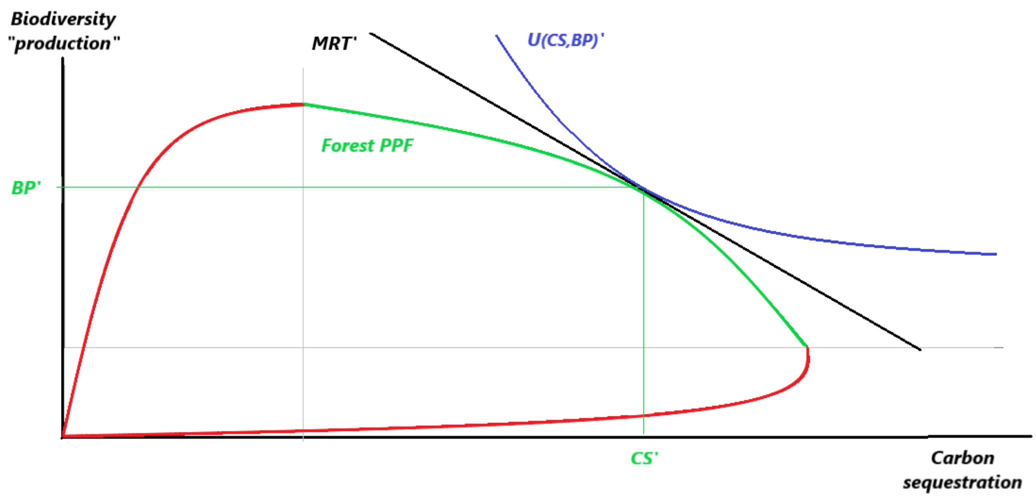


Figure 3.j: The forests production possibility curve

In a scenario with a forest production possibility curve ($Forest\ PPF$), the efficient trad-off between carbon sequestration and biodiversity "production" will be located on the green line. Given that the society's-imposed utility function is equal to $U(CS, BP)'$, the relative price when only considering those two goods, will be equal to MRT'. In this situation, society will produce CS' carbon sequestration and BP' biodiversity "production".

My main message with presenting this model, is that measures to mitigate climate through forestry, and measures to conserve biodiversity, have to be coordinated. If the anthropogenic society demand more biodiversity "production" relative to carbon sequestration, payments for carbon sequestration

18 MRT' is also equal to the society's marginal rate of utility substitution ($MRUS'$) at this point.

should be counteracted by increased payment for conservation of biodiversity, or command and control measures (CAC), in accordance shadow prices, based on the best available ecosystem value function estimates.

3.2.3 The production possibility frontier in single stands

Production possibilities vary widely between single stands of forest. Some have good site quality and climatic conditions but may not be an important habitat for the most precious species. In this case the Forest PMF would stretch along the first axis. In an opposite case, it would stretch along the second axis (see **Error! Reference source not found.**).

When considering single stands, we do not consider the production possibilities that are unwanted and less likely to happen. We are now zooming in so that we no longer see the parts of the production possibility sector that is bordered by det red curves.

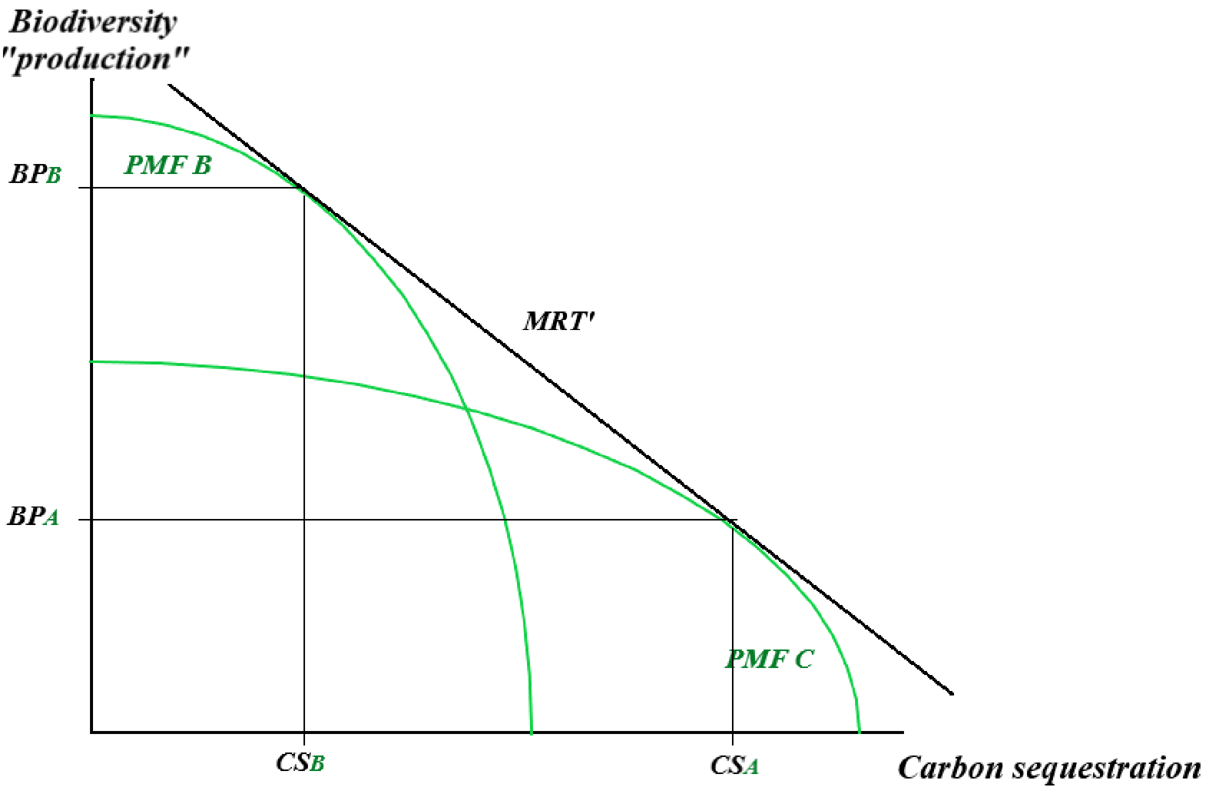


Figure 3.k: Allocation of carbon sequestration and biodiversity "production" within single stand A and B for two forest types

Two production possibility frontiers for two forest types the are presented within the same chart, one for single stand A, and another for single stand B. Single stand A is specialized on carbon sequestration, and sequester CS_A amounts of carbon, and "produces" BP_A amounts of biodiversity. Single stand B have opposite characteristics, and sequester substantially less amounts of CS_B, and "produces" substantially more biodiversity.

As illustrated in **Error! Reference source not found.**, one framework for incentives (represented by MRT' in this case), does not mean that all forests will produce the same quantities of goods or services in optimum.

If all forest properties meet the same regulatory framework, it does not imply that forest owners face incentives to treat their forest properties equally. Some single stands have comparative advantages on carbon sequestration (like stand A in **Error! Reference source not found.**), and can utilize this potential, while other single stands may be more suited for capturing biodiversity qualities.

I want to add a concern about this. If carbon sequestration is provided using economic incentives, while CAC is used for safeguarding biodiversity, forest owners may have financial motives to strictly invest in CS, and thus break the law under incomplete monitoring. This is a valid concern given the technical difficulties and costs of measuring biodiversity.

Planting of alien tree species can be important to ensure large-scale afforestation and reforestation. On the other hand, such species can displace indigenous species, or bring pest and diseases to the forest (Forest Europe, 2020).

3.2.4 The production possibilities with respect to artificial regeneration

The forest owner may decide to clear-cut the stand and regenerate at a given point. At this stage he/she might have the opportunity to do artificial regeneration, or to let seed-trees provide natural regeneration to the area. In practice, most clear-cut stands of spruce in Norway is regenerated with processed seeds, adapted to the growth conditions of their region, which typically grows faster and results in greater volume growth compared to trees from natural regeneration.

The Sitka, a spruce that is not native to Norway, can provide fast-growing voluminous spruces, that extract almost all sunlight in its growing area. Thus, it displaces both other tree species and certain types of wildlife. This specie can sequester 50 percent more carbon than the Norway spruce in parts of Western Norway, and twice as much carbon as Norway spruce in certain northern areas (Andreassen, 2019). As described in chapter 2, regenerating with this tree species is controversial and subject to application in Norway.

Error! Reference source not found., therefore also illustrates the potential trade-offs of consideration when regenerating clear-cut area. It is most evident, when replacing Norway spruce with Sitka, but it is also highly relevant when choosing regeneration strategies for Norway spruce as well.

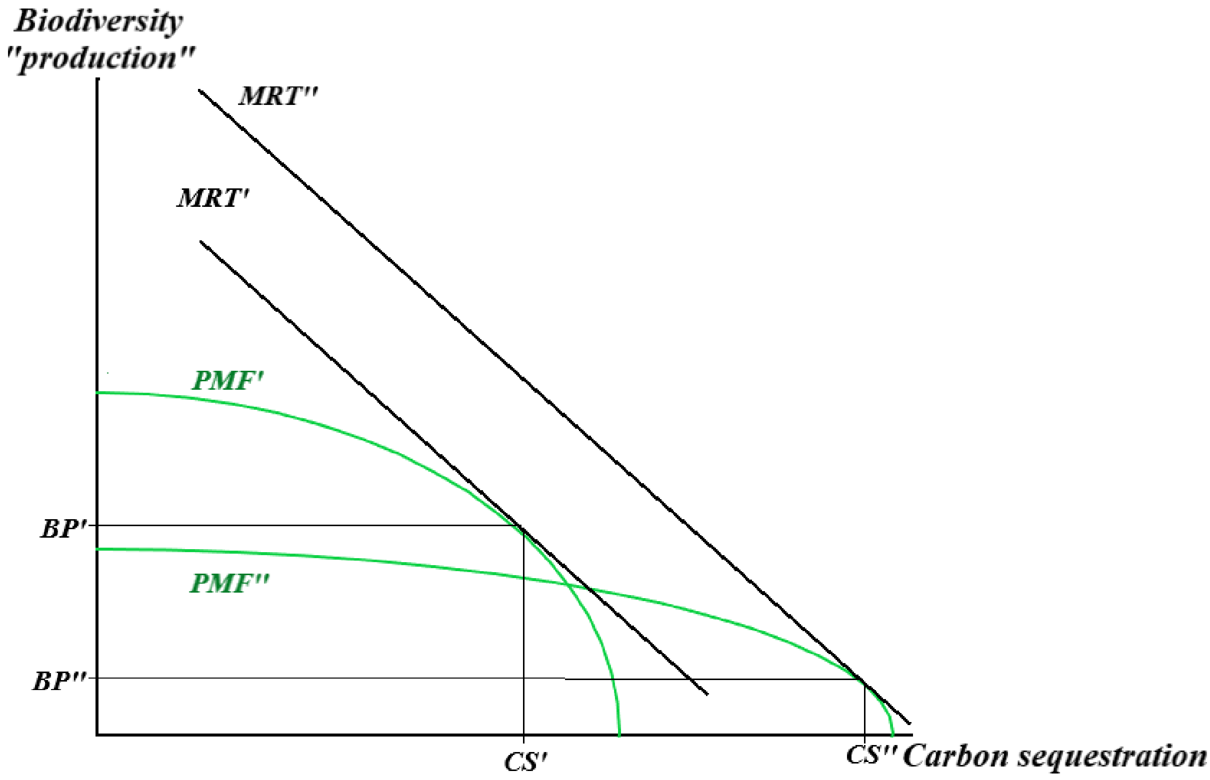


Figure 3.l: Regeneration incentives

Initial stand has the production qualities as described by *PMF'*, with production quantities *CS'* and *BP'*. When clear-cutting, the forester faces an opportunity to utilize processed tree species with the production possibilities represented by *PMF''*. By making this potential trade-off, he/she could stick to the indigenous tree species, or regenerate with an artificial specie that produces more CS (*CS''*), and less BP (*BP''*). The artificial specie result in *PMF''*, which is tied to *MRT''*, and represents a higher level of utility.

By choosing to regenerate a forest with a different species, the forest owner can shift from producing CS' and PB', to producing CS'' and BP''. Even if we do not know the price of any of these goods, we know that this new production corresponds to MRT'', which represent a higher level of utility compared to MRT'. Planting this new species increases the society's utility.

Note that this is a stylized representation that does not take other aspects into account when planting non-native species.

3.2.5 Aggregated effects from utilization of tree seeds with higher volume growth rates

If we analyze the effect of utilization of tree seeds that give higher tree volume growth rates, we could analyze the effect on the aggregated market. **Error! Reference source not found.** illustrates a scenario where foresters get the opportunity to regenerate with species that grow faster and give higher timber volumes than the native species.

Based on analysis related to **Error! Reference source not found.**, I have reason to believe that forest owners have weak incentives to replace the native species in a stand that initially has relatively greater biodiversity "production" than carbon sequestration. Thus, I expect the aggregated production possibility frontier to shift such that it increases possibilities for CS but has a small effect on the potential BP possibilities.

On the other hand, we know that the aggregated effect of including processed seeds will increase the production possibility of CS.

The overall effect of this could be increased CS, and an increase *or* a decrease in BP. **Error! Reference source not found.** illustrates a scenario with these assumptions where production of BP remains on its initial level. The relative production mix now changes (from (CS', BP') to (CS'', BP'')), and ties with the increased utility curve ($U(CS, BP)''$), which results in a shift in the social relative preferences between the two goods (from MRT' to MRT'').

The main point of interest here is that this results in increased societal utility. Given the provided assumptions, shifting from the initial Forest PMF to the outer Forest PMF would result in a pareto improvement no matter what the following production mix would be.

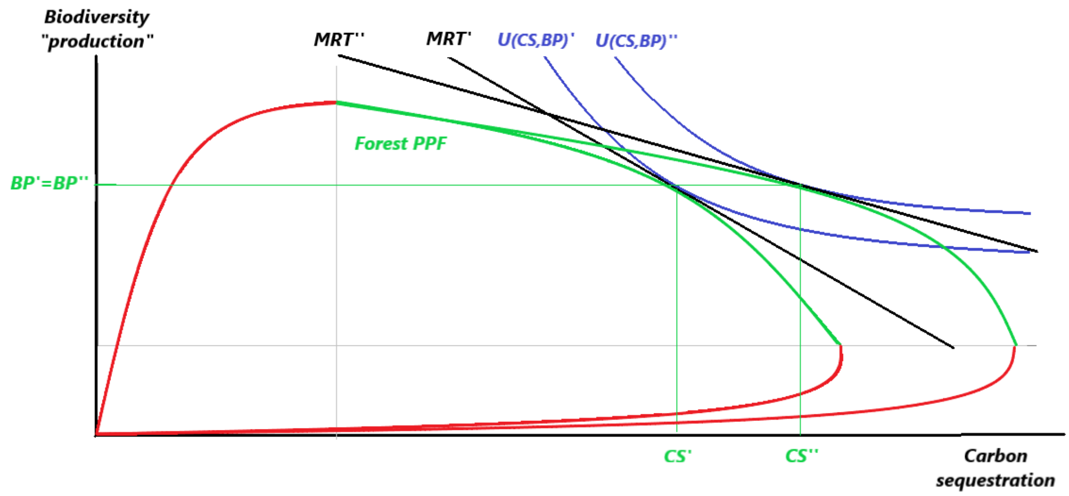


Figure 3.m: Aggregated market with utilization of improved tree seeds

A positive shift in Forest PPF: As a result of increased planting of species from processed seed, the production possibility frontier is assumed to result in potential pareto improvements. In this case, we increase the social utility from $U(CS, BP)'$ to $U(CS, BP)''$, which result in a shift in relative price, status quo for biodiversity production ($BP' = BP''$), and increased carbon sequestration, from CS' to CS''.

3.2.6 Introducing multilateral trade of carbon sequestration and biodiversity "production"

We now imagine that CS and BP could be traded in a multilateral market, where countries connected to the same biome (like the Fennoscandian countries) could utilize added value from their comparative advantages with respect to these goods. Trading biodiversity "production" might sound suspicious. But, if a relatively large country could do internal trade-offs, which is the case of today, trade on equal terms within a conglomerate of Fennoscandian countries would principally be the same. It is of strict interest that trading countries deliver biodiversity "production" based on similar flora and fauna. Other minimum limitations should of course be implemented, which will be subject for discussion.

Error! Reference source not found. extends **Error! Reference source not found.**. I now assume that the multilateral market prefers the same relative production mix as the initial domestic market (MRT' have the same slope as MRT^*, and the external utility function are assumed to be similar to the internal). As a result of this, or hypothetically of any relative change in MRT'', the Norwegian society could now further increase its utility level (from $U(CS, BP)''$ to $U(CS, BP)^*$), due to trading with comparative advantages.

In this scenario, inclusion of other markets has resulted in increased CS (from CS'' to CS_P^*) and decreased BP (from BP'' to BP_P^*). We now import $BP_C^* - BP_P^*$, and exports $CS_P^* - CS_C^*$. Based on the assumptions made, and the concept of the basic production possibility model, I can state that any scenario would at worst result in no trade and status quo.

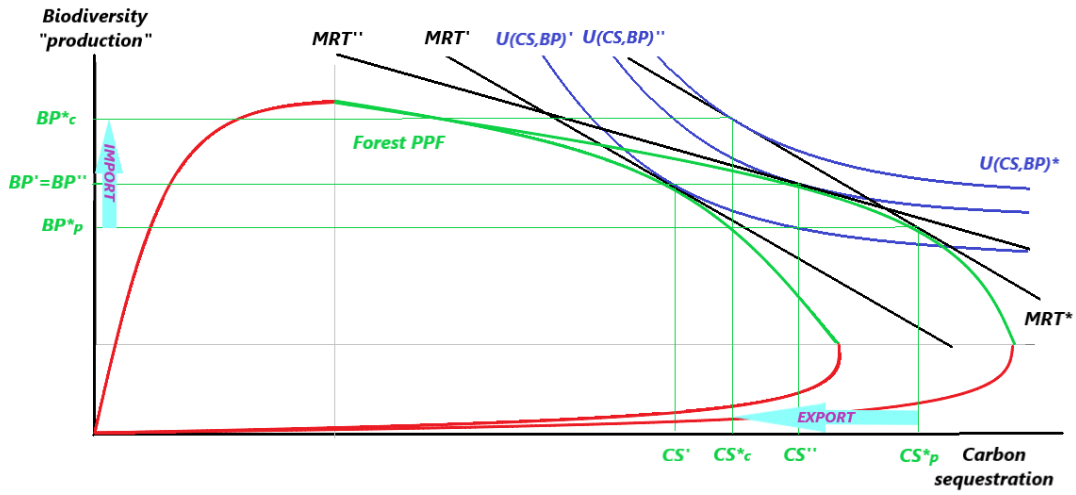


Figure 3.n: Carbon sequestration and biodiversity "production" in a multilateral market

Forest PPF and trade: We now imagine that biodiversity "production" quotas can be traded in the economic area where the carbon market operates. In this case we now face an multilateral relative price ($MRT*$) that allow us to increase utility from $U(CS, BP)''$ to $U(CS, BP)*$. This now result in increased carbon sequestration and decreased biodiversity production. As we now operate in an in international market, we have to pay others to produce part of "our share" of biodiversity production ($IMPORT = BP*c - BP*p$). on the other hand, the carbon sequestration adds a surplus that exceeds this ($EXPORT = CS*p - CS*c$).

Basic trade theory tells us that connecting to any other market, would let both markets extract added value from comparative advantages as long as transaction costs are not too high. In the above analysis, I assume there are practically no transaction costs.

Efficiently connecting to a multilateral market requires several conditions to be met. In addition to similar ecosystems, there should be a common neutral framework for trade and production, trust between countries, and the implemented market mechanisms. Finland, Sweden, and Norway have all the prerequisites for meeting these requirements. In fact, most of them are already incorporated through Scandinavian partnership.

These three Nordic countries already participate in a common carbon market (EU ETS). The forest sector has been well-coordinated for decades, and there are several platforms for policy integration, like the Nordic council of ministers. The report: *Biodiversity, carbon storage and dynamics of old northern forests* from Framstad et al. (2013) is one example of cooperation on the forest sector related to climate and biodiversity.

Nevertheless, I see two major obstacles that could stand in the way of such a multilateral environmental agreement (MEA). First, the Aiche Biodiversity Targets does not allow for degradation of native species and encourages strong limiting the distribution of non-native species within their own national borders (Secretariat of the Convention on Biological Diversity, 2020). Second, it seems intuitively difficult to gather broad political support for foreign trade with biodiversity. A possible reason for the latter is that biodiversity produces *in situ* effects. Related to climate change, local ecosystem resilience is an issue of concern.

3.3 The demand for forest land

Angelsen (2010) starts with von Thünen's (1826) model describing the relationship between the land rent in forestry versus agriculture, and how the relationship between these affects the level of deforestation. von Thünen describes important factors such as commodity prices, production capacity, capital cost, cost of labor and distance to the market, and discuss how changes in these factors may change the aggregated demand for forest land and agricultural land. He also illustrates how internalization of external benefits in forestry may shift the aggregated demand towards less forest degradation.

In this thesis, I analyze a case where demand for forest land is opposing the demand from all other sorts of land use (merged into "Non-forest" in Figure 3.o), and its effect on land-use changes (LUC). Since "Non-forest" includes countless sectors of different characteristics, it is no use specifying the various factors. This exercise rests primarily on the assumption that the aggregated demand for forest land and "non-forest" land can be set up in the same way as in basic microeconomic theory.

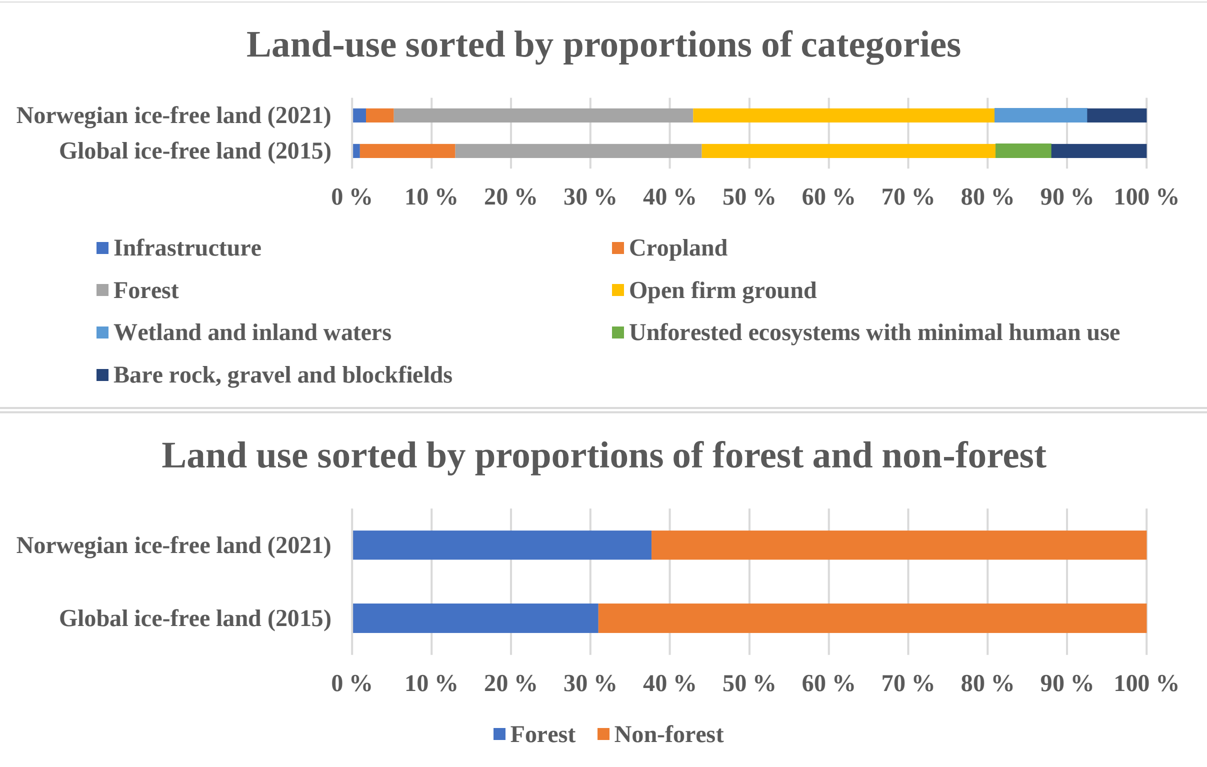


Figure 3.o: Aggregated land use in Norway and globally

Norwegian land use: Statistics Norway. (2021). *Table 06288: Productive forest area, except area under regeneration, by species of tree and surveyed regions (km2)*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06288/

Global land use: IPCC (2019). Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J.

Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press. Retrieved 08.06.21 at https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

Top panel: forest with minimal human use (9%), plantation forests (2%), forests managed for timber and other uses (20%), in the top panel are merged into "Forest" (31%) in the bottom panel. Irrigated cropland (2%) and non-irrigated cropland (10%) are merged into "Cropland" (12%). Intensive pasture (2%), used savannahs and shrublands (16%), and extensive pasture (19%) are merged into "Pasture, savannah and shrubland" (37%).

Bottom panel: illustrates the same as the top panel, but now cropland (12%), pasture, savannah and shrubland (37%), unforested ecosystems (7%), other land (12%) and infrastructure (1%) are now merged into "Non-forest" (69%).

Based on the global land use reported by IPCC (2019), and the von Thünen approach, I sketch a stylistic approach on demand for forest land (expressed as "Land rent value for forest-use") versus demand for non-forest land ("Land rent value for non-forest use") (see Figure 3.p). As land is scarce, I find it reasonable to implement this into a bath-tub diagram. 20 percent of the global ice-free land is assumed to be useless, and the other 80 percent are equally accessible for forest and non-forest purposes. The latter assumption is far from realistic, but in the aggregated market sectors that can access land, which is not useful for forests and croplands, also compete for land that could be used for such purposes. I assume that the aggregated effect will be accurate enough to illustrate the fundamental drivers of LUC.

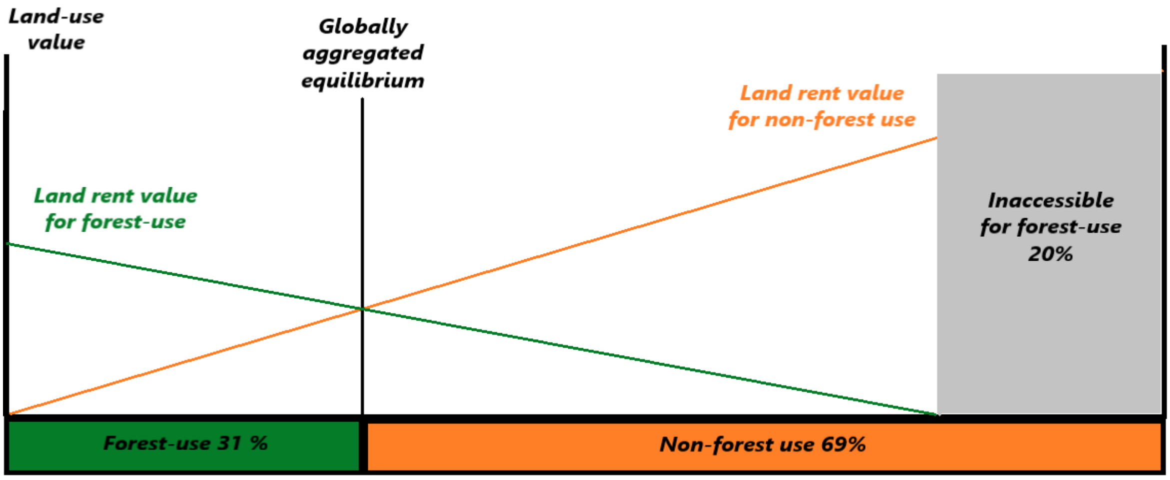


Figure 3.p: Global demand for forest land versus non-forest land

An extended von Thünen bath-tub model illustrates in simplistic manners how land rent value of forest and non-forest could explain the microeconomics behind relevant land-use changes. Given the assumption that all sites are equally convertible between forest and non-forest, and that we could order the aggregated land rent for forest from most profitable to least profitable, and vice versa for non-forests, those could define two competing demand functions. The equilibrium is corresponding to actual global land-use (IPCC, 2019). Angelsen (2010) did extensive work on this, but to describe tropical deforestation in relation to agricultural demand. This was based on input and output variables related to forestry and food production

3.3.1 Predicted land-use changes

Søgaard et al. (2019b) made predictions for the Norwegian LUC in the period 2010-2100. Based on their work we can expect I tiny net deforestation (0.08 percent) throughout this century (see Figure 3.q).

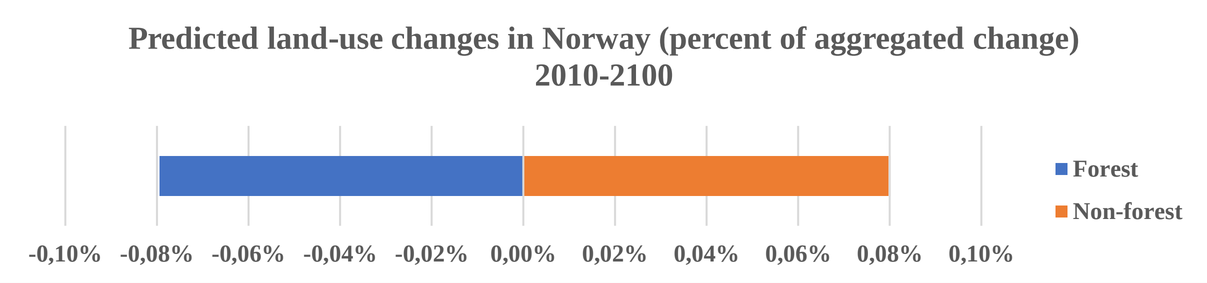


Figure 3.q: Predicted LUC with respect to forest and non-forest land in Norway (2010-2100)

Søgaard, G., Mohr, C. W., Antón-Fernández, C., Alfredsen, G., Astrup, R. A., Breidenbach, J., Eriksen, R., Granhus, A. & Smith, A. (2019b). ***Framskrivninger for arealbrukssektoren – under FNs klimakonvensjon, Kyotoprotokollen og EUs rammeverk*****. In** ***NIBIO Rapport*****.** **NIBIO. Retrieved 02.08.21 at https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2633736**

Predicted land-use changes in the period 2010-2100, by categories, presented as proportions of total change.

Based on the discussion in section 1.4 it seems reasonable to expect that global deforestation will occur on a much larger scale in the period 2010-2100. After all, deforestation at the global scale is the most central target, especially with respect to climate benefits. However, Norway has a privileged global position. Prosperity is high, and forests cover a larger share of the land area (38 percent) than most other countries. The Paris agreement places a significantly greater responsibility on countries with substantial resources versus the less privileged countries (UNFCCC, 2015, Article 2). If countries like Norway accept a net domestic deforestation, we will most likely see global net deforestation on a catastrophic scale globally.

If poor countries with high deforestation experiences that rich countries let their own forests be degraded, their motivation to do their utmost will be weakened.

The World needs pioneers who take elevated responsibilities, and build a framework to preserve the forest, which can be blueprinted by other countries.

Norway's efforts to preserve rainforests in other parts of the world are well known and admirable. But rainforest countries don't just need money to preserve their rainforests. They also need to build the effective institutions and frameworks. Thus, how Norway handles its domestic forest sector is of additional concern

3.3.2 Re-/afforestation in Norway from a von Thünen approach

Let us say that Norway intends to move from expected deforestation to net afforestation levels during this century. Given the assumptions in this framework, this requires the authorities to make it less profitable to own non-forest land, or to make it more profitable to own forest land. Based on the discussion in 1.4, we could rather expect the demand for non-forest land to increase quite a lot. Figure 3.r illustrates this by the shift from the bottom orange line to the top orange line.

In this scenario, the authorities counteract this by increasing the yield on forests, first from the bottom green line to the middle green line, then a second shift to the top green line to achieve the re-/afforestation level accordingly to LUC^*.

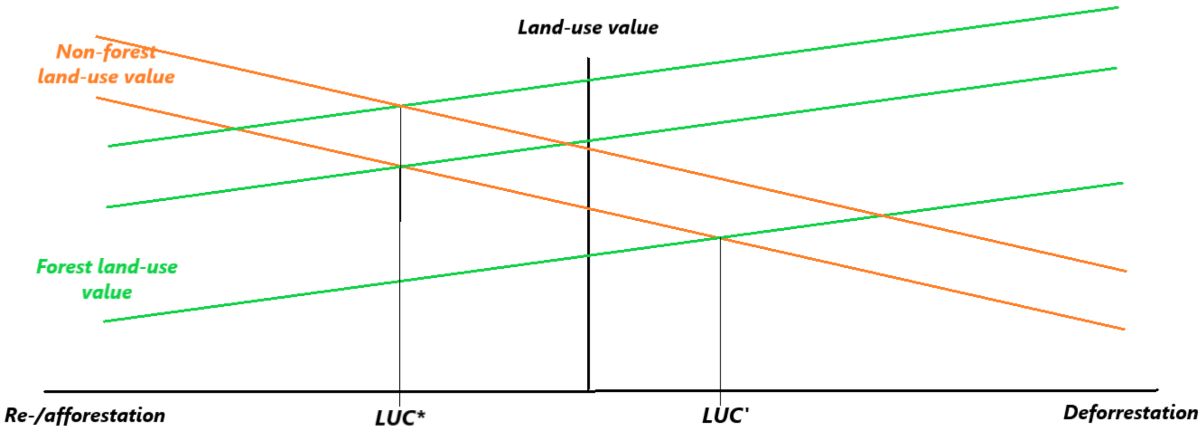


Figure 3.r: Re-/Afforestation and deforestation

The von Thünen approach on re-/afforestation and deforestation: In this context land rent from forests versus non-forests drives the net level of deforestation. In Norway it is projected that we will see net deforestation corresponding to LUC'. If we want to see net re-/afforestation corresponding to LUC^*, we could either make in less profitable to own non-forests or make it more profitable to own forests. In this situation, we chose the latter (middle green line). But as non-forest land also increases, we must further increase the yield on forests (top green line).

Norway has only 3.5 percent cultivated land (Statistics Norway, 2021), and very limited opportunities to convert other land into cropland. Climate change is expected to have positive impact on Norwegian agriculture (15-30 percent increase) (OECD, 2011).

Increased productivity in the agricultural sector will increase the returns on agricultural acreage, and thus increase the demand for acreage that can be converted to agricultural purposes in Norway. Increased demand from an increasing global population would further increase this domestic demand for agricultural acreage. But in Norway's case, the demand side is largely governed by policy decisions related to the scope of agricultural support.

Open land has unleashed the most significant areas over the past decade (National Statistics, 2021), and is predicted to be the land-use category who will have the greatest loss up to 2100 (Søgaard et al., 2019b). Søgaard et al. (2019a) found that 33 percent of Norway's terrestrial area was open land, suited for planting of spruce.

Thus, when discussion LUC in the Norwegian context, we should first and foremost think of this as an issue concerning forest and open land, in addition to the proportionally small but very important wetlands.

4 Discussion

This chapter discusses economic measures to increase carbon sequestration, conserve biodiversity and go from deforestation to re-/afforestation, based on background information provided in chapter 2 and the insight from analysis in chapter 3. The discussion is directly linked to the main research question:

> ***“From a collectively coordinated anthropogenic perspective, what socioeconomic measures can Norway take in the forest sector to help solve the intercorrelated climate and biodiversity crisis?”***

Table 4-a lists suggested potential measures evolving from the discussion in this chapter

Table 4-a: Potential measures

Potential measures	Section for discussion
Shadow price on carbon	**4.1.3**
Carbon flux fee	**4.1.4**
Fixed harvest tax	**4.1.5**
Fee for loss of carbon sequestration	**4.1.6**
Minimum annual carbon sequestration	**4.1.7**
Compulsory insurance	**4.1.8**
Carbon border adjustment and tax on steel and concrete	**4.1.10**
Increased funding of conservation of biodiversity	**4.2.1**
Marginal payment for conservation of biodiversity	**4.2.2**
Identify habitats of special concern	**4.2.3**
Controlled planting of alien species	**4.2.5**
Multilateral Environmental Agreements	**4.2.6**

4.1 Norway’s role in the Anthropogenic project

Annual emissions to air, and through land-use changes (LUC) increased by 1.4 percent in the period 2010-2019 (United Nations Environment Programme, 2020). The anthropogenic effort to reach a stable 1.5°C scenario must be significantly sharpened, to avoid catastrophic consequences for the world’s ecosystems (IPCC, 2018). Without introduction of serious climate policies the world is at risk of having a quarter wiped out of all species within few decades (IPBES, 2019).

This thesis presumes that the world community intends and manages to mobilize the efforts needed to solve these enormous challenges. To solve distributional problems, I have argued that we, founded on the John Rawls' concept: "veil of ignorance", should adopt the 1.5°C pathway, with equal, but differentiated responsibility.

As one of the world's most prosperous countries with ample natural resources, Norway has relative to its size greater opportunities to contribute to this limiting climate change, and therefore also proportionally greater responsibility than most other countries (UNFCCC, 2015).

4.1.1 INCLUSION OF CARBON CREDITS IN THE CARBON MARKET AS AN IDEAL STANDARD

A global emission trading scheme, including all net carbon equivalents, would be the most efficient way to incorporate the cost of carbon. In 2011 the OECD recommended to establish consistent carbon pricing across the Norwegian economy, whether the sector is covered by the EU ETS or not.

IPCC (2018) has illustrated how the 1.5°C pathway requires negative emissions from around 2050, which will most likely have to include net carbon removal from forests. Thus, I have, unlike the EU ETS and most other such carbon trading schemes, included CCS into the prescribed carbon emission trading scheme in Figure 4.a. This will give the anthropogenic entity a tool to control the global net emission level, which is what determines the level of global warming.

Figure 4.a, illustrates how this ideal carbon emission market would benefit from inclusion of CCS. Initially (left panel), M carbon permits are absorbed by the market, and traded for the price P. The marginal abatement cost ($MAC(M)$) curve in the aggregated market represents the demand for permits. Right panel show the extended alternative. By simply opening the market to carbon credits from carbon sequestration in forestry and other CCS (right panel), and adjusting permits to remain at price P, it might be possible to activate re-/afforestation projects and improved forest management to move to a negative emissions pathway, such that the market now absorb NM net emissions.

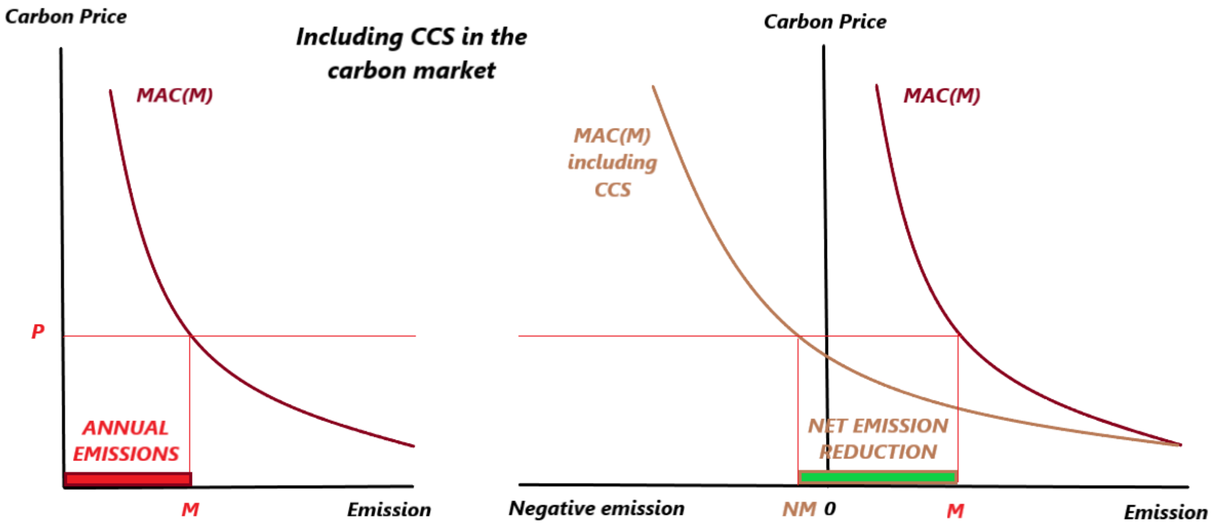


Figure 4.a: Carbon trading with and without carbon sequestration offsets

Figure 4.a builds on insight from Perman et al. (2011). The marginal abatement cost ($MAC(M)$) curves are based on the assumption that all aggregated abatement costs per carbon equivalent (M) in this carbon market could be organized from most expensive to least costly. Given that the market faces a constrained amount of emission permits per period, they will be able to trade such that the least costly abatement is done first, and until the marginal cost of abatement is equal to

the market's equilibrium price (P). In the left panel, annual emissions will thus be M, and the carbon price will be P.

Even if inclusion of all sorts of CCS is included in this ideal framework, my further discussions will focus on carbon sequestration from forest projects.

Forest owners will now be able to sell carbon credits to traditional emitters at the very same market. In my analysis I assume that there are many forest projects that could sequester carbon at much lower prices than regular abatement costs, which is why this curve shifts to the left (light brown curve). In this case, the emission constraint is now moved to net negative amounts (from M to NM), in accordance with the future pathways coherent to the 1.5°C target. I also assume that this could be consistent with the initial permit price (P). Net emission reductions from this envisioned implementation are illustrated by the green bar ($NM - M$ emission reduction).

4.1.2 Setting the reference level in a Norwegian forestry context

Inclusion of carbon credits from carbon sequestration into the carbon market, need some supportive principles. We need to establish a common reference for when to account carbon removals in forestry.

Today, the business as usual (BAU) scenario, describing a hypothetical carbon uptake pathway if we do not undertake severe measures, is often used as a reference level when donors pay recipients to decrease deforestation in developing countries[19], or describing predicted emission pathways[20]. There are several problems with this approach. First, a hypothetical baseline is never indisputable. It is difficult to establish the size of the carbon uptake as this must include normative assessments of what should be considered as anthropogenic impacts.

When choosing a reference level, one should also decide whether the agent should pay the principal in cases where carbon uptake does not occur, compared to the baseline. TEEB (2010) recommended to implement marginal payment for carbon capture and storage (CCS) in forests. Assessing this approach, the agent should pay for such "negative carbon removals" and receive payment for "positive carbon removals".

In the context of Norwegian forestry, I find it reasonable, and politically viable to incorporate a reference level, based on optimal rotation age in forestry when only considering timber production. In chapter 3.1, I have demonstrated how this could be estimated. Surely, we need good data to predict the future optimal rotation age for different forest types and growing conditions, but the National Forest Inventory and other sources can provide this.

4.1.3 Shadow price on Norwegian carbon sequestration

Based on his study of old-growth Norwegian forests, Stokland (2021) concludes that internalization carbon sequestration pricing may significantly prolong the rotation period on sites with sufficient tree density, and it might, in many cases result in the forest never being cut at all.

[19] Example concerning REDD: Angelsen (2008)
[20] Example concerning global emission pathways: IPCC (2018)

Under current international forest policies Norway is not entitled to decide on the sale of Norwegian forest carbon credits in the EU ETS. The decision to include carbon credits from forests (and other sorts of CCS), rests with the EU. However, Norway is not prohibited from imposing a shadow price on carbon sequestration, which could be, and should be a blueprinting the EU ETS carbon price.

A separate national framework also requires a separate financing scheme, as the forester cannot sell his carbon credit to emitters through the carbon market, this must be organized by the Government. A quick estimate shows that annual transaction to foresters based on carbon sequestration can be around 55-60 million €[21].

4.1.4 Carbon flux fee

Clearcutting, which is the common tree harvesting method, will leave the land open for some years. Such open fields will have net emissions of carbon for 10-20 years, until the forest grows back (Luyssaert et al., 2008; Alam et al., 2017 according to Bartlett et al., 2020). Including the fluxes from this phenomenon, referred to as the Covington’s curve, could prolong the optimal rotation lengths with respect net carbon sequestration for decades, according to Nilsen et al. (2008).

If one wishes to assert the polluter pays principle, it may seem reasonable that the forester should also pay the same market price for marginal carbon fluxes associated to the clearcutting, as he/she receives for marginal carbon sequestration. Even if these fluxes are considerable (Bartlett et al., 2020), it sems unrealistic to be able to estimate these fluxes for each case of clearcutting.

A pragmatic solution could be to incorporate an “properly high” general fixed carbon flux fee and link it to the rejuvenation process. This fixed carbon flux fee is then locked to the forest trust fund and can be deducted from annual carbon rates for ten years. If the forest owner can document that the newly planted trees are well established, the carbon payment period will end, and the rest of the allocated funds will be retransferred to the property owner. Remote sensing would be one way of providing this documentation at low costs.

This facility will have several advantages. First, the “discounting effect” will give the forester incentives to postpone harvest, as he/she would like to defer the costs, while biomass growth sill ensures return on timber and carbon. Second, the “can’t afford to harvest” effect could make some foresters prefer to let the carbon sequestration income accumulate before he/she indulges in withdrawing from the forest account. Third, and maybe the most important, the “urgent reforestation” effect suggest that the forester should rejuvenate at first opportunity, to shorten the carbon flux fee period and save as much of the allocated funds as possible.

All three effects are assumed to deliver positive climate impacts, and the third will also increase aggregated long-term timber growth. The forestry Act, §6 and Regulations relating to sustainable forestry, §§6 and 7 (see Table 7-d) already defines a deadline of 3-5 years after harvest for replanting. For forest owners with a short-term horizon and a high discount rate, it may be tempting to expedite logging and defer the cost of panting.

Varying, but significant subsidies have been provided for planting, and with minimum density norms, in the search of additional carbon sequestration and timber production (Miljødirektoratet, 2020). In established forestry, the carbon flux fee can either support, or provide similar incentives, but with the opposite direction of transaction. In terms of planting in new areas, this suggested fee will have no

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[21] $(carbon\ price) 55.98€/tCO2 * (2019\ net\ uptake\ in\ Norwegian\ forestry) 20.79 * (average\ increase\ in\ carbon\ sequestration) 5\% = 58.19\ million\ €$

effect. Thus, subsidies associated with climate motivated should be maintained for as long as one wants this to occur.

4.1.5 Fixed harvest tax

An alternative solution is to simply introduce a fixed per cubic or per hectare harvest tax. This scheme can quickly be introduced and will ensure money transactions to the state immediately after it is introduced. If taxing per cubic of harvest, the incentives to postpone cutting is not expected to be as strong as taxing per hectare. This is because postponed harvest in most cases would involve that the harvested volume grows, and so the tax also grows.

If taxing per hectare, owners of properties with good site qualities and high tree density would have relatively weaker incentives to postpone harvest compared to those who own sites with less productive forests. Thus, the incentives would not be targeted towards postponing forests with the most substantial impact on carbon sequestered. Forests with lower production potential might tend to go out of timber production, which could harm the long-term supply of timber. A mix of per hectare and of timber harvest volume might give the appropriate impact on carbon sequestration.

4.1.6 Fee for loss of carbon sequestration

If the forester should be paid on the margin for additional carbon sequestration of postponing harvest beyond the timber-only optimal rotation age, it might be reasonable that he/she pays on the margin when harvesting in advance, for lost carbon sequestration. This would be in line with the polluter pays principle. This measure will focus on forest owners operating efficiently in a long-term perspective, both in in terms of forest owners' timber profit, and society's benefit from the increased carbon storage.

For some forest owners, it may seem like an unreasonable punishment to receive a "double tax claim" for logging of own, relatively young forest. On the other hand, such harvesting of young forests is poor resource utilization in a socio-economic perspective. The urgency and severity of climate issues may mandate such strong countermeasures. As PEFC certification has become a standard for commercial forestry (Tomter & Dalen, 2018), the impact on this part of the sector might be limited.

This "double tax claim" also provides incentives against degrading forests and make it relatively cheaper to build infrastructure and buildings on land types with less unwanted impact on ecosystem services.

4.1.7 Minimum annual carbon sequestration

As described in Figure 7.b, there is a strong tendency towards logging occurring in spruce forests on high tree volume growth areas. My study looks at forests located in Eastern Norway. Low tree volume growth forest types in other parts of the country are unlikely to be cut for the foreseeable future unless the demand for timber grows out of proportions. Such areas may therefore be exempt from this policy, at least in the beginning.

With this in mind, paying all forest owners for carbon sequestration, based on a common framework, might seem like a waste of state funds. Nevertheless, I would advise against limiting the scope of carbon pricing based in these criteria.

Not only would it trigger unwanted distortions and/or expose forest owners to unfortunate discrimination. It will also make it very challenging to coordinate the framework with other countries. The starting point of this thesis was precisely the global crisis concerning climate, biodiversity, and land-use changes. It is in the nature of the matter that we need to move towards a global and efficient solution to these crises.

If one would like to limit carbon sequestration payments, this should be done by implementing universal rules measures that can in principle be adopted by other countries, or at least our neighboring countries, on equal terms. My suggestion in this regard is to introduce minimum limits for carbon sequestration payments based on annual volume increment per hectare. Documentation of growth rates a few years back should be a prerequisite.

4.1.8 Compulsory insurance

I should mention that a carbon sequestration scheme including payments and fees, should include some exceptions and impositions.

Extending the rotation age involves risk related to for example forest fires, rot, insect attacks, extensive wind fellings, and other natural disasters. Such events may trigger huge carbon costs in addition to loss of timber. Insurance would be one way to lower the financial risk associated with such unforeseen events. A compulsory insurance could also serve as a general risk relief, which should in theory reduce the foresters time cost, and thus, extend the rotation lengths.

An alternative solution to relieve private financial disasters, is to simply make exceptions by law, which exempts forest owners from having to pay for carbon emissions in the event of such incidents. Loss of net income from carbon payments as a result of direct orders from authorities, like conservation of burned forests, or expropriation should of course have its own arrangements.

4.1.9 Other concerns

It is extremely important that incentives concerning other carbon pools like wetlands are included when designing climate policies for forests. Fluxes from carbon sinks in ground, the albedo effect, and effects on harvested wood products complicates this, but should be considered, even if these aspects are barely mentioned in this thesis.

In the 2021 National inventory report for 2019 (Norwegian Environment Agency, 2021), carbon sequestered in living biomass (78 percent) was accounted for the substantial part of carbon stored in Norwegian forests, but the litter pool (20 percent), and the dead wood pool (4 percent) also had important contributions (see Figure 2.u). As decomposition of dead trees may take 70-200 years (40-100 years, according to Bartlett et al., 2020), Stokland (2021) estimated that 24 percent carbon in dead wood ends up as stored in the soil during this process.

A satisfying analysis of carbon fluxes from these pools are not within the boundaries of this thesis. But, the substantial part of dead wood is expected to be found in old-growth forests, which should be protected by other measures, like payment for conservation of biodiversity.

4.1.10 Carbon border adjustment and carbon tax on steel and concrete

This topic is beyond the scope of this thesis, but it should briefly be mentioned that as we introduce measures to increase the rotation lengths in Norwegian forests, it affects other aspects of importance. If we assume that supply of domestic timber is reduced, we could also assume that net timber export decreases, meaning that the harvest is moved elsewhere. To prevent such carbon leakage, it is appropriate to counteract this by coordinating an implementation of a proportional carbon tax on imported timber.

As the domestic supply of timber declines in short to medium run, and this is counteracted by carbon border adjustments, we could expect timber prices to increase. Hence, the use of substitutes for timber as building materials, like steel and concrete, could increase. The total effect of this may be counteractive, as the production of these materials are associated with substantial carbon emissions.

4.2 Taking the three key issues into account

In Table 1-a I described three key issues to resolve the global intertwined climate and biodiversity crisis: interdependency between biodiversity and climate, competition for land, and valuation of biodiversity.

This section discuss the model findings in relation to these key issues and the literature review on these topics.

4.2.1 INTERDEPENDENCY IMPLIES MUTUAL PRICE INCREASE

The analysis of the production possibility frontier provides a useful illustration on how the relative production of these two ecosystem services depends on society's relative pricing, explicitly or implicitly. Thus, it seems reasonable to extend the normative anthropogenic framework, by incorporating a second common principle (recapture the "veil of ignorance"): all countries have similar but differentiated responsibilities to take their proportionate actions to support conservation of biodiversity in the global interest, based on the best available scientific knowledge. As this knowledge evolves over time, knowledge is likely to be updates.

GDNs proposed guiding principle on this subject, is to connect and protect minimum 50 percent of all biomes on earth by 2050 (Dinerstein et al., 2019). Even though the Storting[22] adopted a target of protecting 10 percent of Norwegian forests in 2016 (Meld. St. 14 (2015-2016), Vedtak 667), only 5.1 percent have been given such status (Regjeringa.no, 2021). These are quite small proportions measured with all boreal coniferous forest (10 percent), and all global forest (18 percent) (FAO & UNEP, 2020).

MEASURES TO SAFEGUARD BIODIVERSITY AND REDUCE NET CLIMATE EMISSION SHOULD BE guided by SCIENCE (Secretariat of the Convention on Biological Diversity, 2003; CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY, 2018C; 2018D; Dinerstein et al., 2019). Negative impact on biodiversity and climate are mutually reinforcing (CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY, 2018A; DASGUPTA, 2021). Thus, there must be upper and lower boundaries of the relative prices on these services. In short, those services are a lot like ice cream scoops and waffles, complementary goods, which are most valuable when the proportions are

[22] In Norwegian: Stortinget. Stortinget is the supreme legislature of Norway

within certain relative ratios. If values from carbon sequestration are internalized, one should therefore consider increasing payments for conservation of biodiversity.

4.2.2 Marginal payment for conservation of biodiversity

Putting a price tag on species, is difficult and controversial (TEEB, 2010), but sticking with implicitly underpriced biodiversity, are ethically more challenging than to internalize some added value to it. Highlighting the missing economic values of the ecosystem can provide a better basis for decision-making for politicians, thereby facilitating rational trade-offs (TEEB, 2010). National valuation systems are required to use land resources in a purposeful way (FAO & UNEP, 2020).

In the light of this thesis framework, it seems obvious that CCS has a value to society. I have argued that the most cost-efficient path towards a stable 1.5°C scenario suggests that this price should be equal to the price of emissions. TEEB's (2010) advice to introduce marginal clearing for this service, with optimal timber value rotation as a reference appears sound to me.

I have also argued that the price on carbon should be within certain proportionate relation to the price on biodiversity. This was demonstrated by assessing the production possibility frontier framework.

By using the carbon price as a foundation, a corresponding price of biodiversity can be derived through trade between these services, initially on a national level. As mentioned, a thorough preparation must be carried out to investigate which habitat types are most valuable. A crucial first step is to clarify the conservation status of indispensable areas.

Again, I suggest implementation of marginal payments. As simulated in 3.1, it could be useful to first include carbon sequestration payments to trigger societally optimal carbon rotation periods. To extend the rotation period further, society could then pay for forest habitat qualities in the following period. If the framework provides clear and stable guidelines over long periods of time, the forest owner will know that it can be a valuable bargaining chip for lucrative biodiversity payments, if he/she works to safeguard biodiversity in the forest decades before the age of carbon optimal rotation.

As showed in Figure 3.j, the production possibility frontier (if production is assumed to be pareto efficient) defines society's relative price on these services within its markets. That means that the domestic relative price on these services will remain in force until the market is expanded, just like any other forms of trade.

The implication from this model suggests that a bigger market always allows for welfare exchanging improvements, if the external relative price is different from the internal prices. In cases where internal and external relative prices are identical, there is little scope for welfare improvements by further price internalization.

We should remind ourselves forests delivers many other ecosystem services as well (Table 3-a). We could expect the relative prices between these that are mentioned, and those that are not mentioned, operates in the same manners. This indicates that, when introducing carbon sequestration payments, all other ecosystem services should also have an increase in their pricing.

To some extent, I expect that ecosystem services that are crucial to communities, like water supply and flood protection have the necessary command and control regulations to avoid being degraded by these changing prices. The outdoor creational Act also protects cultural and aesthetic, and recreational values, even if prices on carbon sequestration and conservation of biodiversity increases. I expect the prescribed price changes to have an overall positive impact on pollinators and wildlife.

4.2.3 Habitats of special concern

A major downside of the prescribed carbon pricing, followed by biodiversity payment schemes would be if it triggered re-/afforestation on wetlands. Carbon makes up about half the volume in wetlands, and stores more than 20 percent of domestic mainland ecosystems, being the second largest store after the forest (32 percent) (Bartlett et al., 2020).

When wetlands are forested, the ground dries up, resulting in carbon that has been captured in the soil, being released to the atmosphere (Bartlett et al., 2020). The impact from these fluxes can surpass the gains from CCS in the growing biomass, especially at the start of the rotation period. In addition to being important carbon sinks (Dinerstein et al., 2019), wetlands also host valuable habitats (Dinerstein et al., 2019). Currently wetlands are protected in Norway (see Regulations relating to sustainable forestry, §5 in Table 7-d), albeit this is under pressure.

Rørholt & Steinnes (2020) found that 2 percent of degraded land in Norway in the period 2008-2019 originated from wetlands. In the recently introduced, enhanced climate framework, the EU has asked member countries to account emissions from forests, wetlands, plains, and cropland in the periods 2021-2025 and 2026-2030 (NIBIO, 2021b). This gives strong hope that such unwanted side-effects will be relatively small.

Heather moorlands[23], a semi-natural nature type which is listed as endangered (EN) (Norwegian Biodiversity Information Centre, sine anno), are challenged by afforestation and invasive native and alien species (Jakobsson & Pedersen, 2020, p. 69-73). This nature type is found on the west coast, and kept in place by traditional farming, grazing, and heather burning until the middle of the 20th century. Sitka spruce was planted here around the same time and is currently considered as a threat to the heather moorland (Hovstad et al., 2018).

When increasing the profit on carbon sequestration, we could expect afforestation, which would be threatening to some nature types. This is why I suggest mapping all habitats of special concern, and fund enhanced protection of these valuable nature types. As habitat fragmentation is of major concern, scientists should develop overall plans for larger strategic protection of intertwined ecosystems.

4.2.4 Increased competition for land

The agricultural sector now occupies more than a third of global terrestrial area (IPBES, 2019), and must further substantially increase its food production towards 2050 (OECD, 2020). It seems reasonable to estimate the aggregated demand on scarce land will increase considerably on a global scale. We could expect that a small open economy like Norway will be affected by the increasing global demand for land.

When discussion LUC in the Norwegian context, we should first and foremost think of this as an issue concerning the two largest categories, forest (38 percent) and open land (38 percent), in addition to the proportionally small but very important wetlands (5 percent). Søgaard et al. (2019a) found that open land, suited afforestation by planting of spruce made up 33 percent of the total terrestrial land. In the Nature index 2020, forests (woodland) and open lowlands scores consistently lower than other nature types in the period 1990-2020 (Jakobsson & Pedersen, 2020). Climate change is expected increase production in Norwegian forests by 20-40 percent (OECD, 2011). Based on the assumption that forests get more productive, and that carbon sequestration payments are carried out, this counts for increases profitability in the forest sector. This imply that the demand for forest land will also increase.

[23] In Norwegian: Kystlynghei.

Jakobsen & Pedersen (2020) found that climate motivated afforestation will have the greatest potential in Westerns and Northern areas where lowlands would be degraded. Except that certain habitat of special concern is suggested to get enhanced protection, there are no implications suggesting that there will be substantial shifts in the demand for open land. Thus, we expect to see net afforestation when introducing carbon sequestration payments.

4.2.5 Controlled planting of alien species

When paying for carbon sequestration, it can become more tempting to plant alien species with higher volume growth than Norwegian species. Andreassen (2019) found that the Sitka had twice the carbon uptake of Norwegian spruce in Northern Norway, and a corresponding 50 percent in parts of Western Norway. The Norwegian Agency (2019) points out that such alien species increase timber volume and climate benefits.

The Biodiversity Act, §30 and Regulations relating to the release of alien species for forestry purposes controls the use of foreign tree species, to protect indigenous species. Planting of such species are subject to application.

On one hand, we have shown in section Figure 3.n that specialization of single stands can be increase the aggregated social welfare, and potentially increase both biodiversity and carbon sequestration. On the other hand, these species are invasive, and swiftly takes over valuable nature types like heather moorlands on the west coast. If alien species should be utilized as a measure to increase carbon sequestration, it should be done with caution. Preferably, it should be grown within naturally confined areas where the impact on the surroundings is carefully considered.

4.2.6 Multilateral Environmental Agreements

Dasgupta (2021) concludes that restoration and conservation are of global interest, thus steps should be implemented across borders, and funded through multilateral environmental agreements (MEAs). This is situation is analyzed and confirmed to be economically efficient in Figure 3.n.

In a Norwegian context it seems most promising to start incorporating a national carbon emission trading scheme. Even if carbon credits from forestry are not yet included in the EU ETS, it makes sense to incorporate a shadow price on carbon sequestration, coordinated by a proportional increase in payments for conservation of ecosystems.

An extended version of this, could be incorporated as a common framework including other countries connected to the boreal zone.

Norway have already been cooperating with Russia through Joint Environmental Commission, and Barents-Arctic Council, working on radioactivity, biodiversity, and climate change (OECD, 2011). Norway also has extensive cooperation with Sweden and Finland through, amongst other channels, the Nordic Council of Ministers. The Nordic countries have also funded many small and medium-sized environmental projects in Russia, Ukraine, and the Baltic states (OECD, 2011).

The platform for extended cooperation is already created. Except for Russia, all countries mentioned are a part of the EU/EEA cooperation, and thus are exposed to a common price on carbon for sectors under EU ETS. If incorporating such trading schemes further, it is important to take certain reservations.

Some forests are more valuable than others. Primary mature forests have greater ability to support surrounding habitats and are more resilient than younger forests (Secretariat of the Convention on Biological Diversity, 2003, p. 8-9). Thus, nature types should be classified by their quality and quantity.

Biodiversity is particularly vulnerable to fragmentation of ecosystems (Dinerstein et al., 2019; FAO & UNEP, 2020). Thus, which areas are most in need of protection should also be considered through an overall plan for conservation of larger networks of ecosystems.

Including a carbon price on harvest and extended payment for conservation of ecosystems, would not only increase the overall income of Norwegian forestry. It would also make forest owners less dependent on timber prices, which have been volatile over the past decade. Adu & Romstad (2020) have showed how such volatile local timber prices can provide stronger incentives, among forest owners who accept risk, to delay harvesting, in anticipation of possible timber price increases. As the proportionate income from timber decreases, this incentive becomes weaker.

5 Conclusion

This chapter sums up the suggested measures, and briefly described how to incorporate them. It also sums up identified drawbacks and synergy effects. The validity of assumptions made, what could have been investigated, and what future research is needed will also be subject of discussion.

5.1 Shadow price on carbon

I propose to implement a shadow price on carbon sequestration in the Norwegian forest sector. The shadow price should be equal to the carbon price in the EU ETS, but as there are no buyers of carbon sequestration credits for the Norwegian market, the Government should organize these transfers through a forest fund.

The reference level for payments and fees should be such that the forester must keep standing forest beyond the timber volume optimal timber rotation age before carbon sequestration payments occur.

5.2 Carbon flux fee versus fixed harvest tax

A carbon flux fee should be collected when logging occurs. A sum to cover carbon fluxes over ten years (as an example) should be reserved on the forester's forest fund account, and the difference is paid back to him/her if the trees on the clear-cut stand are well-established before this period ends. This rule is in line with the polluter pays principle.

As an alternative, the Government could put a general tax on harvest based on a mix of per hectare and of timber harvest volume to capture the appropriate impact on carbon sequestration from logging.

5.3 Fee for loss of carbon sequestration

A fee for loss of carbon sequestration should be collected from foresters who harvest before the timber volume optimal rotation length. This rule is in line with the polluter pays principle and should be based on the climate gas emissions shadow price.

This fee should be deduced from the tree stand's growth function, as is also the basis for the shadow price on carbon.

5.4 Minimum annual carbon sequestration

Paying foresters to postpone a harvest that would not have occurred in the first place is a transaction without means. Hence, there should be introduced a minimum annual carbon sequestration rate to qualify to receive such funds.

5.5 Compulsory insurance

A compulsory insurance could avoid random private financial burdens from extending the rotation age beyond the privately optimum, and thus serve as a general risk relief, which should in theory reduce the foresters time cost, and thus, extend the rotation lengths

5.6 Carbon border adjustment and carbon tax on steel and concrete

Carbon leakage through net export and substitution of construction materials with extensive carbon emissions building materials like concrete and steel may take place. Counter measures such as a carbon adjustment tax on timber imports , and tax on steel and concrete should be implemented and coordinated. Even if this proposal is not a part of this study, it is an important element that should be implemented when introducing a shadow price on carbon sequestration. The detailed regulations of these border adjustment policies are beyond the scope of this thesis due to time constraints, but they are interesting areas for further research.

5.7 Increased, and marginal funding of conservation of biodiversity

As the forester receives payments for carbon sequestration, he/she should also receive payments for extended conservation of the forest as a habitat. If the relative pricing between those elements is changed, the incentive to conserve is also changed. Thus, these prices should be coordinated, or alternatively be implemented through jurisdictional measures.

Payments for biodiversity conservation should be at the margin, i.e., the forester should receive biodiversity payments for tree stands older than the climate adjusted optimal rotation age.

5.8 Identifying and mapping of habitats of severe interests and controlling planting of alien species

It is important that all habitats and nature types are identified, mapped, and valued in categories. The most valuable nature types and habitats should receive funding immediately to avoid these forest and other land types to be degraded by harvest or afforestation when incentives for carbon sequestration are strengthened.

5.9 Multilateral Environmental Agreements (MEAs)

First, Norway should implement domestic trade on biodiversity conservation based on the mapping and valuation done by scientists. When this has been tested, Norway can coordinate this scheme with surrounding countries like Sweden and Finland as MEAs.

6 References

[1] References for each source table assessed from Statistics Norway's web page are cited under their corresponding figures and tables.

[2] References for laws and regulations are cited under Table 7-d.

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7 Appendices

Table 7-a: The global collective action problem in relation to Ostrom's approach, and suggested remedies

	Ostrom's form	Remedies introduced	Relevant potential remedies
1	The number of participants involved	Coordinated climate commitment for EU.	Cooperation through continental unions like AU, USAN, and other regional organizations. Multilateral cooperation concerning ecoregions and continental unions etc.
2	Whether benefits are subtractive or fully shared (i.e., public goods vs common-pool resources)	Several emission trading schemes, but uncoordinated. Wide use of different and uncoordinated national climate and biodiversity measures.	Common emission trading markets, with overall limitations of permits, corresponding with climate mitigation targets. Common biodiversity trading schemes, with overall safe minimum targets.
3	The heterogeneity of participants	Regular COP of CBD and UNFCCC. Coordinated climate commitment for EU.	Cooperation through continental unions like AU, USAN, and other regional organizations. Multilateral cooperation concerning ecoregions and continental unions etc. Redistribution of monetary values, emission permits, technology, education, and responsibility.
4	Face-to-face communication	Regular COP of CBD and UNFCCC.	
5	Information about past actions	UN organizations and other scientists contributes to a common platform of knowledge.	
6	How individuals are linked	Regular COP of CBD and UNFCCC	Common emission trading markets, with overall limitations of permits, corresponding with climate mitigation targets. Common biodiversity trading schemes, with overall safe minimum targets.
7	Whether individuals can enter or exit voluntarily	Convention on Biological Diversity (1992), Article 38 gives right to withdraw after two years. Paris Agreement (UNFCCC, 2015), Article 28 gives right to withdraw after one year. Entries are open for all nations.	

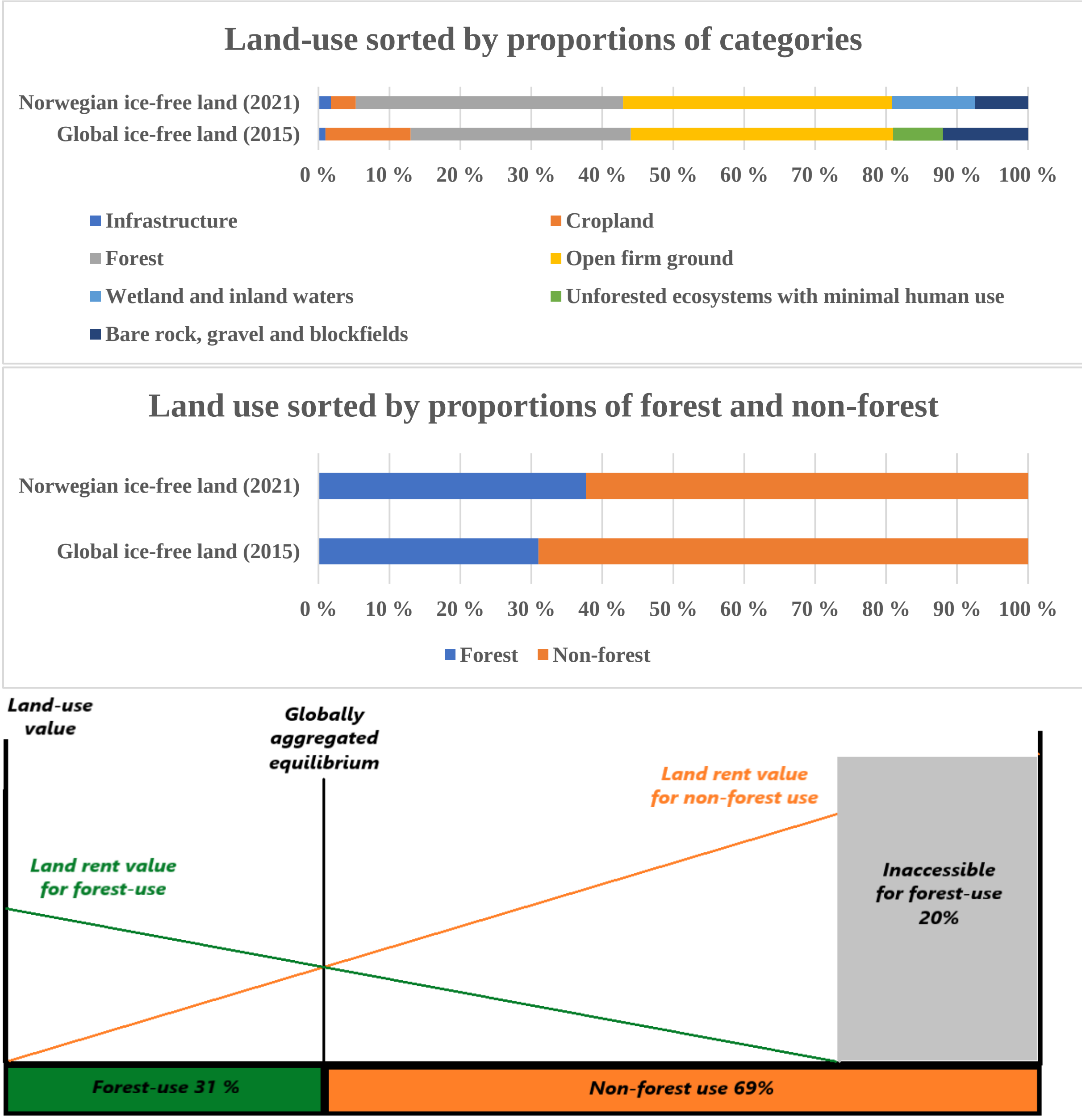

Figure 7.a: Aggregated demand for forest and non-forest land

Norwegian land use: Statistics Norway. (2021). *Table 06288: Productive forest area, except area under regeneration, by species of tree and surveyed regions (km2)*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06288/

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The top panel illustration of the proportions of land-use is taken from the IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (2019, p. 8). Forest with minimal human use (9%), plantation forests (2%), forests managed for timber and other uses (20%) are merged into "Forest" (31%). Irrigated cropland (2%) and non-irrigated cropland (10%) are merged into "Cropland" (12%). Intensive pasture (2%), used savannahs and shrublands (16%) and extensive pasture (19%) are merged into "Pasture, savannah and shrubland" (37%).

The middle panel illustrates the same as the top panel, but now cropland (12%), pasture, savannah and shrubland (37%), unforested ecosystems (7%), other land (12%) and infrastructure (1%) are now merged into "Non-forest" (69%).

The bottom panel outline an extended von Thünen bath-tub model to illustrate in simple manners how land rent value of forest and non-forest could explain the microeconomics behind relevant land-use changes. Given the assumption that all sites are equally convertible between forest and non-forest, and that we could order the aggregated land rent for forest from most profitable to least profitable, and vice versa for non-forests, those could define two competing demand functions. The equilibrium is corresponding to actual global land-use (IPCC, 2019, p. 8). Angelsen (2010) did extensive work on this, but to describe tropical deforestation in relation to agricultural demand. This was based on input and output variables related to forestry and food production.

Table 7-b: Regional distribution of various factors related to forestry

Region	Northern Norway	Central Norway	Western Norway	Southern Norway	Eastern Norway	Norway
Consists of (counties)	Nordland, Troms og Finnmark$_1$	Trøndelag$_2$	Rogaland, Vestland, Møre og Romsdal$_3$	Agder$_4$	Viken, Oslo, Innlandet, Vestfold og Telemark$_5$	All Counties
Terrestrial area, mainland (percent)	34.9$_1$	13.0$_2$	17.8$_3$	5.1$_4$	29.2$_5$	100.0
Protected area – all purposes (km^2) 2020$_6$	17,012	7,944	12,497	2,982	16,364	56,799
Protected area – all purposes (percent) 2020	30.0	14.0	22.0	5.2	28.8	100.0
Productive forest (km^2) 2019$_7$	79,765	104,897	74,384	60,330	474,419	793,795
Productive forest (percent) 2019	10.0	13.2	9.4	7.6	59.8	100.0
Unproductive forest (km^2) 2019$_7$	199,328	52,659	33,136	20,626	167,462	473,211
Unproductive forest (percent) 2019	42.1	11.1	7.0	4.6	35.4	100.0
Productive and unproductive forest (km^2) 2019	279,093	157,556	107,520	80,956	641,881	1,267,006
Productive and unproductive forest (percent) 2019	22.0	12.4	8.5	6.4	50.7	100.0
Annual increment from productive forests – Spruce, Pine and Broad-leaved (1000m^3) 2015-2019$_8$*	1,797	2,800	2,922	3,635	10,950	22,104
Annual increment from productive forests – Spruce, Pine and Broad-leaved (percent) 2015-2019	8.1	12.7	13.2	16.4	49.5	100.0
Annual increment from productive forests – Spruce (1000m^3) 2015-2019$_8$*	769	1,861	1,391	1,761	6,574	12,356
Annual increment from productive forests – Spruce (percent) 2015-2019	6.2	15.1	11.3	14.3	53.2	100.0
Annual increment from productive forests – Pine (1000m^3) 2015-2019$_8$*	176	294	520	1,118	2,649	4,757
Annual increment from productive forests – Pine (percent) 2015-2019	3.7	6.2	10.9	23.5	55.7	100.0

Annual increment from productive forests – Broad-leaved (1000m^3) 2015-2019[8]*	853	645	1,012	756	1,727	4,993
Annual increment from productive forests – Broad-leaved (percent) 2015-2019	17.1	12.9	20.3	15.1	34.6	100.0
Annual increment from unproductive forests – Spruce, Pine and Broad-leaved (1000m^3) 2015-2019[8]*	358	287	390	419	628	2,082
Annual increment from unproductive forests – Spruce, Pine and Broad-leaved (percent) 2015-2019	17.2	13.8	18.7	20.1	30.2	100.0
Annual increment from unproductive forests – Spruce (1000m^3) 2015-2019[8]*	34	79	32	101	243	489
Annual increment from unproductive forests – Spruce (percent) 2015-2019	7.0	16.2	6.5	20.7	49.7	100.0
Annual increment from unproductive forests – Pine (1000m^3) 2015-2019[8]*	70	118	112	210	185	695
Annual increment from unproductive forests – Pine (percent) 2015-2019	10.1	17.0	16.1	30.2	26.6	100.0
Annual increment from unproductive forests – Broad-leaved (1000m^3) 2015-2019[8]*	255	90	246	108	199	898
Annual increment from unproductive forests – Broad-leaved (percent) 2015-2019	28.4	10.0	27.4	12.0	22.2	100.0
Annual increment from productive and unproductive forests – Spruce, Pine and Broad-leaved (1000m^3) 2015-2019[8]*	2,155	3,087	3,312	4,054	11,578	24,186
Annual increment from productive and unproductive forests – Spruce, Pine and Broad-leaved (percent) 2015-2019	8.9	12.8	13.7	16.8	47.9	100.0
Annual increment from productive and unproductive forests – Spruce (1000m^3) 2015-2019[8]*	803	1,940	1,423	1,862	6,817	12,845
Annual increment from productive and unproductive forests – Spruce (percent) 2015-2019	6.3	15.1	11.1	14.5	53.1	100.0
Annual increment from productive and unproductive forests – Pine (1000m^3) 2015-2019[8]*	246	412	632	1,328	2,834	5,452
Annual increment from productive and unproductive forests – Pine (percent) 2015-2019	4.5	7.6	11.6	24.4	52.0	100.0
Annual increment from productive and unproductive forests – Broad-leaved (1000m^3) 2015-2019[8]*	1,108	735	1,258	864	1,926	5,891
Annual increment from productive and unproductive forests – Broad-leaved (percent) 2015-2019	18.8	12.5	21.4	14.7	32.7	100.0
Gross value of roundwood removals (1000€) 2020[9]**	6,203	27,251	22,823	26,979	276,815	360,070

Gross value of roundwood removals (percent) 2020	**1.7**	**7.6**	**6.3**	**7.5**	**76.9**	**100.0**
Quantity removed – Spruce (1000m^3) 2020$_{10}$	**186**	**733**	**648**	**458**	**5,139**	**7,164**
Quantity removed - Spruce (percent) 2020	**2.6**	**10.2**	**9.0**	**6.4**	**71.7**	**100.0**
Quantity removed – Pine (1000m^3) 2020$_{10}$	**24**	**78**	**58**	**312**	**2,300**	**2,772**
Quantity removed - Pine (percent) 2020	**0.9**	**2.8**	**2.1**	**11.2**	**83.0**	**100.0**
Quantity removed – Broad-leaved (1000m^3) 2020$_{10}$	**4**	**12**	**3**	**16**	**272**	**306**
Quantity removed - Broad-leaved (percent) 2020	**1.2**	**3.9**	**0.9**	**5.1**	**88.8**	**100.0**
Quantity removed – Spruce, Pine and Broad-leaved (1000m^3) 2020$_{10}$	**214**	**823**	**708**	**785**	**7,712**	**10,242**
Quantity removed – Spruce, Pine and Broad-leaved (percent) 2020	**2.1**	**8.0**	**6.9**	**7.7**	**75.3**	**100.0**
Quantity produced of saw logs (1000m^3) 2020$_{11}$	**57**	**382**	**398**	**443**	**4,144**	**5,424**
Quantity produced of saw logs (percent) 2020	**1.1**	**7.1**	**7.3**	**8.2**	**76.4**	**100.0**
Quantity produced of unsorted saw logs and pulp wood (1000m^3) 2020$_{11}$	**5**	**1**	**48**	**64**	**112**	**229**
Quantity produced of unsorted saw logs and pulp wood (percent) 2020	**2.0**	**0.3**	**20.9**	**28.1**	**48.8**	**100.0**
Quantity produced of pulp wood (1000m^3) 2020$_{11}$	**152**	**440**	**262**	**278**	**3,456**	**4,589**
Quantity produced of pulp wood (percent) 2020	**3.3**	**9.6**	**5.7**	**6.1**	**75.3**	**100.0**
Summed quantity of saw wood and pulp wood produced (1000m^3) 2020$_{11}$	**214**	**823**	**708**	**785**	**7,711**	**10,242**
Summed quantity of saw wood and pulp wood produced (percent) 2020	**2.1**	**8.0**	**6.9**	**7.7**	**75.3**	**100.0**
Growing stock on productive area – Spruce, Pine and Broad-leaved (1000m^3) 2015-2019$_{12}$*	**73,287**	**103,688**	**121,656**	**154,896**	**412,604**	**866,131**
Growing stock on productive area – Spruce, Pine and Broad-leaved (percent) 2015-2019*	**8.5**	**12.0**	**14.0**	**17.9**	**47.6**	**100.0**
Growing stock on productive area – Spruce (1000m^3) 2015-2019$_{12}$*	**20,875**	**64,427**	**38,817**	**58,943**	**218,752**	**401,814**
Growing stock on productive area – Spruce (percent) 2015-2019*	**5.2**	**16.0**	**9.7**	**14.7**	**54.4**	**100.0**
Growing stock on productive area – Pine (1000m^3) 2015-2019$_{12}$*	**7,702**	**17,512**	**39,290**	**61,029**	**13,0754**	**25,6287**
Growing stock on productive area – Pine (percent) 2015-2019*	**3.0**	**6.8**	**15.3**	**23.8**	**51.0**	**100.0**

Growing stock on productive area – Broad-leaved (1000m^3) 2015-2019$_{12}$*	44,710	21,749	43,549	34,923	63,098	208,029
Growing stock on productive area – Broad-leaved (percent) 2015-2019*	21.5	10.5	20.9	16.8	30.3	100.0
Growing stock on unproductive area – Spruce, Pine and Broad-leaved (1000m^3) 2015-2019$_{12}$*	17,828	17,716	17,544	23,062	36,197	112,347
Growing stock on unproductive area – Spruce, Pine and Broad-leaved (percent) 2015-2019*	15.9	15.8	15.6	20.5	32.2	100.0
Growing stock on unproductive area – Spruce (1000m^3) 2015-2019$_{12}$*	1,782	5,084	936	5,111	13,601	26,514
Growing stock on unproductive area – Spruce (percent) 2015-2019*	6.7	19.2	3.5	19.3	51.3	100.0
Growing stock on unproductive area – Pine (1000m^3) 2015-2019$_{12}$*	4,082	8,281	7,759	12,826	12,623	45,571
Growing stock on unproductive area – Pine (percent) 2015-2019*	9.0	18.2	17.0	28.1	27.7	100.0
Growing stock on unproductive area – Broad-leaved (1000m^3) 2015-2019$_{12}$*	11,964	4,352	8,850	5,124	9,972	40,262
Growing stock on unproductive area – Broad-leaved (percent) 2015-2019*	29.7	10.8	22.0	12.7	24.8	100.0
Growing stock on productive and unproductive area – Spruce, Pine and Broad-leaved (1000m^3) 2015-2019$_{12}$*	91,115	121,404	139,200	177,958	448,801	978,478
Growing stock on productive and unproductive area – Spruce, Pine and Broad-leaved (percent) 2015-2019*	9.3	12.4	14.2	18.2	45.9	100.0
Growing stock on productive and unproductive area – Spruce (1000m^3) 2015-2019$_{12}$*	22,657	69,511	39,753	64,054	232,353	428,328
Growing stock on productive and unproductive area – Spruce (percent) 2015-2019*	5.3	16.2	9.3	15.0	54.2	100.0
Growing stock on productive and unproductive area – Pine (1000m^3) 2015-2019$_{12}$*	11,784	25,793	47,049	73,855	143,377	301,858
Growing stock on productive and unproductive area – Pine (percent) 2015-2019*	3.9	8.5	15.6	24.5	47.5	100.0
Growing stock on productive and unproductive area – Broad-leaved (1000m^3) 2015-2019$_{12}$*	56,674	26,101	52,399	40,047	73,070	248,291
Growing stock on productive and unproductive area – Broad-leaved (percent) 2015-2019*	22.8	10.5	21.1	16.1	29.4	100.0
Area planted (km^2) 2020$_{13}$	84	301	79	123	1706	2,292
Area planted (percent) 2020	3.7	13.1	3.5	5.4	74.4	100.0

Pieces planted (1000 pieces) 2020$_{13}$	1,412	5,037	2,108	2,094	32,880	43,531
Pieces planted (percent) 2020	3.2	11.6	4.8	4.8	75.5	100.0
Plant expenditures (1000€) 2020$_{13}$***	814	2,700	1,277	1,329	16,999	23,119
Plant expenditures (percent) 2020	3.5	11.7	5.5	5.7	73.5	100.0
Total silviculture (1000€) 2020$_{14}$***	1,071	4,114	2,272	3,148	36,112	46,718
Total Silviculture (percent) 2020	2.3	8.8	4.9	6.7	77.3	100.0
Subsidies on silviculture (1000€) 2020$_{14}$***	607	1,444	888	892	5,337	9,168
Subsidies on silviculture (percent) 2020	6.6	15.8	9.7	9.7	58.2	100.0
Employment by place of work – Forestry and logging (employees) 2020$_{15}$**	260	674	498	661	3,982	6,075
Employment by place of work – Forestry and logging (percent) 2020**	4.3	11.1	8.2	10.9	65.5	100.0
Employment by place of work – Wood and wood products (employees) 2020$_{15}$**	740	1,553	2,832	1,921	5,916	12,962
Employment by place of work – Wood and wood products (percent) 2020**	5.7	12.0	21.8	14.8	45.6	100.0
Employment by place of work – Paper and paper products (employees) 2020$_{15}$**	0	755	77	0	1,697	2,529
Employment by place of work – Paper and paper products (percent) 2020**	0.0	29.9	3.0	0.0	67.1	100.0
Employment by place of work – Forestry and logging, Wood and wood products, and Paper and paper products (employees) 2020$_{15}$**	1,010	3,005	3,437	2,608	11,706	21,766
Employment by place of work – Forestry and logging, Wood and wood products, and Paper and paper products (percent) 2020**	4.6	13.8	15.8	12.0	53.8	100.0
Productive forest area in all size classes (km^2) 2019$_{16}$******	79,248	105,469	87,465	60,209	367,461	699,852
Productive forest area in all size classes (percent)	11.3	15.1	12.5	8.6	52.5	100.0
Productive forest area in size class 25-499 decares (km^2) 2019$_{16}$	14,281	7,632	21,103	5,972	28,593	77,581
Productive forest area in size class 25-499 decares (percent)	18.4	9.8	27.2	7.7	36.9	100.0
Productive forest area in size class 500-4,999 decares (km^2) 2019$_{16}$******	31,782	51,845	35,934	36,258	154,474	310,293
Productive forest area in size class 500-4,999 decares (percent)	10.2	16.7	11.6	11.7	49.8	100.0
Productive forest area in size class 5,000 decares or more (km^2) 2019$_{16}$******	20,665	36,254	1,207	5,059	155,707	218,891
Productive forest area in size class 5,000 decares or more (percent)	9.4	16.6	0.6	2.3	71.1	100.0

Roundwood cut for sale from all property size classes (1,000m^3) 2019[17]*****	**254**	**810**	**730**	**882**	**8,557**	**11,232**
Roundwood cut for sale from all property size classes (percent)	**2.3**	**7.2**	**6.5**	**7.9**	**76.2**	**100.0**
Roundwood cut for sale from all property size class 25-499 decares (1,000m^3) 2019[17]*****	**88**	**216**	**438**	**233**	**1,980**	**2,954**
Roundwood cut for sale from all property size class 25-499 decares (percent)	**3.0**	**7.3**	**14.8**	**7.9**	**67.0**	**100.0**
Roundwood cut for sale from all property size class 500-4,999 decares (1,000m^3) 2019[17]*****	**129**	**480**	**223**	**564**	**3,937**	**5,334**
Roundwood cut for sale from all property size class 500-4,999 decares (percent)	**2.4**	**9.0**	**4.2**	**10.6**	**73.8**	**100.0**
Roundwood cut for sale from all property size class 5,000 decares or more (1,000m^3) 2019[17]*****	**30**	**114**	**0**	**51**	**2,665**	**2,760**
Roundwood cut for sale from all property size class 5,000 decares or more (percent)	**1.1**	**4.1**	**0.0**	**1.9**	**92.9**	**100.0**

****Telemark are counted as a part of Southern Norway, not as a part of Eastern Norway.***

*****Due to confidentiality concerns, some counties are left out of the statistics. Oslo is left out of Forestry and logging. Agder, Møre og Romsdal, Nordland, Vestfold og Telemark, and Vestland are left out of Paper and paper production.***

******NOK valued in average 2019 exchange rates (9.8502NOK/€) and 2020 exchange rates (10.7258NOK/€) according to the central bank of Norway: according to the central bank of Norway:*** **https://www.valuta-kurser.no/norges-banks-m%C3%A5nedlige-gjennomsnittlige-2020-valutakurser**

******13.3 percent of all areas are unclassified by size by Statistics Norway, out of confidentiality concerns. Aust-Agder, Rogaland, Sogn og Fjordane, and Finnmark (counties by definitions valid before 2020) are left out of the size class "500-999 decares". Vest-Agder, Rogaland, and Finnmark (counties by definitions valid before 2020) are left out of the size class "5,000-19,999 decares". Aust-Agder, Vest-Agder, and Sogn og Fjordane (counties by definitions valid before 2020) are left out of the size class "20,000 decares or more".**

*******1.3 percent of all volume cut are unclassified by property size by Statistics Norway, out og confidentiality concerns. Møre og Romsdal and Troms (counties by definitions valid before 2020) are left out of the size class "1,000-1,999 decares". Vest-Agder, Rogaland, and Sogn og Fjordane (counties by definitions valid before 2020) are left out of the size class "2,000-4,999 decares". Vestfold, Vest-Agder, Rogaland, Møre og Romsdal, and Troms (counties by definitions valid before 2020) are left out of the size class "5,000-19,999 decares". Vestfold, Vest-Agder, and Sogn og Fjordane (counties by definitions valid before 2020) are left out of the size class "20,000 decares or more".**

[1]***Thorsnæs, G. (2021b). Nord-Norge i Store norske leksikon. Retrieved 12.07.21 at*** **https://snl.no/Nord-Norge**

[2]***Thorsnæs, G. (2021a). Midt-Norge i Store norske leksikon. Retrieved 12.07.21 at*** **https://snl.no/Midt-Norge**

[3]***Thorsnæs, G. (2021c). Vestlandet i Store norske leksikon. Retrieved 12.07.21 at*** **https://snl.no/Vestlandet**

[4]***Thorsnæs, G. (2020a). Sørlandet i Store norske leksikon. på snl.no.*** **Retrieved 12.07.21** ***at*** **https://snl.no/S%C3%B8rlandet**

[5]***Thorsnæs, G. (2020b). Østlandet in Store norske leksikon. Retrieved 12.07.21 at*** **https://snl.no/%C3%98stlandet**

[6]**Statistics Norway. (2021).** ***Table 08936: Protected area (M) 1975 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/08936/**

[7]**Statistics Norway. (2021).** ***Table 10206: Agricultural properties*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/10206/**

[8]**Statistics Norway. (2021).** ***Table 06291: Annual increment under bark, by type of land, species of tree and surveyed regions (1 000 m^3), 1996-2000 - 2015-2019*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06291/**

[9]**Statistics Norway. (2021).** ***Table 03794: Gross value. Commercial roundwood removals (NOK 1 000) (M) 1996 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03794/**

[10]**Statistics Norway. (2021).** ***Table 03795: Commercial roundwood removals, by species of tree (m³) (M) 1996 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03795/**

[11]**Statistics Norway. (2021).** ***Table 03895: Commercial removals of industrial roundwood, by assortment (m³) (M) 1996 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03895/**

[12]**Statistics Norway. (2021).** ***Table 06290: Growing stock under bark, by type of land, species of tree and surveyed regions (1 000 m³) 1996-2000 - 2015-2019*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06290/**

[13]**Statistics Norway. (2021).** ***Table 03522: Forest planting. Number, area and expenditure (C) 1971 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/03522/**

[14]**Statistics Norway. (2021).** ***Table 06108: Expenditure and public subsidies on silviculture (NOK 1 000) (C) 2005 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/06108**

[15]**Statistics Norway. (2021).** ***Table 08536: Employed persons (aged 15-74), by industry division (88 groups, SIC2007) and sex. 4th quarter (M) 2008 - 2020*. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/08536/**

[16]**Statistics Norway. (2021).** ***Table 06331: Productive forest area, by size class (decares) (C) 2005 - 2019*. Retrieved 15.07.21 at https://www.ssb.no/en/statbank/table/06331/**

[17]**Statistics Norway. (2021).** ***Table 06310: Roundwood cut for sale, by size class (m³) (C) 2005 - 2019*. Retrieved 15.07.21 at https://www.ssb.no/en/statbank/table/06310/**

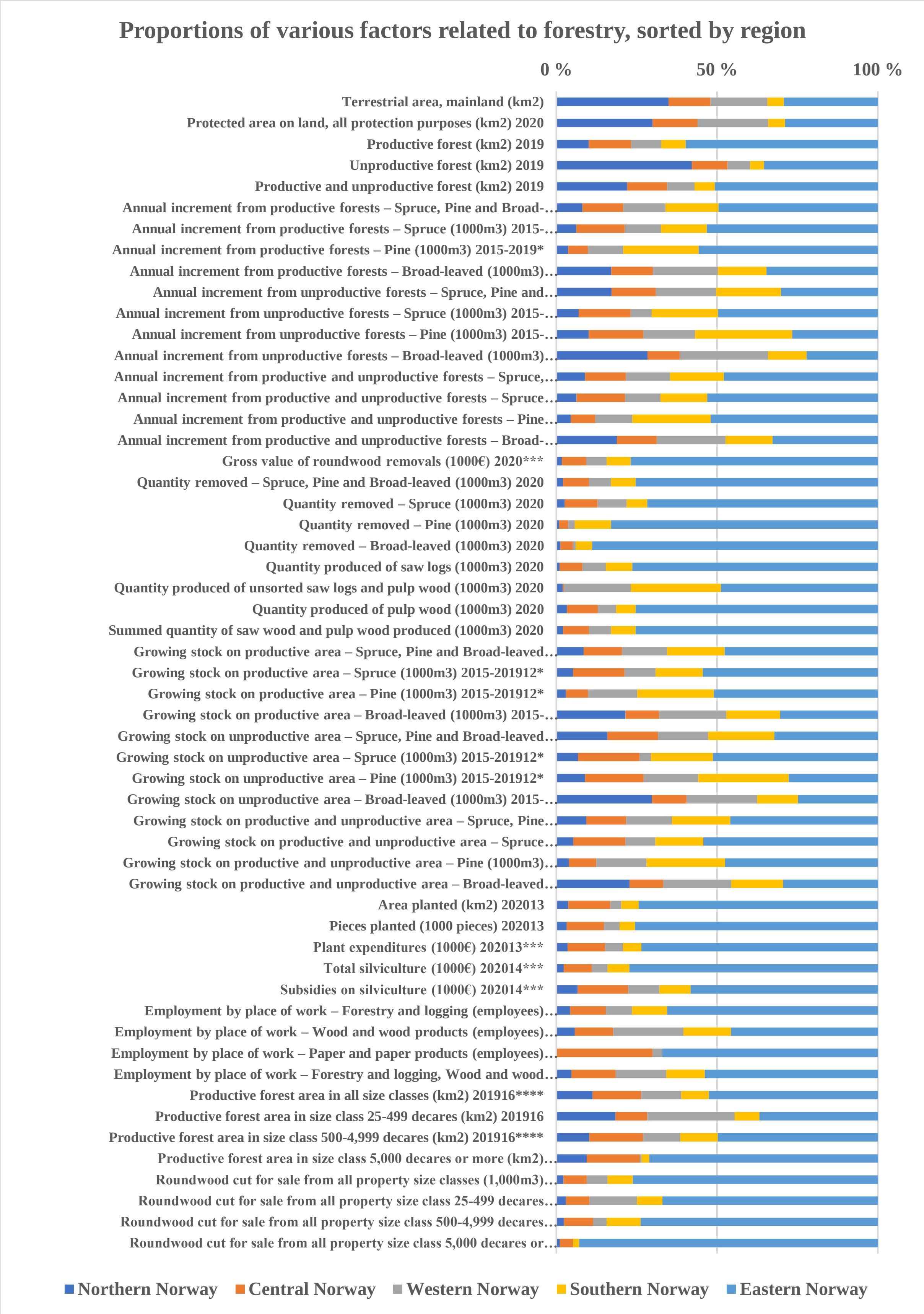

Figure 7.b: Regional distribution of various factors related to forestry

All data presented in Figure 6-c are identical with that presented in Table 6-c.

Table 7-c: Brief description of types of protection

Type of protection	Objective	Characteristics
National parks	Protect large areas of undisturbed nature	Preserving potential for outdoor activities and recreation. Usually allows traditional farming
Nature reserves	Conservate biodiversity	Activities that negatively affect the protected targets are forbidden. Some measures are used to counter unwanted succession.
Protected landscape areas	Conservate unique and aesthetic nature or agricultural areas	Careful and suitable farming and forestry can persist.
Biotope reserves	Protect habitats of precious species	The area is not protected explicitly, only the targeted habitats.

Fjellstad, K. B., & Skrøppa, T. (2020, p. 38-39). State of forest genetic resources in Norway 2020. In *NIBIO Report 6(167)*. NIBIO. Retrieved 03.07.21 at https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2720189

Table 7-d: Brief description of relevant laws and regulations

Law/regulation		Sections of attention
Forestry Act	§5	Forestry and environmental values in each property, shall be registered and managed in accordance with a unique forest management plan. Environmental values shall be open to public, in line with the Environmental Information Act.
	§6	Replanting or regenerating should be effective within three years after cutting. The deadline could be prolonged with two years.
	§7	Building and repairing forest roads must be approved by the municipality.
	§8	Environmental values and future forest production should be valuated before cutting decision is made. The municipality can overrule a decision to cut, based on these concerns.
	§10	After damages from natural causes, the municipality can order improvements within two years.
	§12	The County governor can protect forest areas to prevent natural damages on surrounding forest areas.
	§13	The ministry could restrict forestry whenever it finds it necessary with concern to biodiversity, landscape qualities, outdoor activities, and cultural heritage.
	§14	It is mandatory to put aside parts of the income from logging into the Forest Trust Fund. This account belongs to the forest property. The ministry is privileged to regulate the proportional size of funding.
	§15	Withdrawals are supposed to cover silviculture, forest planning, production, forest roads, and improving the environment on the very same property where the funding origins. The

		withdrawal could be relocated to an alternative forest property within the same municipality or applied to be allocated to an external forest property.
	§16	Interests from the Forest Trust Fund should accrue the government, and first cover administration cost of the fund, and second be spent on public forest measures.
Outdoor Recreations Act	§1	The purpose of the Outdoor Recreations Act is to sustain general right to access outdoor activities.
	§2	Everybody has the right to free access to outfield any time of year.
	§5	There should be public access to considerate harvesting of nuts, plants, berries, and mushrooms in the outfield. Cloudberries have the northern counties have site specific restrictions.
Biodiversity Act	§1	The purpose of the Biodiversity Act is to ensure sustainable use of nature and take care of biodiversity and environmental values.
	§4	Biodiversity and nature types should be preserved within their natural environment.
	§5	Biodiversity and genetic variation within natural its habitats should be protected.
	§8	Scientific knowledge should form the overall basis for decisions that concerns biodiversity.
	§9	The precautionary principle should be applied whenever scientific basis is insufficient.
	§13	The Government can make guiding regulations concerning biodiversity and should take necessary steps to attend certain environmental values.
	§30	The use of alien species, like tree species, requires governmental approval.
	§34	The government decides which areas should be protected, makes regulations to ensure this.
	§35	Large areas with characteristic ecosystem or landscape values can be given the status National Park.
	§36	Areas with cultural heritage and landscape of characteristic value can be given the status Protected Areas.
	§37	Areas with endangered species, or species of specific value can be given the status Nature Reserve.
	§38	Habitats of particular importance to their ecosystem can be protected as Key Biotopes.
	§50	Owners of properties that are protected are entitled to compensation in consultation with the Expropriation Act.
Game Act	§27	Within the provisions of the Game Act, the landowner has exclusive rights to hunting and fishing benefits.
Regulations relating to sustainable	§1	The purpose of the Regulation is to safeguard environmental values, reforestation, and the overall health of the forest.
	§3	The forest owner is obliged to take environmental considerations into account when measures are carried out in the forest.

	§4	Logging is normally only permitted when environmental registrations have been carried out in accordance with the Regulations relating to subsidies for forestry planning with environmental registration. The PEFC assumptions concerning precautionary standard shall be used when logging is planned in areas without such environmental registrations.
	§5	Key biotopes should be preserved, in accordance with the PEFC requirements. Logging waste shall be cleared. Soil damage shall be repaired. Five lifecycle trees per hectare shall be left on logging site. Logging shall be adapted to the landscape qualities, and the function of the edge zones must be safeguarded. Minimum 10 percent broad-leaved trees among coniferous regenerated forests shall be targeted. Ditching of wetlands are prohibited. Afforestation and change of tree species require mandatory application to the authorities. Use of alien tree species requires a specific application.
	§6	Cutting methods and regeneration methods should be harmonized.
	§7	Regeneration shall take place within three years after cutting, no later than five years if postponement is granted.
	§8	Specific requirements are set for minimum plant density, and recommended density intervals per acre, are provided for different site qualities.
	§9	The main principle for all forest measures shall be to prevent damage to the forest.
Regulations relating to grants for forestry planning with environmental registration	§1	The purpose of the Regulation is to safeguard biodiversity, landscape qualities, potential of outdoor activities and cultural remains.
	§6	Maps shall be prepared with a population overview on the forest property. Such a forestry plan shall describe area, harvesting classes, site qualities, volume per tree species, age, growth and environmental values related to the population. The entire forestry property shall describe the total area per tree species, productive forest area per site quality and logging class, volume per tree species, site qualities and logging class, growth and production capacity.
	§7	The County Governor decides on the scope of grants for the preparation of forestry plans. Up to 50 percent grants may be given to appropriate courses.
Regulations relating to the release of alien species for forestry purposes	§1	The purpose of the Regulation is to avoid biodiversity loss due to planting of alien tree species.
	§4	The Environment Agency is responsible for these regulations but can delegate responsibility to the County Governor.
	§5	Planting of alien tree species requires a mandatory permission from the authority in charge.
	§6	Applications must include, among other things, the scope and purpose of planting, as well as planned measures to prevent it to spread.
	§8	The forest owner is obliged to account for effects on biodiversity, and to initiate measures to prevent the spread. In the event of injury or risk of harm, the authorities must be notified.
	§9	The authorities have an obligation to inform forest owners about these regulations.
	§10	The forest owner has a duty to introduce internal control.
	§11	The authorities shall supervise when alien species are planted and monitor the spread.

Regulations related to forest funds etc.	§6	It is mandatory to deposit 4-40 percent of the income from logging in a Forest Fund account.
	§8	The County Governor shall seek the best market rate for the Forest Fund.
	§11	The Forest Fund provision can be used for silviculture, forest roads, environmental measures, environmental registration and planning, bioenergy measures, fire and storm insurance, competence enhancement, real estate survey and sales taxes.
	§14	Interests from the Forest Fund shall accrue to authorities, and cover administration costs, and otherwise be used for various purposes in forestry sector.

Forestry Act. (2005). ***Lov om skogbruk. (LOV-2005-05-27-31)*****.** **https://lovdata.no/dokument/NL/lov/2005-05-27-31**

Outdoor Recreations Act. (1957). ***Lov om friluftslivet. (LOV-1957-06-28-16)*****.** **https://lovdata.no/dokument/NL/lov/1957-06-28-16**

Biodiversity Act. (2009). ***Lov om forvaltning av naturens mangfold. (LOV-2009-06-19-100)*****.** **https://lovdata.no/dokument/NL/lov/2009-06-19-100**

Game Act. (1981). Lov om jakt og fangst av fisk. (). https://lovdata.no/dokument/NL/lov/1981-05-29-38

Regulations relating to sustainable forestry. (2006). ***Forskrift om berekraftig skogbruk***

(FOR-2006-06-07-593**). https://lovdata.no/dokument/SF/forskrift/2006-06-07-593**

Regulations relating to grants for forestry planning with environmental registrations. (2004). ***Forskrift om tilskudd til skogbruksplanlegging med miljøregistrering. (FOR-2004-02-04-449)*****.** **https://lovdata.no/dokument/SF/forskrift/2004-02-04-449**

Regulations relating to the release of alien species for forestry purposes. (2012). ***Forskrift om utsetting av utenlandske treslag til skogbruksformål. (FOR-2012-05-25-460)*****.** **https://lovdata.no/dokument/SF/forskrift/2012-05-25-460**

Regulations related to forest funds, etc. (2006). ***Forskrift om skogfond o.a. (FOR-2006-07-03-881)*****.** **https://lovdata.no/dokument/SF/forskrift/2006-07-03-881**

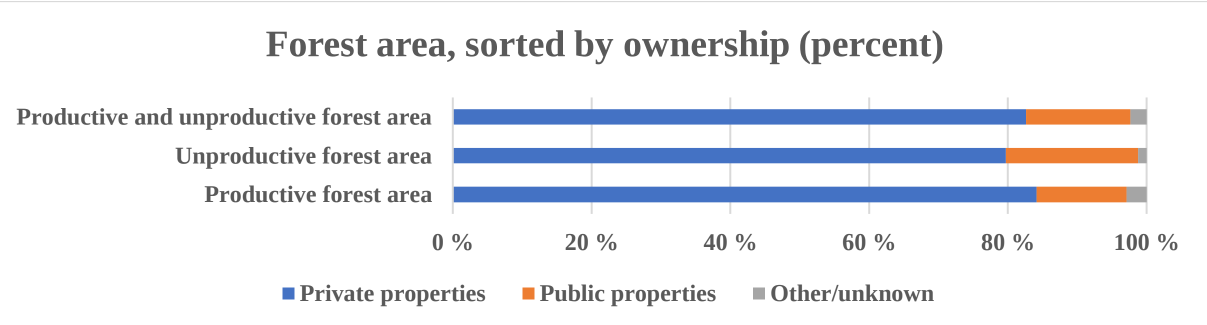

Figure 7.c: Productive forest, unproductive forest, and total forest, sorted by ownership

Statistics Norway. (2021). ***Table 10613: Forest properties and productive forest area, by type of forest owner 2013 - 2019*****. Retrieved 12.07.21 at https://www.ssb.no/en/statbank/table/10613/**

Private properties consist of categories: individual owners, private owners except individual owners, and properties of persons deceased. Public properties consist of categories: state and local government. Other/unknown consist of categories: other/unknown and common forest not owned by central government.

Table 7-e: Acronyms (organizations)

Collaboration's acronym	Full name	Description
AU	African Union	Continental union
AWG	Anthropocene Working Group	Interdisciplinary working group
CBD	convention on biological diversity	Multilateral treaty
EEA	European Economic Area	EU and EFTA
EFTA	European Free Trade Organization	Trade organization including 4 member states
EU	European Union	Political and economic union including 27 member states
EU ETS	European Union Emission Trading Scheme	EEAs common carbon market
GDN	Global Deal for Nature	Scientific working group
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services	United Nations scientific working group on biodiversity and ecosystem services
IPCC	Intergovernmental Panel on Climate Change	United Nations scientific working group on climate change
JRC	Joint Research Center	European Commissions science and knowledge service
NINA	Norsk institutt for naturforskning – Norwegian Institute for Nature Research	Foundation with research areas nature and society
SCBD	Secretariat of the Convention on Biological Diversity	CBDs secretariat, operating under UNEP
TEEB	The Economics of Ecosystems and Biodiversity	A study aiming to identify costs and benefits of biodiversity
UNDP	United Nations Development Programme	United Nations global development network
UNEP	United Nations Environment Programme	United Nations department for environmental issues
UNFCCC	United Nations Framework Convention on Climate Change	United Nations treaty for combating climate change
USAN	Union of South American Nations	Continental union
WWF	World Wide Fund for Nature	World-wide non-governmental organization

Table 7-f: Acronyms (definitions)

Expression's acronyms	Full expression	Explanation
AFOLU	Agriculture, Forestry and Other Land Use	LULUCF included agricultural sector
BAU	Business as usual	Reference level describing a hypothetical progress without intervention
BECCS	Bioenergy with Carbon Capture and Storage	Capturing and storing bioenergy from biomass (crops, etc.)
CAC	Command and Control	Direct judicatory regulation
CCS	Carbon Capture and Storage	Capturing and storing carbon
CDR	Carbon Dioxide Removal	Greenhouse gas removal
COP	Conference of the Parties	Supreme governing body of an international convention
DACCS	Direct Air Carbon Catch and Storage	Carbon removal by artificial sequestration
FOLU	Forestry and other land use	See LULUCF
GHG	Greenhouse gases	Gases that absorb and emit radiant energy
HWP	Harvested wood products	Dynamic measure of a carbon reservoir in harvested wood
LUC	Land-use change	See LULUCF
LULUCF	Land use, land-use change, and forestry	Developing land from one category to another, normally used in a context where it has impact on climate emissions, biodiversity, and other environmental issues
MEA	Multilateral Environmental Agreement	International treaty for environmental issues, involving more than two parties, often many countries
NET	Negative Emission Technology	Greenhouse gas removal