Exploring the Interplay between Future Wood Demands and Ecosystem Services Trade-Offs in Norway

Marta Vergarechea
Division of Forest and Forest Resources, Norwegian Institute of Bioeconomy Research, Ås, Norway, marta.vergarechea@nibio.no

Rasmus Astrup
Division of Forest and Forest Resources, Norwegian Institute of Bioeconomy Research, Ås, Norway, rasmus.astrup@nibio.no

Clara Antón Fernández
Division of Forest and Forest Resources, Norwegian Institute of Bioeconomy Research, Ås, Norway, clara.anton.fernandez@nibio.no

ABSTRACT

Many European countries are promoting a bioeconomy based on renewable resources to mitigate climate change. However, using renewable resources will increase timber and biomass demand and will conflict with other ecosystem services. Here, we analysed whether Norwegian forests could meet the projections for wood and biomass demands from the international market while also meeting targets for other FES. Using data from the NFI we simulated the development of forests under different management regimes and defined forest policy scenarios, according to the most relevant forest policies in Norway: national forest policy (NFS), biodiversity policy (BIOS), and bioeconomy policy (BIES). Through multi-objective optimization, we identified the combination of management regimes matching best with each scenario. Our results revealed that Norway will be able to meet demands for wood and biomass in all policy scenarios, but that the future provision of FES will be strongly determined by policy targets at the national scale.

KEYWORDS

Forest ecosystem services, forest management, forest policy, multi-objective optimization

1 INTRODUCTION

The 2030 Sustainable Development Goals of the United Nations and the Paris Climate Change Agreement have recently prompted several European countries to develop strategies promoting bioeconomies based on renewable resources (European, 2018). It is anticipated that these strategies will increase wood demand since they promote the use of renewable biological resources to produce food, materials, and energy (Schulz et al., 2021). However, the increased wood and biomass demands may conflict with other ecosystem services provided by forests (Blattert et al., 2022) such as biodiversity conservation, flood control, or climate regulation. Additionally, bioeconomy development is only one of many policy targets that influence forest resources and management in most countries (BMU, 2007). For example, many countries have a biodiversity strategy, which focuses mostly on forest ecosystem services (FES) related to biodiversity. In Norway, the main policies that impact forest management, and therefore forest ecosystem services, are the bioeconomy strategy [BIES] (Skog 22) (INNR, 2015), the biodiversity strategy [BIOS] (Natur for livet) (MCE, 2015) and the white paper on forest policy and the wood industry [National forest strategy, NFS] (Verdier i vesk) (NMAF, 2016). The extent and diversity of objectives related to Forest Ecosystem Services (FES) addressed in these policies vary significantly due to their specific policy focus. For example, BIOS acknowledges the significance of conserving biodiversity and enhancing resilience, NFS takes more of a value chain perspective, and BIES strives to augment timber and biomass production (Nilsson et al., 2012; Nabuurs et al., 2019). This can result in a lack of coherence, causing a mismatch in policy objectives and leading to suboptimal management and divergent flows of FES (Aggestam and Pülzl, 2018). Here, determining the "optimal" forest management regime -or combination of them- will rely on the specific policy objectives for FES and the presence of trade-offs between them (Temperli et al. 2012; Schulz et al., 2021). In this context, a diversified forest management approach, which allocates areas to different management objectives, can reconcile these trade-offs, as opposed to maintaining a single management regime for all FES targets (Eyvindson et al. 2021; Messier et al., 2021).

This research offers insight into how ecosystem services can be integrated into decision-making in the Norwegian context. Prior research has successfully assessed conflict arising from diverse policy objectives utilizing NFI data and multi-objective optimization (Blattert et al., 2022). In this case, these conflicts were effectively resolved by identifying management programs that offer optimal combinations of regimes, meeting the demands of the Forest Ecosystem Services (FES). Our main questions here were:

1. Can Norwegian forests meet the projected wood and biomass demand for achieving climate mitigation targets while simultaneously meeting FES demands under the three different national policies?
2. What is the optimal combination of forest management to meet these demands? What is the effect on the rest of FES?

2 METHODS

2.1. Forest data and management regimes

We used data collected during 2005- 2019 as part of the Norwegian National Forest Inventory (NFI). The NFI is based on a five-year cycle, so each plot is resampled every 5th year with 1/5 of all NFI plots visited annually. These NFI plots are 250 m2 in size and were established at each intersection of a 3 × 3 km (easting x northing) grid in the lowlands, a 3 × 9 km grid in the mountains excluding Finnmark, and a 9 × 9 km grid in Finnmark (Fig. 2). In the study, plot-level forest inventory data served as input for a single-tree forest growth simulator integrated into the SiTree platform (Antón-Fernández and Astrup, 2022). This modelling approach enabled an assessment of the potential impacts of climate change on Norwegian forests, providing valuable insights into their future dynamics (Antón-Fernández et al., 2016).

Using SiTree, we simulated different management alternatives, classified into seven management regimes. These management regimes represent different levels of harvest intensities, rotation times, green tree retention levels, numbers of thinnings, and types of regeneration. Seven management regimes were examined, including modifications of the prevalent “business as usual” regime (BAU) in Norway. These regimes consisted of extensified BAU (EBAU) with a longer rotation age, intensive (INT) with heightened management intensity, and intensive-short (SINT) with a shortened rotation age. Additionally, the multispecies (MULT) regime aimed to promote mixed stands of spruce, pine, and birch, while the continuous cover forestry (CCF) regime sought to diversify forest structures without a final clear-cut. Lastly, the set aside (SA) regime represented the alternative of no management activities.

2.2. Forest Ecosystem services and policy scenarios

We examined six key ecosystem services (FES) in our study: timber production, bioenergy, biodiversity conservation, erosion and water regulation, climate regulation, and recreation. To capture the complexity of estimating these services, we employed multiple indicators, as outlined in Table 1. For a comprehensive explanation of how these indicators were calculated, please refer to the work of Vergarechea et al. (2023).

Based on the main national policy documents reflecting Norway’s goals and governance mechanisms for FES provision, we defined three policy scenarios: The white paper on forest policy and wood industry, labeled here National Forest Strategy, NFS, (Verdier i vekst) (NMAF, 2016). This scenario aims to raise the value of the forestry and timber industry, increasing the production and sustainable extraction of raw materials, as well as the profitable production of bioenergy and biofuels. It also establishes objectives related to the conservation of biodiversity, through restrictions that prevent a decrease in the MIS area from its initial state. The Biodiversity Strategy, BIOS, (MCE, 2015) (Natur for livet), focused mainly on the promotion and conservation of biodiversity as well as the role that forests play in regulating services, such as erosion control. And finally, the Bioeconomic Strategy, BIES (INNR, 2015) (Skog 22). This scenario assumes more intense forestry, with a special focus on wood production, but also granting an important role to the rest of the ecosystem services, such as the increase in biodiversity or recreational aspects. Details of the policy scenarios are provided in Table 1.

Wood and biomass demand targets for Norway were expressed as timber demands and modelled using the GLOBIOM-forest model (IIASA's Global Biosphere Management Model, (Lauri et al., 2021)). GLOBIOM is an economic model that jointly covers the forest, agricultural, livestock, and bioenergy sectors, allowing it to consider a range of direct and indirect origins of biomass used. Therefore, by using multi-objective optimization, we matched the projected wood and biomass demand with the simulated timber harvest to determine whether Norway is capable of meeting climate mitigation targets.

2.3. Optimization

Using a multi-objective framework, we addressed the wood (GLOBIOM) and FES demands of the national strategies. Based on the preferences defined (Table 1) we designed policy-specific multi-optimization problem formulations to find a specific solution for each policy scenario while meeting the wood demands from GLOBIOM. Through specifying constraints and objectives, representing the policy targets, the optimization aimed to seek an efficient solution for individual forests defined from NFI plots. To do so, we followed a step-wise approach: 1) the hard targets or epsilon constraints were included, so we constrained timber harvest to match GLOBIOM demands; 2) the national policy targets for FES were then optimized (as a reference point), considering the objectives and constraints defined in Table 1. For a more detailed description of the mathematical formulation and individual functions used here see Vergarechea et al. (2023).

3 RESULTS

Figure 1a shows that Norway can meet GLOBIOM biomass demands for wood and bioenergy in all scenarios, NFS, BIOS, and BIES, due to the harvest volume aligning perfectly with GLOBIOM demands. Notably, there was a substantial and consistent increase in volume during the initial 50 years of the simulations, rising from 11 million m3 in 2018 to 16.8 million m3 in 2073. Following this period, the growth of the harvest volume became more gradual, ultimately reaching 17 million m3 by the end of the simulation in 2093.

In the NFS scenario, the extensive regime class (BAU) - traditionally employed in Norway - covered nearly 40% of the area, while in the BIOS scenario, it only accounted for 20%. Conversely, BIOS had a reduction of approximately 2 million ha in the area allocated to BAU (Figure 1b), with an increase of 1.2 million ha for set-aside and a 0.5 million ha increment for continuous cover forest. In the BIES scenario, BAU and extensified BAU (EBAU) held almost equal proportions at 28.1% and 30.7% respectively, followed by set-aside at 15.3% and intensive management (INT) at 11.8%. Compared to NFS, BIES exhibited a smaller area (1 million ha) assigned to BAU, but had an increased allocation for intensive (INT), extensified-BAU (EBAU), set-aside (SA) and continuous cover forestry (CCF).

Table 1. Set of indicators and constraints used in each of the policy scenarios, NFS, BIOS, and BIES. MiS area = set-aside areas of "Complementary Hotspot Inventory".

Forest ecosystem service (FES)	Indicator (unit)	NFS objective / constraint	BIOS objective / constraint	BIES objective / constraint
Wood production	Harvest net value (NOK)	Maximize		Maximize
	Harvested volume (Mm^3)		Maximize (even-flow)	
Bioenergy	Harvested residues (kt)	Maximize		
Biodiversity	MiS* area (ha)	No decline allowed		No decline allowed
	Deadwood volume (Mm^3)			
	Bilberry (%)			
	MIS area (ha)			
	Deadwood volume (Mm^3)			
	Bilberry (%)			
Water protection	Harvest vol. in steep terrain and mountain forests (Mm^3)		No decline allowed	
Climate regulation	CO_2 storage in harvested wood product (kt)	Maximize		Maximize
	CO_2 storage in harvested wood product (kt)	No decline allowed		
	Flow of carbon sink in forests (Million kt)			Maximize
Recreation			No decline allowed	No decline allowed
			No decline allowed	No decline allowed

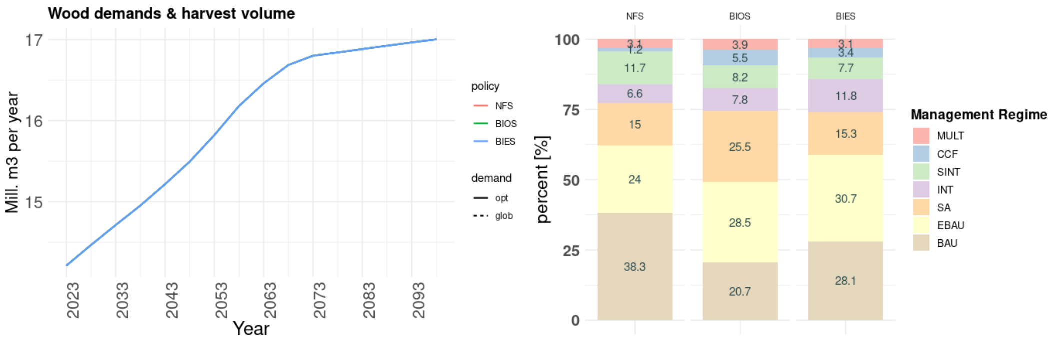

Figure 1.

a) **GLOBIOM wood and biomass demands for the NDC scenario, and provision of harvested volume under the three policy scenarios. Here, the attained harvest volumes and GLOBIOM wood and biomass demands for the NDC scenario completely match all 3 scenarios**

b) **Optimal management solution for the three policy scenarios.**

MiS area showed a consistent increase under both BIOS and BIES scenarios. Initially, the most significant increase was observed under BIOS, where the indicator served as both an objective to maximize and a constraint to prevent a decline from the current state in 2018. However, starting from 2042, there was a notable upward trend in the BIES scenario, resulting in higher values compared to BIOS by the end of the simulations. The BIOS scenario maintained a steady yield of bilberry, demonstrating the impact of constraints in preventing a decrease from the current state. Conversely, the other two scenarios, particularly NFS, experienced a decline in the bilberry area particularly during the initial years (Figure 2).

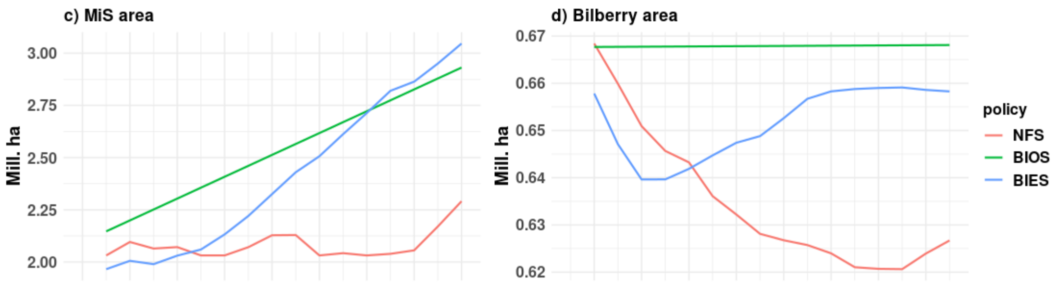

Figure 2. Effect of optimal solution on the future development of some biodiversity indicators

4 DISCUSSION AND CONCLUSION

Wood and biomass demand for climate mitigation targets (GLOBIOM) were easily met in all scenarios. By 2093, the demand reached almost 17 million m3, a 64% increase from 2018. This agrees with the findings of Solberg et al. (2021) who also predicted a substantial increase in Norway's harvest levels, rising from 10 million m3 in 2010 to 15.6 million m3 by 2050. Norway's harvest levels have historically remained fairly stable at around 10-13 million m3, while annual increment net growth has increased from 20 million m3 in 1990 to 24 million m3 in 2020 (SSB, 2020). This could indicate that current growth rates in Norwegian forest are below their potential for production. However, despite wood stocks are predicted or expected to increase in our scenarios, diverse uncertainties could considerably affect forest growth and development in the future.

Under the BIOS scenario, set-aside (SA) and continuous cover forestry (CCF) areas increase significantly. These practices positively impact forest structure and biodiversity, such as canopy structure, amount of deadwood, rotation length, presence of old trees and species mixture, and are crucial for ensuring the long-term sustainability of forests (Castro et al., 2015). However, achieving these benefits while meeting the demands for bioenergy and wood may require compensatory increases in timber harvest from other forest areas dedicated to intensive production (Duncker et al., 2012). Due to this, some areas of the forest may degrade to some extent, especially in NFS and BIES, where biodiversity targets have been more challenging to achieve. To minimize this, policies should establish instruments to encourage forest owners to adapt their management practices so that they can reduce forest degradation by using forest landscapes more effectively. Existing programs in Norway, such as those established by the Norwegian

Ministry of Agriculture and Food (2005) and MCE (2005), already address certain regulations and support for sustainable forestry practices. These include requirements for forest owners to regenerate harvested areas within three years and financial assistance for sustainable activities. Recent efforts have prioritized improving forestry infrastructure, such as forest roads and timber terminals, in areas with limited access, which helps maximize the utilization of forest resources.

According to Figure 2, BIOS and partially BIES were the most consistent scenarios for biodiversity FES indicators. Under the NFS and BIES scenarios, the decline in bilberry cover area could be explained by a lack of constraints on this indicator and could be related with the trade-off between timber production and ecosystem services. In this regard, Lõhmus and Remm (2017) demonstrated the influence of stand density on bilberry habitat. They found that the intensification of forestry brings reductions in bilberry cover, which agrees with the decline of the bilberry cover area under NFS and BIES (Figure 2). Differences in MiS area between scenarios could be explained by the fact that in NFS and BIES the indicator was included in the optimization framework as a constraint and not as an objective to maximize, as in BIOS (Table 1). As a result, BIOS and BIES both exhibit a non-decreasing pattern for MiS area, compatible with policy targets related to this indicator, while NFS shows significantly lower levels of MiS area.

In summary, the comparison of the three policy scenarios highlights that no single management strategy can fully optimize the provision of multiple ecosystem services simultaneously. A combination of these scenarios, incorporating different preferences, may be the most desirable approach. However, the analysis reveals conflicts among policies in terms of management. It emphasizes the importance of aligning future policies to address these inconsistencies.

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https://doi.org/10.20315/SilvaSlovenica.0022.13