ALTERFOR

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Abbreviations used

AFM – Alternative Forest Managements
C – Coniferous
GLOBIOM – Global Biosphere Management Model
G4M – Global Forest Model
MFM – Multifunctional Forest Management
NC – Non-Coniferous
PES – Payments for Ecosystem Services
PFM – Production Forest Management
RCP – Representative Concentration Pathway
ROW – Rest Of the World
RWeq – Roundwood equivalent
SFM – Set-aside Forest Management
SSP – Socioeconomic Pathway

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Transition to alternative forest managements in EU28: compensation costs, leakage effects and implications to forest sector

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ABSTRACT

In this study we investigate a transition to alternative forest managements (AFM) in EU28. The analysis is based on the Global Biosphere Management Model (GLOBIOM), which is a global spatially explicit partial equilibrium model of agricultural and forest sectors. The model is updated to include three different AFM: production forest management (PFM), multifunctional forest management (MFM) and set-aside forest management (SFM). The biophysical data for different AFM is based on 10 case study areas around EU28. The case study results were upscaled to EU28 level using land-scape level forest management models, Global Forest Model (G4M) and GLOBIOM. The suitable areas for AFM were determined by comparing the case study areas to similar forest areas across EU28. Our results indicate that forest owners seeking economic profits shift voluntarily to PFM while they do not shift MFM or SFM without additional compensation payments, as these managements decrease the harvest potential and expected income from wood sales. The estimated compensation payments for MFM transition are 50-100 €/ha/yr while for SFM transition they are 3-5 times higher. In addition to compensation payments, the transition to MFM decreases coniferous harvests in EU28. However, the leakage effects on harvests or forest industry production from the EU28 to rest of the world remain small, because EU28 forest industry can substitute coniferous biomass use by non-coniferous biomass use. The leakage effect on bioenergy feedstocks is small in the RCPref scenario, but it leads to considerable increase of pellets import to EU28 in the RCP2p6 scenario. The transition to SFM decreases both coniferous and non-coniferous harvests, and consequently leads to substantial higher leakage effects on harvests or forest industry production. Due to lower leakage effects and compensation costs MFM can be considered a better option than SFM, or combination of SFM and PFM, to produce wood and other ecosystem services in EU28. Moreover, MFM is also a less risky option to produce these services, as SFM and PFM tend to be more vulnerable for natural disturbances than MFM.

Keywords: production forests, multifunctional forests, set-aside, EU28 forest sector, leakage effect, payments for ecosystem services (PES)

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1 Introduction

Forest management in EU28 will face different types of challenges in the future. First, harvest volumes are expected to increase due to socioeconomic development and biomass use for energy to substitute fossil fuels. This would increase pressure to expand the managed forest area and intensify management in the managed forests (Lauri et al. 2019). Second, the demand for other forest ecosystem services besides wood production is expected to increase, which would increase the competition on forest resources (Thorsen et al. 2014). Third, climate change is expected to increase temperatures and extreme weather events, which are likely to increase the impact of natural disturbances, such as storms, fires and insect invasions, on forests (Seidl et a., 2017). This increases the role of risk management and adaptation to future climate risks in forest management.

Traditionally forest management in EU28 has mainly focused on fuelwood and construction materials production (McGrath et al 2015). During the last decades the interest in alternative forest managements has increased, as awareness of changes in demand, climate and ecosystem services has grown, and interaction between different functions of forests is understood better (Hengeveld et al. 2012, Thorsen et al. 2014, Kauppi et al. 2018, Schwaiger et al. 2019). Alternative forest managements (AFM) can be divided into three categories (Schwaiger et al. 2019). First, a production forest management (PFM) increases the wood production capacity of forests by focusing on even-aged management and shifting the forest vegetation from non-coniferous (NC) species and mixed forests towards coniferous (C) species and monocultures. It can be considered as adaptation strategy against increasing demand for forest industry products and bioenergy. Second, a set-aside forest management (SFM) excludes any forest management interventions. The absence of forest management interventions increases other ecosystem services supply. Other ecosystem services such as biodiversity are typically non-market goods and may not benefit forest owners directly. However, they benefit all humans indirectly. For example, biodiversity maintains ecological life supporting systems and providing basis for other all other ecosystem services (Costanza et al. 2017). SFM also sequestrates more carbon in the standing stock than a traditional production-oriented management (Schwaiger et al. 2019). From this perspective SFM can be considered also as mitigation strategy against climate change, at least in the short term. Third, a multifunctional forest management (=MFM) is a combination of PFM and SFM. MFM integrates wood production and other ecosystems services supply within a single forest stand. The difference of MFM relative to a combination of separate PFM and SFM stands is that MFM decreases landscape fragmentation (Simonsson et al. 2016).

MFM increases the supply of other ecosystem services by employing uneven-aged management and shifting forest vegetation from C species towards NC species and mixed forests. Uneven-aged management and mixed forest also improve resistance and resilience of forests to natural disturbances (Lafond et al. 2014, Jactel et al. 2017). Forest left without management (SFM) and monocultures (PFM) tend to be more vulnerable for natural disturbances than MFM in the European forests (Seidl et al. 2014, Kauppi et al. 2018). From this perspective MFM can be considered also as adaptation strategy against climate change risks, as climate change is expected to increase natural disturbances (Seidl et al. 2017). However, MFM does not sequestrate substantially more carbon in the standing stock than a traditional production-oriented management (Schwaiger et al. 2019).

Therefore, MFM should be considered more as adaptation rather than mitigation strategy against climate change.

A transition to MFM can be expected to affect the EU28 forest industry considerably, as MFM shifts forest vegetation towards NC species. For the last hundred years C biomass has dominated NC biomass in the global forest industry woody biomass use.[1] The main reason for this is that the forest industry is traditionally located in North America and Europe, where C trees are dominant species (FRA 2015). During the last decades the forest products markets has experienced a structural change, which has moved forest products production and consumption from North America and Europe to Asia and South-America (Hetemäki and Hurmekoski 2016). The structural change has decreased the relative share of C biomass in the global forest industry from 70% to 55% (FAO 2020), as in Asia and South America NC trees are dominant species (FRA 2015). This trend is expected to saturate in the future, as C and NC biomass have different material properties (density, strength, elasticity, lignin content etc.), which make them as imperfect substitutes. Thus, C biomass cannot be replaced fully by NC biomass in forest products production, and consequently, the tree species distribution becomes a critical factor in the regional level competitiveness of forest industry. Therefore, we can expect that North America and Europe continue to maintain competitiveness in the future forest products markets as long as C trees stay dominant species there.

In the product level C biomass use has decreased more in the paper and paperboard industry than in the sawmill industry. The relative share of C biomass in the global sawmill industry has decreased from 75% to 65% while in the paper and paperboard industry from 80% to 50% during the last 60 years (FAO 2020). Sawmill industry favors C biomass, because C sawlogs grow faster and have lower density than NC sawlogs, which makes them cheap and easily processable raw material for construction. NC sawlogs are used mainly for more value-added products like furniture and flooring where high density is required. The decreasing development of C biomass use in the paper and paperboard can be explained by increased supply of cheap NC pulpwood from planted forests (Payn et al. 2015). However, this development is expected to saturate in the future while C biomass has more suitable material properties for certain paper and paperboard grades (Chauhan et al. 2013). C biomass has long fibers, which provides good flexibility and strength properties needed in packaging materials and sanitary paper. NC biomass has short fibers and less lignin, which makes bleaching easier and provides good printing properties needed in newsprint and printing and writing papers. The demand for packaging materials and sanitary paper has been increasing while the demand for newsprint and printing and writing papers has been decreasing during the last 20 years and we can expect this development to continue in the future (Johnston 2016, Latta 2016).

Commonly, production value maximizing forest owners are not specifically concerned about other ecosystem services or increased tolerance against climate risks, because other ecosystem services usually do not provide income for them. Moreover, higher tolerance against climate risks does not necessary increase forest owners' incentives to apply MFM, because forest owners tend to underestimate the climate change risks (Keenan 2015). Due to these reasons forest owners do not voluntarily apply MFM/SFM and a transition to MFM/SFM requires additional incentives (Paloniemi and Vilja 2009, Viszlai et al. 2016, Roessiger et al. 2017, Obeng et al. 2018). One way to create such

[1] Before the 20th century NC species were dominant in Europe and woody biomass was used mainly as fuelwood for industrial processes. The share of C species started to increase in the mid-19th century when the demand for fuelwood decreased and demand for other forest products increased (McGrath et al. 2015).

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incentives is payments for ecosystem services (PES) (Viszlai et al. 2016). However, the monetary valuation of other ecosystem services is difficult due to imperfect and unreliable data on the benefits of other ecosystem services (Verkerk et al. 2014, Obeng et al. 2018). Therefore, PES is usually based on the lost production value of forests, i.e., opportunity costs of other ecosystem services, rather than actual value of other ecosystem services (Roessiger et al. 2017). The advantage of this approach is that lost production value of forests can be determined easily in the partial equilibrium model as a shadow price of hypothetical MFM/SFM transition.

Besides compensation payments to forest owners, the transition to MFM/SFM decreases EU28 harvest volumes, which tends to increase harvest volumes and/or forest industry production in other regions. This might lead to unsustainable land-use changes in other regions, which might eliminate benefits MFM/SFM transition in the global scale (Mayer et al. 2005, Gan and McCarl 2007). Moreover, MFM/SFM transition might shift forest industry production and employment from EU28 to other regions, and consequently decrease economic activity in EU28 (Kallio et al. 2018). MFM/SFM transition decreases also domestic woody biomass supply for energy, which is replaced by energy crops and imported pellets. This might lead to unsustainable land-use changes and reduced food security in the agricultural sector (Frank et al. 2013, Frank et al. 2017). Such a leakage effect is considered by Sohngen et al. (1999), Mayer et al. (2005), Gan and McCarl (2007), Sun and Sohngen et al. (2009), Kallio et al. (2018) and Kallio and Solberg (2018) among all. The general conclusion of these studies is that restricting harvests or forest management in one region tends to increase harvests in other regions substantially (estimates of leakage rates vary in range 40-100%).

A transition to AFM has been considered in global forest sector models by a few studies. Sohngen et al. (1999) show that SFM transition in USA and Europe leads to leakage of harvests outside USA and Europe, particularly in natural forests. Sun and Sohngen et al. (2009) extend Sohngen et al. (1999) analysis to include MFM and carbon accounting. They show that SFM could become nearly twice as expensive as MFM to sequestrate carbon due to larger leakage effects. Kallio et al. (2018) investigate the effects of EU28 level harvest constraints, which can be interpret as SFM. They show that EU28 level harvest constraints imply considerable leakage of harvests, forest industry production and employment outside EU28. Schier et al. (2018) investigate the implications of MFM transition in Germany. They show that MFM decreases C sawnwood export from Germany and increases C industrial roundwood import to Germany.

Usually global forest sector models like Global Forest Products Model (GFPM) (Buongiorno et al. 2003) do not distinguish between C and NC biomass. The main reason is missing data, since FAOSTAT provides C/NC disaggregation only for sawnwood, industrial roundwood and fuelwood (FAO 2020). The C/NC disaggregation is considered in the global forest sector models by Jonsson et al. (2018) and Schier et al. (2018). However, in these models the C/NC disaggregation is applied only for sawnwood and industrial roundwood, ignoring important trade-offs between C and NC biomass in the paper and paperboard production.

In this study, we consider a transition to AFM in EU28. The analysis is conducted by the Global Biosphere Management Model (GLOBIOM), which is extended to include forest products and forest area disaggregation to C/NC biomass/tree species and AFM. AFM are applied for EU28 while C/NC disaggregation globally. The study extends the literature of global forest sector models to include different types of AFM and a comprehensive C/NC disaggregation. The biophysical data for AFM is based on the ALTERFOR project (ALTERFOR 2019a). In the analysis, we focus on the economic trade-offs between current managements and AFM. In particular, we consider compensation payments for forest owners for the lost production value of forests. Such compensations are more generally called payments for ecosystem services (PES). In addition to compensation costs, we consider also the leakage of AFM on harvests, forest industry production and bioenergy feedstocks.

2 Method

2.1 GLOBIOM

The Global Biosphere Management Model (GLOBIOM) is a global spatially explicit partial equilibrium model of agricultural and forest sectors, in which the world is divided into about 200 000 land-use units (Havlik et al. 2011, 2014). In this study, we use the EU-version of the model, which has 58 economic regions (28 in EU28 and 30 outside EU28). The forest sector representation includes forestry, forest industry modules and bioenergy modules (Lauri et al. 2019).

The model is solved recursively using biophysical data from Global Forest Model (G4M) (Kindermann et al. 2006, 2008, Gusti and Kindermann 2011) and from Environmental Policy Integrated Climate Model (EPIC) (Williams 1995). Biophysical data for different forest types is generated by the G4M utilizing available biomass, land-cover and NPP data (Cramer et al. 1999, JRC 2003, FRA 2015). Biophysical data from G4M includes biomass growth rates, mortality, biomass stocks and maximum available harvest volumes of different feedstocks for each land use unit. To handle forest age-class dynamics in the recursive optimization model, it is assumed that managed forests are normal forests. Normal forests have a uniform distribution of age-classes and in each period the oldest age-class is removed by harvesting or mortality. This implies that available harvest volumes and biomass stocks stay constant in the managed forests.

The model includes four forest management practices: primary forests, secondary forests and managed forests (low/high intensity) (Lauri et al. 2019). Primary forests are forestland that has not been used historically for production. Managed forests are forest land that is actively used for production while secondary forests are abandoned managed forests. Harvest volumes can be increased be increasing managed forest area (converting secondary and primary forests to managed forests) and by intensifying forest management (converting low intensity management to high intensity management). The initial areas for different management practices are calibrated to match FRA (2015) data on production forest, primary forest, planted forest and total forest areas. The transition between different forest types is controlled by a non-linear transition costs, a mapping of allowed management changes and suitable areas for different managements.

The biomass demand for modern bioenergy is based on the PRIMES energy sector model for EU28 countries (PRIMES 2014) and on the SSP-RCP scenario data for the rest of the world (IIASA 2020). The biomass demand for traditional bioenergy is based on FAOSTAT data (FAO 2020) and kept constant after 2020 similar to Lauri et al. (2014) and Kallio et al. (2018). The biomass demands for material products are based on FAOSTAT data (FAO 2020) and shifted over time by SSP-specific GDP and population growth (IIASA 2020). Income and price elasticities for material products are based on historical estimates, similar to Buongiorno et al. (2003) and Morland et al. (2018). Forest products bilateral trade volumes are calibrated to the BACI (Base pour l’analyse du commerce international) bilateral trade data (Gaulier and Zignago 2010) and FAOSTAT data (FAO 2020). Trade costs are based on constant elasticity functions, which are parametrized by reference volumes and costs. The trade

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cost elasticities are assumed to be lower for roundwood and by-products, and higher for final products and pellets.

The model includes 5 harvested products (pulpwood, sawlogs, other industrial roundwood, fuelwood, logging residues). The forest industry module includes 4 paper grades (newsprint, printing and writing papers, packaging materials, other papers), 4 pulp grades (chemical pulp, mechanical pulp, recycled pulp, other fiber pulp), 3 mechanical forest industry products (sawnwood, plywood, fiberboard), 4 forest industry by-products (woodchips, sawdust, bark, black liquor) and 2 recycled products (recycled paper, recycled wood). The bioenergy module includes 2 final products (traditional bioenergy, modern bioenergy) and one intermediate product (pellets).

2.2 Coniferous vs. non-coniferous disaggregation

In this study, GLOBIOM is extended to include forest products and forest area disaggregation to C and NC biomass/tree species. The forest products disaggregation to C/NC biomass is based on the FAOSTAT data, which distinguishes between C/NC sawnwood, C/NC industrial roundwood and C/NC fuelwood (FAO 2020). The remaining forest products are disaggregated by using region material balances so that demand and supply of C and NC biomass match with each other for each region. The disaggregation is not implemented for traditional and modern bioenergy, as C and NC biomass are closed substitutes in the energy use.[2]

Income- and price-elasticities are assumed to be same for C/NC products except for NC sawnwood, which is assumed to have 50% lower income-elasticity than for C sawnwood based on Morland et al. (2018).

The forest area disaggregation to C/NC tree species is based on the on the FRA (2015) growing stock data. The tree-species distribution is assumed to stay unchanged over time in the forest area without AFM. The main reason for this simplification is that the current version of the model lacks global biophysical data about suitable areas for different tree species.

2.3 Alternative forest managements

In this study, GLOBIOM is extended to include AFM. AFM are modelled as additional forest management practices besides current managements practices in EU28. The biophysical data for AFM is based on ALTERFOR project, which included 10 case study areas around EU28. The case study results are upscaled to land-scape level by using different national forest growth simulation models (ALTERFOR 2019a, Schwaiger et al. 2019). The land-scape level results are upscaled to EU28 level by using GLOBIOM and G4M (ALTERFOR 2019b). The detailed description of case study results and upscaling method is out of the scope of this study and can be found from above publications.

Some case study areas included MGM, but not PFM and SFM. The missing data for PFM and SFM was created by using data from other case study areas. Due to the diversity of case study areas and forest management models, the results from forest management models are implemented to GLOBIOM by

[2] There are some differences between C and NC biomass in the energy use (Alakangas et al. 2016). However, these differences matter less than some other properties of biomass, e.g. moisture content. First, NC biomass has higher density, which makes it better household fuelwood. Second, C biomass has higher lignin content, which makes it better raw material for pellets.

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shifting the parameters of current management practices. The shifted parameters and the range of parameter shifters are displayed in Table 1. The availability of roundwood is increased in PFM 18-22% relative to current managements while in MFM it decreases 3-14% depending on the applied alternative management type. The availability of logging residues is assumed to be similar in PFM than in current managements (max 50% of harvest losses, branches and stumps) while in MGM it is decreased 50%. The share of non-coniferous species (NC-share) is decreased in PFM 9-42% relative to current managements while in MFM it increases 2-56% depending on the applied alternative management type.

Table 1. Parameter shifters for alternative managements relative to current high intensity management (PFM=production forest management, MFM=multifunctional forest management, SFM=set-aside forest management)

	Available roundwood (m3/ha/yr)	Available logging residues (m3/ha/yr)	NC-share
PFM	1.18-1.22	1	0.58-0.91
MFM	0.86-0.97	0.5	1.02-1.56
SFM	0	0	1

The suitable areas for different AFM outside the case study areas are based on the suitability index, which was estimated by comparing each case study area to similar forest areas across EU28 (ALTERFOR 2019b). For simplicity, the suitability index is assumed to be same for MGM, SFM and PFM for each case study area. Suitable areas are assumed to increase linearly from zero in 2020 to total suitable area in 2100, which is 79 Mha in EU28 level (50% of the forest area). This constraint was added in the model to avoid "too fast" transition to AFM. The suitable area is considered the same for all different types of AFM. For the area not considered suitable for AFM, we apply current management practices with constant tree species distribution.

2.4 Scenarios

We investigate 2 two mitigation/socioeconomic scenarios and 10 management scenarios (Table 2). The mitigation/socioeconomic scenarios include RCPref-SSP2 and RCP2p6-SSP scenarios. The data and description of these scenarios can be found from the SSP-RCP database (IIASA 2020). The management scenarios include baseline scenario without AFM, AFMfree scenario without forcing and AFM scenarios with forcing. In the AFMfree scenario forest owners can choose freely between AFM and current managements. In this case, the only competitive AFM relative to current management practices will PFM, since MFM/SFM decrease available harvest volumes (table 1). In the remaining scenarios forest owners are forced to choose MFM/SFM for x% of suitable areas while for 1-x% of suitable areas they can choose freely between current managements and AFM.

Table 2. Different scenarios

Mitigation/socioeconomic	
RCPref	No mitigation scenario (3.8°C temperature increase in 2100 relative to the pre-industrial level). Intermediate socioeconomic development (SSP2).
RCp2p6	High mitigation scenario (1.8°C temperature increase in 2100 relative to the pre-industrial level). Intermediate socioeconomic development (SSP2).

Management	

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Baseline	No AFM available.
AFMfree	AFM available for suitable areas. No forcing.
MFM25	MFM forced to 25% of suitable area. Other AFM available for remaining suitable areas.
MFM50	MFM forced to 50% of suitable area. Other AFM available for remaining suitable areas.
MFM75	MFM forced to 75% of suitable area. Other AFM available for remaining suitable areas.
MFM100	MFM forced to 100% of suitable area. No other AFM available.
SFM25	SFM forced to 25% of suitable area. Other AFM available for remaining suitable areas.
SFM50	SFM forced to 50% of suitable area. Other AFM available for remaining suitable areas.
SFM75	SFM forced to 75% of suitable area. Other AFM available for remaining suitable areas.
SFM100	SFM forced to 100% of suitable area. No other AFM available.

2.5 Leakage effects

A leakage means that a decrease of production activity in one region caused by a domestic policy is replaced by an increase of production activity in the other region or sector. The decrease might be caused by different types of domestic policies, e.g. mitigation policy (Sun and Sohngen et al. 2009), conservation policy (Sohngen et al. 1999, Mayer et al. 2005, Gan and McCarl 2007) or forest policy (Kallio et al. 2018). The production activity might be harvests, forest industry production, employment, bioenergy production, bioenergy feedstocks use, carbon sequestration, biodiversity or other ecosystem services. The amount of leakage can be measured in absolute volumes as well as in relative volumes, i.e., in leakage rates.

In this study, we investigate the leakage effects of AFM on harvests, forest industry production and bioenergy feedstocks. The leakage effects of AFM on carbon sequestration, biodiversity or other ecosystem services were not considered, as the modelling approach (recursive dynamic partial equilibrium model) is not the best fitted method to analyze these issues. The leakage effect on harvests is calculated by comparing roundwood harvests decrease in EU28 to roundwood harvests increase in ROW in 2100. The leakage effect on forest industry production is calculated by comparing the forest industry production decrease in EU28 to the forest industry production increase in ROW in 2100. Different forest industry products are aggregated by using roundwood equivalent units. The leakage effect on bioenergy feedstocks use is calculated by comparing the decrease of logging residues and forest industry by-products to increase of energy crops and imported pellets. Remark that the total bioenergy is taken as given in the analysis, i.e., the leakage rate of bioenergy feedstocks will be always 100%.

The leakage effects depend on three things. First, how much of the decrease in C harvests can compensate by increase in NC harvests. This effect is relevant in the MFM transition where the availability of domestic C biomass is decreased, but remains small in the SFM transition, where availability of domestic C as well as NC biomass is decreased. Second, how much of the decrease in domestic harvests can be compensated by import or products from other sectors. This effect is relevant in the MFM as well as in the transition SFM transition. Third, other regions forest policy. For example, if other regions apply AFM, then the leakage effect of EU28 AFM will be different. For simplicity, this issue was not considered in this study, i.e., we assume that regions outside EU28 do not shift to alternative forest managements.

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3 Results

In the sections 3.1-3.3 we focus on baseline, AFMfree, MFM100 and SFM100 scenarios, since the results for the mixed AFM scenarios (MFM25-75 and SFM25-75) can be easily interpolate from other scenarios. The mixed AFM scenarios are considered explicitly in sections 3.4-3.7 in connection with leakage effects and compensation payments.

3.1 Sawlogs and pulpwood harvests in the baseline scenario

In the global level sawlogs and pulpwood harvest volumes have grown relatively steadily during 1960-2018 (FAO 2020) and this trend is expected to continue in the future (Figure 1). C sawlogs harvests have been fluctuating more NC sawlogs, because the demand for C sawnwood (construction industry) is more sensitive for business cycles than the demand for NC sawnwood (furniture industry).

The relative share of C sawlogs has decreased from 75% to 66% while the relative share of C pulpwood from 82% to 50% during the last 60 years. The reason is that the structural change in global forest products markets, which has affected more on the relative share of C pulpwood than the relative share of C sawlogs (Hetemäki and Hurmekoski 2016). During 2020-2100 the relative share of C sawlogs is expected to stay around 66% while the relative share of C pulpwood is expected to increase slightly from 50% to 53% due to increasing demand for packaging materials and other papers (Johnston 2016, Latta 2016).

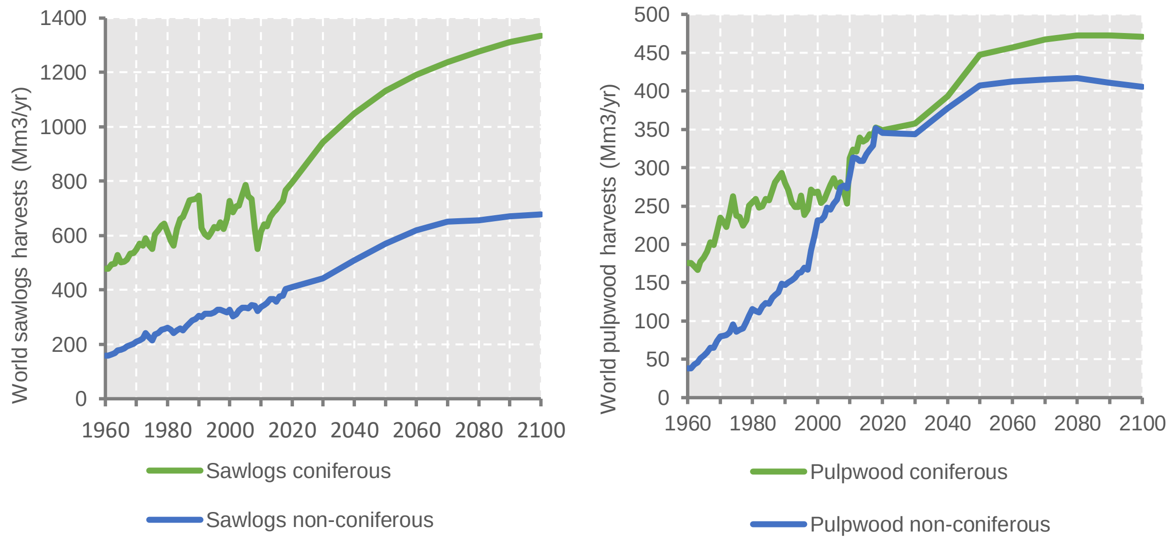

Figure 1 Global sawlogs and pulpwood harvests (Mm3/yr) (1960-2018 FAOSTAT data, 2020-2100 baseline scenario)

The development of EU28 harvest volumes differs somewhat from the global development (Figure 2). First, the increase of harvest volumes is expected to saturate in the future. The reason is limited EU28 forest resources (see chapter 3.2). In particular, there is not much potential to increase C biomass harvesting in the baseline scenario, as tree species distribution and available harvest volumes are assumed to stay constant over time. Second, the relative share of C sawlogs and C

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pulpwood is higher than globally. The reason for this is that coniferous trees are dominant species in EU28 (60% of EU28 growing stock is C biomass) while globally non-coniferous trees are dominant species (64% of global growing stock is NC biomass). The relative share of C sawlogs has increased from 77% to 87% during 1960-2018 and it is expected to decrease to 83% in the future. The relative share of C pulpwood has decreased from 87% to 68% during 1960-2018 and it is expected to stay around 68% in the future.

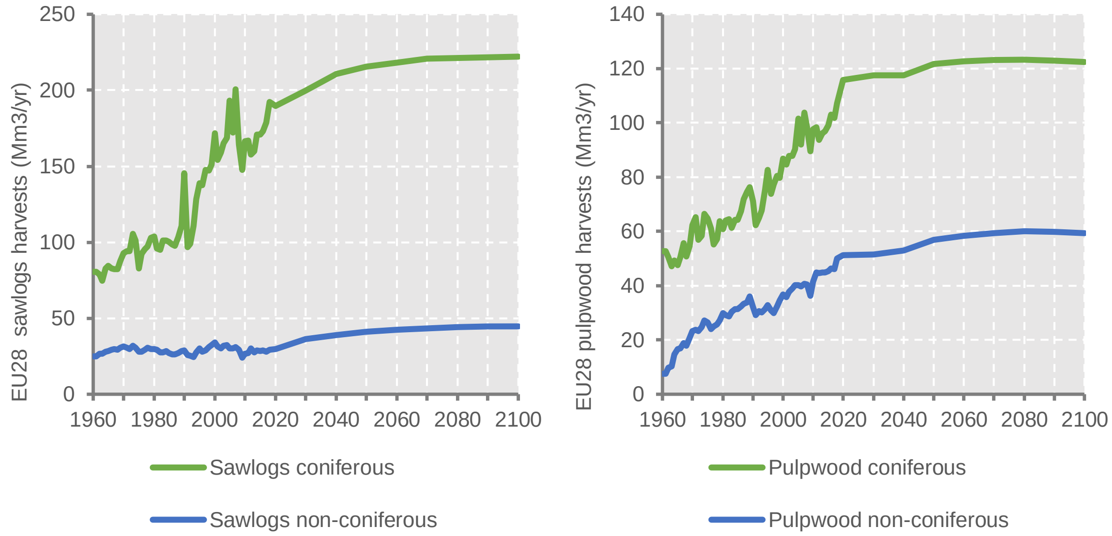

Figure 2 EU28 sawlogs and pulpwood harvests (Mm3/yr) (1960-2018 FAOSTAT data, 2020-2100 GLOBIOM baseline scenario)

3.2 EU28 forest areas

In 2020, EU28 total forest area is 161 Mha, which consists of 106 Mha high intensity forest management, 31 Mha low intensity management and 24 Mha unmanaged forest area (Figure 3). The total forest area increases due to afforestation from 161 Mha in 2020 to 175 Mha (RCPref) and 182 Mha (RCP2p6) in 2100. Afforested areas are based on G4M and they included to unmanaged forests until they are harvested.

In the baseline scenario, the high intensity area increases from 106 Mha in 2020 to 121 Mha (RCPref) and 138 Mha (RCP2p6) in 2100 (Figure 3a,b). This means that the intensity of forest management and harvest volumes are expected to increase in the future, as the demand for forest products increases. On the other hand, low intensity and unmanaged areas do not change much, since these areas have typically low productivity and it is not economically profitable to convert them to high intensity management forests. In the AFMfree scenario, PFM area increases to 59 Mha (RCPref) and 68 Mha (RCP2p6) in 2100 (Figures 3c,d). This implies that forest owners shift voluntarily to PFM, as it increases available harvest volumes, but they do not shift to MFM or SFM, as such shifts would decrease available harvest volumes. PFM are located mainly to current high intensity management areas, because suitable areas for alternative forest management overlap mostly with these areas. In the MFM/SFM100 scenarios forest owners are forced to choose MFM/SFM instead of PFM or current managements, which increases MFM/SFM area up to 79 Mha in 2100 (Figures 3e,f,g,h). In the SFM100 scenario low intensity and unmanaged areas decrease

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more and high intensity areas less than in the MFM100, since SFM100 increases wood prices substantially and makes the utilization of low productivity areas economically profitable.

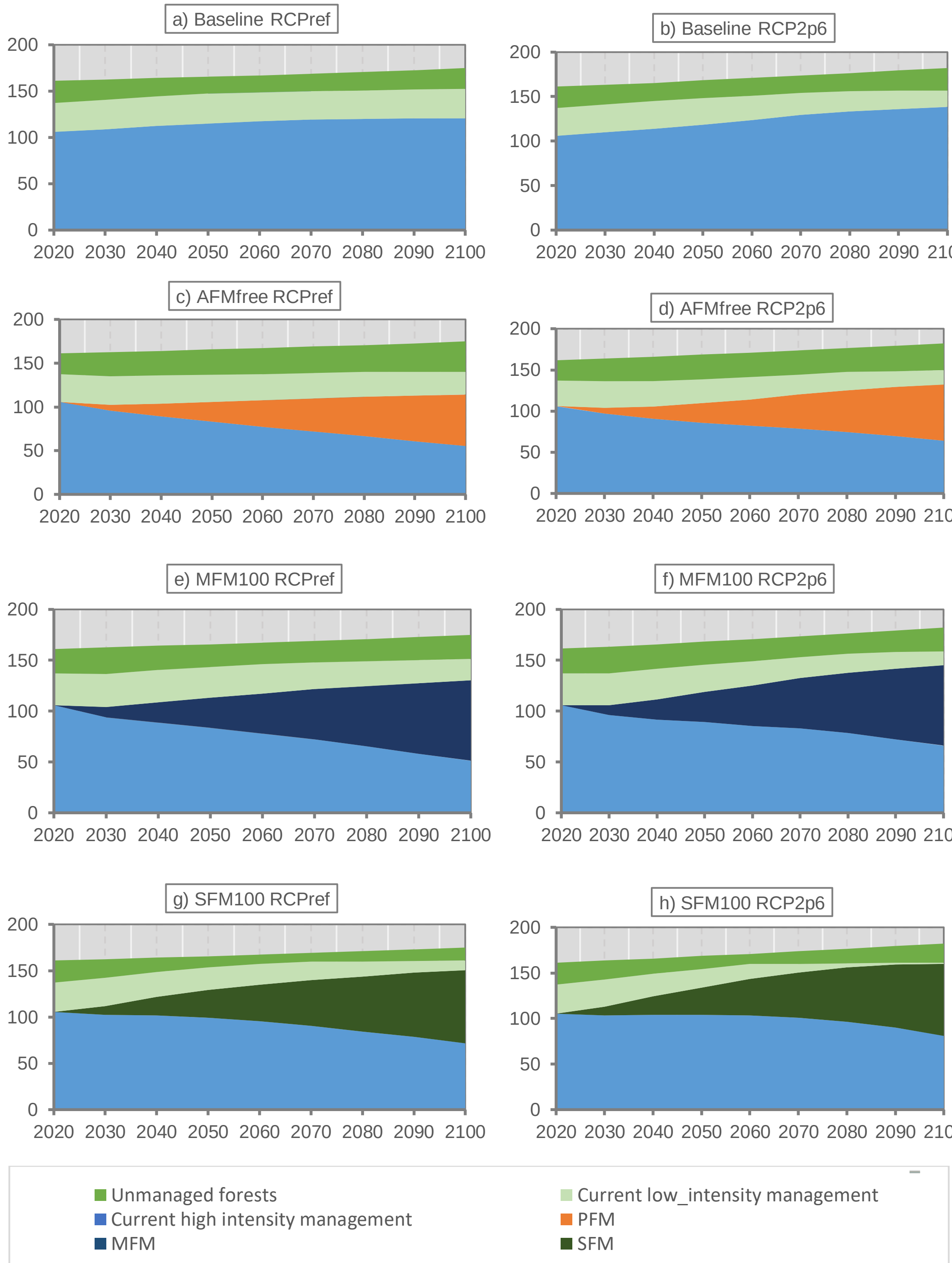

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Figure 3 EU28 forest area development in different scenarios

3.3 EU28 roundwood harvests and forest products net exports

In the RCPref baseline scenario C roundwood harvests increase from 378 Mm3/yr in 2020 to 410 Mm3/yr in 2100 (Figure 4). In the same time C forest products net exports decrease from 16 Mm3/yr RWeq in 2020 to -27 Mm3/yr RWeq in 2100 (Figure 5).[3] This happens, because current management practices do not allow forest owners to increase C roundwood harvests sufficiently to match the future demand. Consequently, EU28 is forced to increase import and/or decrease forest industry production. NC roundwood harvests increases from 115 Mm3/yr in 2020 to 171 Mm3/yr in 2100, and NC forest products net exports decrease -39 Mm3/yr RWeq in 2020 to -43 Mm3/yr RWeq in 2100. This indicates that current management practices restrict NC roundwood harvests less than C roundwood harvests.

In the RCP2p6 baseline scenario harvests and net exports development is similar to RCPref baseline scenario except that NC roundwood harvest volumes increases to 246 Mm3/yr in 2100. This is caused by higher demand for bioenergy, which increases NC forest industry by-products use for energy, but does not affect much on C forest industry by-products use for energy.

In the AFMfree scenario forest owners apply PFM to adapt the higher future demand. This increases EU28 C roundwood harvests by 44-73 Mm3/yr relative to baseline in 2100 and keeps C forest products net exports positive. Consequently, EU28 does not need to increase import and decrease forest industry production. NC roundwood harvests and net exports stay approximately in the same level than in the baseline.

In the MFM100 scenario forest owners are forced to apply MFM for all suitable areas. This decreases C roundwood harvests by 46-63 Mm3/yr relative to baseline in 2100 while C forest products net exports remain unchanged. In the same time NC roundwood harvests increase by 50-52 Mm3/yr relative to baseline in 2100 while NC forest products net exports remain unchanged. Consequently, MFM transition does not affect much total harvest volumes relative to baseline, as decrease in C harvests is compensated by increase in NC harvests. On the other hand, MFM transition decreases harvest volumes relative to AFMfree, as adaptation to higher demand by PFM is not possible.

In the SFM100 scenario forest owners are forced to apply SFM for all suitable areas. This decreases C roundwood harvests by 226-251 Mm3/yr and C forest products net exports by 197-200 Mm3/yr RWeq relative to baseline in 2100. In the same time NC roundwood harvests are decreased by 40-97 Mm3/yr and NC forest products net exports by 25-48 Mm3/yr RWeq relative to baseline in 2100. Consequently, SFM transition decreases total harvest volumes considerable relative to baseline, as it is not possible compensate decrease in C harvests by increase of NC harvests. The decrease is even larger relative to AFMfree, as adaptation to higher demand by PFM is not possible.

[3] Forest products net exports are measured in roundwood equivalent (RWeq) units, which allows aggregation over different forest sector products. RWeq measures forest products by roundwood volume that is needed for their production. Forest products net exports exclude pellets, because pellets can be produced also from energy crops in the model.

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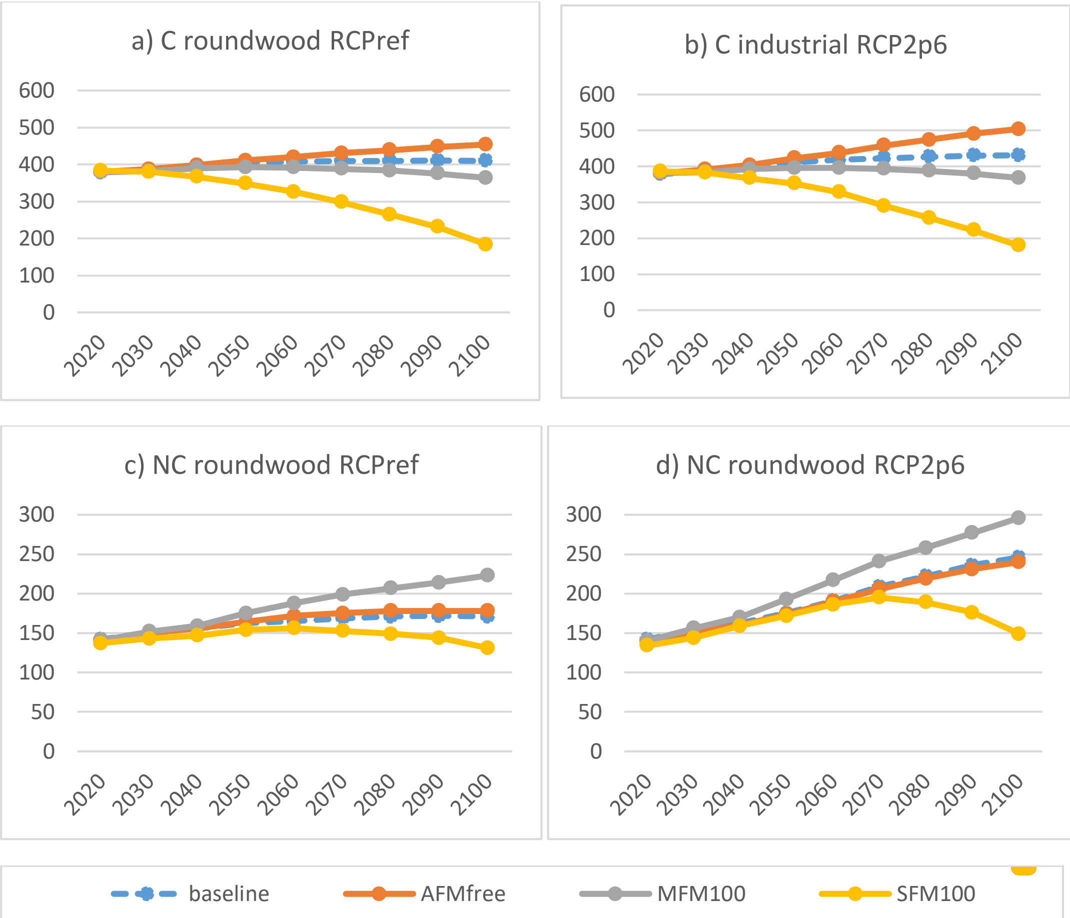
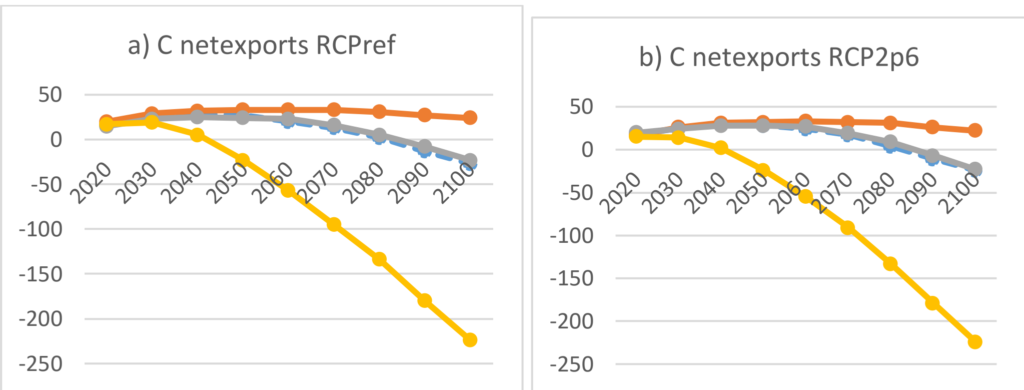


Figure 4 EU28 roundwood harvests (Mm3/yr)



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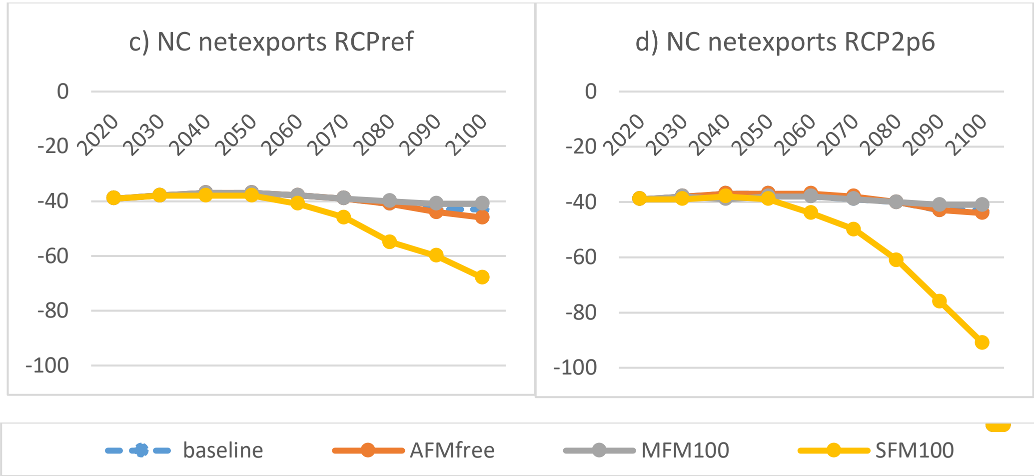

Figure 5 EU28 forest products net exports (Mm3/yr RWeq)

3.4 The leakage effect on roundwood harvests

In the RCPref AFMfree, MFM25-100 and SFM25 scenarios EU28 roundwood harvests are higher and ROW lower than in the baseline (Table 3). This means that there is an inverse leakage effect from EU28 to ROW. There are two reasons for this. First, current managements are replaced by PFM, which increases EU28 harvests and competitiveness relative to ROW. Second, the decrease in C harvests due to MFM is compensated by increase in NC harvests. The substitution happens mainly between C and NC pulpwood while there is little substitution between C and NC sawlogs (Figure 6). In the RCPref SFM50-100 scenarios EU28 roundwood harvests are lower than in the baseline, since current managements are replaced by SFM. With SFM it is not possible to compensate decrease in C harvests by NC harvests, because both C and NC harvests are decreased. The leakage rates are quite high and range from 50-90% similar to other studies (e.g. Kallio et al. 2018).

In the RCP2p6 scenarios the leakage effect on harvests in comparable to RCPref scenarios, but leaked harvests are 30-100% higher than in the RCPref scenarios. The reason for this is higher demand for bioenergy in RCP2p6, which increases logging residues and forest industry by-products demand for energy, and consequently causes an indirect effect on roundwood harvests.

Table 3. Changes in EU28 roundwood harvests relative to baseline (Mm3) and the associate leakage rates (%) in 2100.

RCPref

	AFMfree	MFM25	MFM50	MFM75	MFM100	SFM25	SFM50	SFM75	SFM100
EU28	51	49	45	32	6	24	-45	-138	-266
ROW	-37	-34	-33	-26	-5	-22	23	87	159
World	14	15	12	6	1	2	-22	-51	-107
Leakage rate	-73%	-69%	-73%	-81%	-83%	-92%	51%	63%	60%

RCP2p6

	AFMfree	MFM25	MFM50	MFM75	MFM100	SFM25	SFM50	SFM75	SFM100
EU28	67	55	37	11	-13	20	-89	-201	-349
ROW	-46	-40	-35	-14	17	-18	43	150	240
World	21	15	2	-3	4	2	-46	-51	-109
Leakage rate	-69%	-73%	-95%	-127%	-131%	-90%	48%	75%	69%

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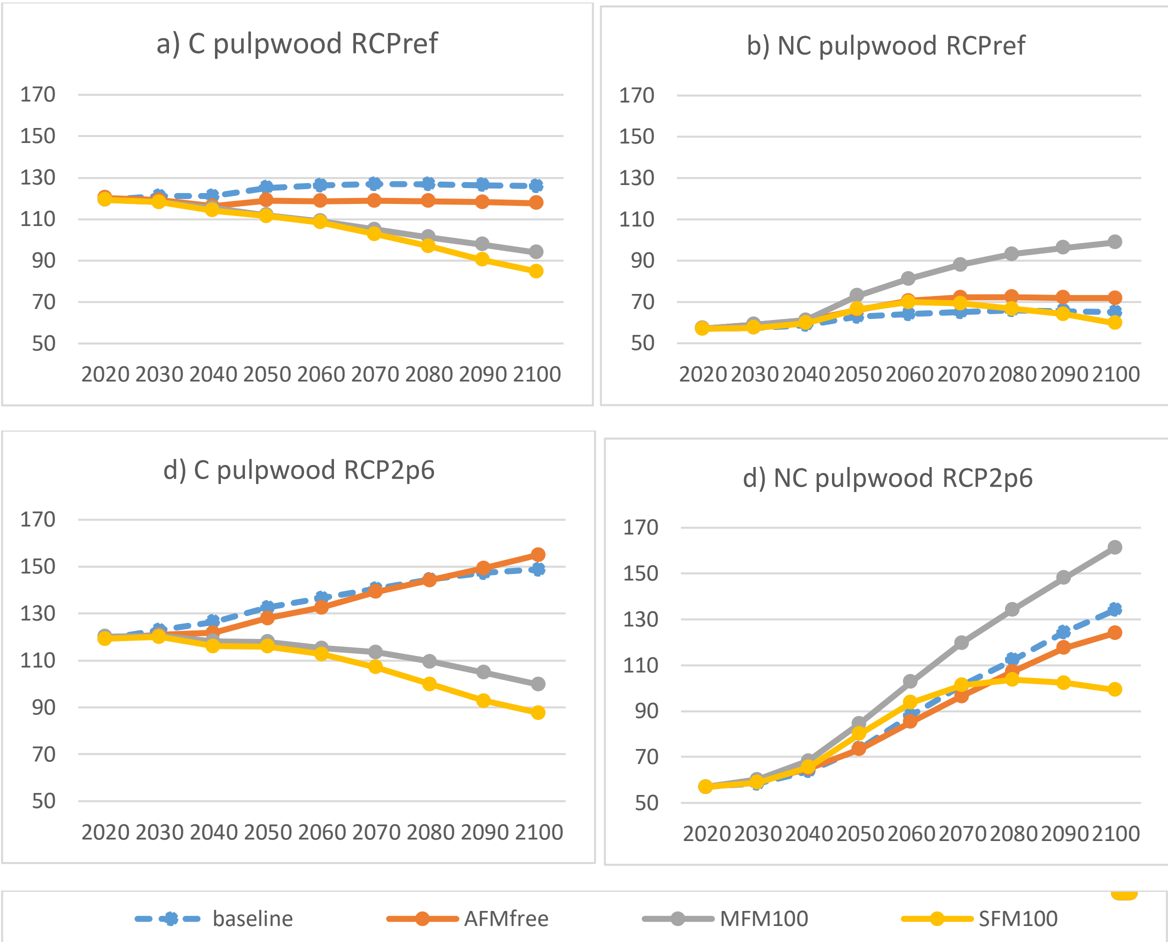

Figure 6 Substitution between C and NC pulpwood use in the EU28 forest industry (Mm3/yr)

3.5 The leakage effect on forest industry production

The decrease of forest industry production and the leakage effects are somewhat lower than the decrease of harvest volumes and the leakage effects on roundwood harvests (Table 4). The reason for this is forest industry can adapt the decrease of roundwood harvests also by increasing roundwood import (Figure 7).

Table 4. Changes in EU28 forest industry production relative to baseline (Mm3 RWeq) and the associate leakage rates (%) in 2100.

RCPref

	baseline	MFM25	MFM50	MFM75	MFM100	SFM25	SFM50	SFM75	SFM100
EU28	49	51	46	33	13	24	-33	-84	-136
ROW	-33	-35	-32	-26	-9	-18	24	50	83
World	16	16	14	7	4	6	-9	-34	-53
Leakage rate	-67%	-69%	-70%	-79%	-69%	-75%	73%	60%	61%

RCP2p6

	baseline	MFM25	MFM50	MFM75	MFM100	SFM25	SFM50	SFM75	SFM100
EU28	65	56	45	33	16	16	-49	-114	-161

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ROW	-41	-33	-31	-24	-7	-8	33	77	104
World	24	23	14	9	9	8	-16	-37	-57
Leakage rate	-63%	-59%	-69%	-73%	-44%	-50%	67%	68%	65%

The leakage effect on EU28 forest industry production is partly compensated by roundwood and woodchips import (woodchips=chipped roundwood). Majority of imported roundwood and woodchips is coniferous species and comes from boreal zone, i.e., from Canada and Russia (Figure 7). The import is substantial higher in the SFM transition than in the MFM transition while the difference between RCPref and RCP2p6 scenarios is small. The reason is that imported roundwood and woodchips are not used directly for bioenergy EU28, and consequently higher demand for bioenergy impacts on the import only indirectly through higher demand for forest industry by-products for energy (Lauri et al. 2017). Increasing EU28 roundwood and woodchips import from 33 Mm3 in 2020 to 45-190 Mm3 in 2100 seems high, but not implausible given that China was importing 60 Mm3 roundwood and 22 Mm3 woodchips in 2018 (FAO 2020).

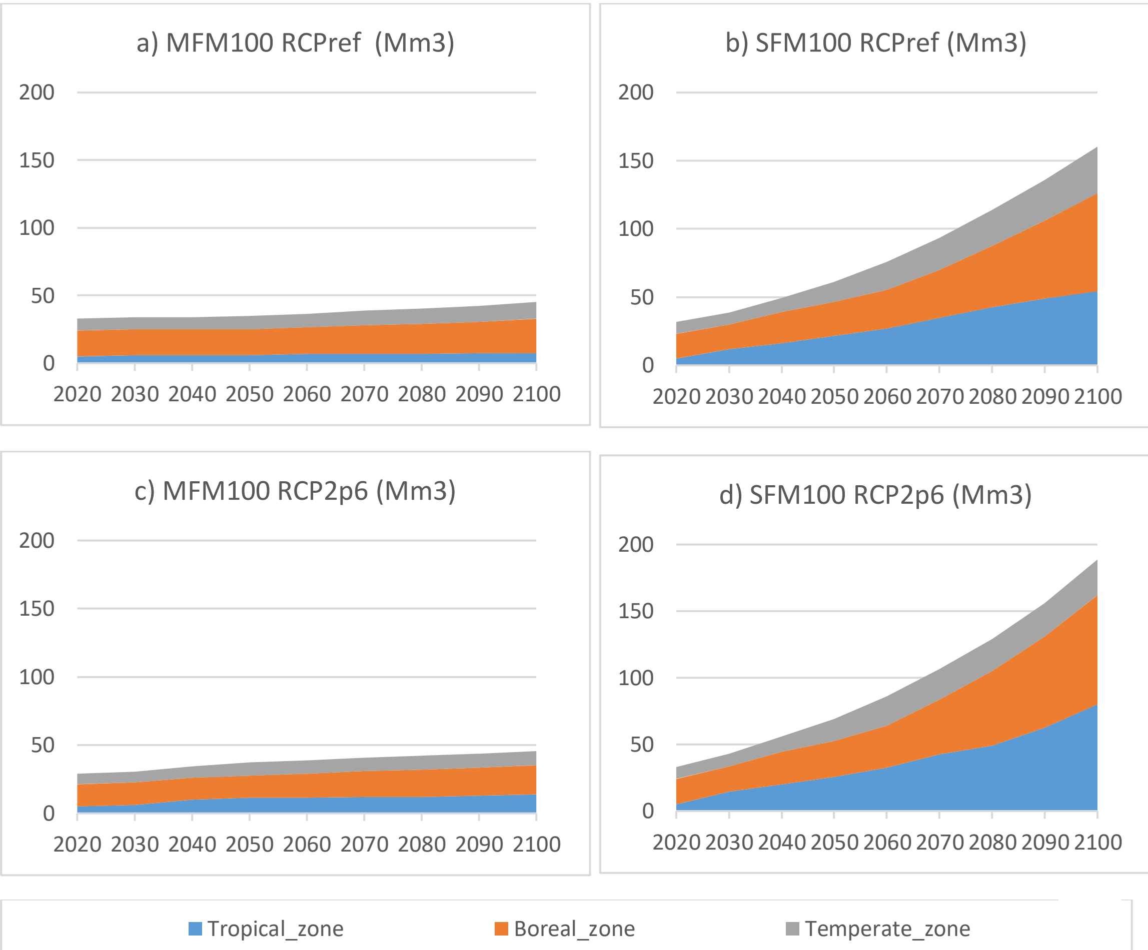

Figure 7 Industrial roundwood and woodchips import to EU28 in the MFM100 and SFM100 scenarios (Mm3/yr).

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3.6 The leakage effect on bioenergy feedstocks

The leakage effect on bioenergy feedstocks is relatively simple, since leakage rate is always 100% due to fixed bioenergy demand. The decrease in EU28 logging residues and by-products use for energy is compensated by increase in domestic energy crops (leakage to agricultural sector) and by increase in imported pellets (leakage to other regions) (Table 5). In the RCP2p6 scenario the decrease of EU28 logging residues and by-products use for energy is much higher than in the RCPref scenario, since the bioenergy demand is higher. This leads considerable increase in pellets import and energy crops.

Table 5. Changes in EU28 bioenergy feedstocks relative to baseline (Mm3) and the associate leakage rates (%) in 2100.

RCPref

	AFMfree	MFM25	MFM50	MFM75	MFM100	SFM25	SFM50	SFM75	SFM100
LR harvests	-11	-14	-17	-18	-19	-11	-1	-15	-31
By-products	19	23	22	20	10	16	-19	-41	-56
Energy crops	-5	-4	-3	-2	1	-3	5	23	30
Pellets import	-2	-3	-2	2	8	0	15	33	59
Leakage rate	100%	100%	100%	100%	100%	100%	100%	100%	100%

RCP2p6

	AFMfree	MFM25	MFM50	MFM75	MFM100	SFM25	SFM50	SFM75	SFM100
LR harvests	28	11	-11	-36	-61	3	-31	-76	-129
By-products	38	32	17	-4	-17	-5	-57	-96	-121
Energy crops	-9	-3	0	8	18	0	16	49	70
Pellets import	-55	-37	-3	31	63	3	73	124	181
Leakage rate	100%	100%	100%	100%	100%	100%	100%	100%	100%

3.7 Compensation payments for AFM

The shadow price of AFM forcing constraint can be interpreted as compensation payment for forest owners from the lost production possibilities. For simplicity, we aggregate the land-use unit level payments to EU28 level by using area weighted average.[4]

In the baseline scenario there is no forcing, which implies that shadow prices and payments for PFM are zero. In the MFM scenarios the payments increase up to 50 €/ha/yr (RCPref) and 100 €/ha/yr (RCP2p6) (Figure 8). The payments are higher in the RCP2p6 scenario, because of higher demand for logging residues and forest industry by-products for energy, which tends to increase forest owners lost due to MFM. In the SFM scenarios the payments increase up to 250 €/ha/yr (RCPref) and 300 €/ha/yr (RCP2p6). The payments are higher in the SFM scenario, because set-side management causes higher lost for forest owners that multifunctional management.

The payments are substantially lower in the MFM/SFM scenarios that combine MFM/SFM to PFM. Reason is that PFM compensates losses of MFM/SFM. Interestingly, the payments for MFM100 are

[4]The payments could be aggregated also to country level. The variation of country level payments is higher than EU28 level payments due country level differences in the suitable area for alternative managements. In the countries where the suitable area is high relative to total forest area (e.g. Germany), the compensation payments are higher.

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close to the payments for SFM25. Consequently, the compensation costs of 100% MFM transition are comparable to combination of 25% SFM and 75% PFM transition.

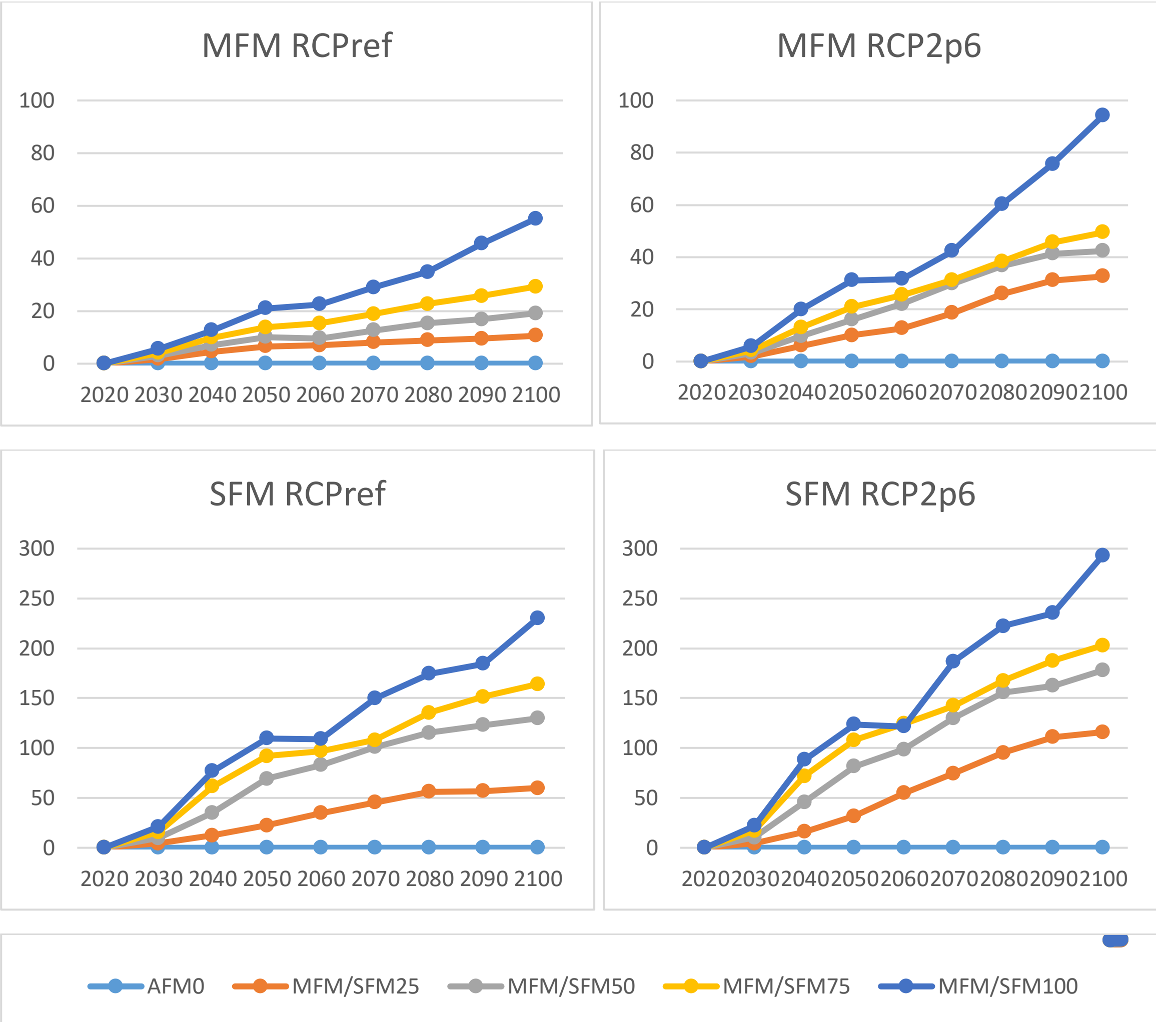

Figure 8 Payments for alternative forest managements (€/ha/yr)

4 Discussion and conclusions

In this study, we have investigated the transition to alternative forest managements (AFM) in EU28 level. AFM include production forest management (PFM), multifunctional forest management (MFM) and set-aside forest management (SFM). Our results indicate that forest owners do not apply MFM or SFM without additional compensation payments, as these managements decrease the harvest potential and expected income from wood sales. It is possible to create incentives for forest owners to apply MFM and SFM by compensating them for lost production value of forests, but this is relatively expensive policy option and it is unclear where the required finance for such compensations would come. One alternative to decrease compensation payments is combined transition to MFM or SFM, where 25-75% of suitable area is converted to MFM or SFM, and the

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remaining area to PFM. Combined transition decreases compensation payments, because the production value loss in the MFM or SRM areas is compensated by increased production value in the PFM area. Interestingly, the payments for 25% SFM transition area close to the payments for 100% MFM transition.

In addition to compensation costs, transition to MFM or SFM tends to imply leakage effects on harvests, forest industry production and bioenergy feedstocks outside EU28. Our results confirm the finding of previous studies that transition to SFM would imply considerable leakage effects. The new and surprising finding is that transition to MFM implies much lower leakage effects, because EU28 forest industry can substitute coniferous biomass use by non-coniferous biomass use. This substitution is not possible in the SFM transition, as SFM decreases both coniferous and non-coniferous harvests.

The leakage effect on forest industry production and bioenergy feedstocks depends on the possibility to compensate lower domestic harvests by import. If EU28 can increase roundwood imports sufficiently (e.g. from Russia or other nearby areas), then the leakage effect on EU28 forest industry and employment remains small. The leakage effect on bioenergy feedstocks is small in the RCPref scenario, but it leads to considerable increase of pellets import to EU28 in the RCP2p6 scenario. If EU28 cannot increase pellets import sufficiently, then decrease in logging residues and forest industry by-products is compensated by domestic energy crops. Increasing EU28 energy crops production is possible, but it might reduce food security in the agricultural sector.

Our analysis and results indicate that MFM would be a better option to produce wood and other ecosystem services than SFM, or combination of SFM and PFM, because it has lower leakage effects and compensation costs. The main reason for this result is that the difference between available roundwood in PFM and MFM is small in the European forests (Table 1). If the difference were greater, the results of the analysis could be different. For example, in tropical forests the combination of SFM and PFM could be better solution to produce wood and other ecosystem services than MFM, as available roundwood from tropical forest plantations is much higher than from tropical natural forests (Price et al. 2005).

In addition to leakage effects and compensation costs, MFM has also other advantages relative to SFM, or combination of SFM and PFM. First, MGM leads to integrated forest area while combination of SFM and PFM to fragmented forest area. The integrated forest area is often considered better option for other ecosystem services like biodiversity than the fragmented forest area (Simonsson et al. 2016). Second, MFM provides higher tolerance of forests against climate risks than SFM or PFM in the European forests (Seidl et al. 2014, Kauppi et al. 2018). Therefore, it is also a safer option to produce wood and other ecosystem services in European forests than SFM, or combination of SFM and PFM. Third, SFM provides higher carbon benefits in the short run, as SFM increase carbon sequestration in the standing volume. However, MFM has higher carbon benefits in the long run, as SFM carbon sequestration saturates (Schwaiger et al. 2019).

One important caveat of our analysis is that compensations to forest owners are based on the opportunity costs of AFM, i.e., we do not account the non-market benefits of other ecosystem services and improved tolerance of forests against climate risks. This means that we might overestimate the compensation costs of AFM transition. Therefore, including the social value of other ecosystem services and the “insurance effect” of improved tolerance of forests against climate risks

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in the analysis would be an important subject of the future study (Roessiger et al. 2011, Verkerk et al. 2014, Schwaiger et al. 2019, Augustynczik et al. 2020). As the social value of other ecosystem services is often difficult to measure, one possibility to quantify the trade-off between production and other ecosystems services could forest decision support systems (DSS) (Nordstrom et al. 2019). However, it remains an open question how the outcome of DSSs could be utilized in partial equilibrium models like GLOBIOM.

Another limitation of the study is that suitable area for different types of AFM is same and covers only 50% of EU28 forest area. For the remaining area, we apply current management practices with constant tree species distribution, as the model lacks data about suitable areas for different tree species and alternative managements there. This increases somewhat the opportunity costs of MFM and SFM, because it is not possible to compensate MFM and SFM by applying PFM in the remaining areas. Therefore, extending suitable area for the whole EU28 forest area, and also forest areas outside EU28, would be another important subject of the future study.

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