A I.3. Regional Report BIO SCREEN CEE

Bio Screen CEE project

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Consortium

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Welcome to Bio Screen CEE

The project will advance evidence-based knowledge and policy implementation of the energy sector in Romania, Bulgaria and Hungary to alleviate energy demand growth and dependency on forestry biomass for energy, especially as a result of the coal transition.

The project will review biomass strategies and underlying data defined within national energy and climate plans (NECP) and seek to improve the capacity and engagement of stakeholders to embrace alternatives to forest biomass and apply stricter sustainability criteria beyond that prescribed in the Renewable Energy Directive II (RED II). It will recommend specific pilot projects for local municipalities dependent on firewood that can then be advocated at the national level.

Scope

Within Activity A.I.3. “Regional Report”, REKK will integrate the three country study findings for Bulgaria, Hungary, and Romania. Based on shared methodology and scope of research, the three country studies will allow experts to draw comparisons and develop an aggregated regional interpretation of the factors and trends influencing forest biomass utilization for direct energy production. Part of the wider project mission is to assess how much more carbon sequestration the region’s forest could efficiently contribute to the climate economy under realistic policy conditions.

1. Policy goals and measures along the value chain of forest biomass to energy

National forest strategies

Dedicated forestry strategies

Of the three analysed countries, only Hungary has a national forestry strategy in place. It has been more than a decade since Romania’s last National Forestry Strategy, but the Recovery and Resilience Plan (RRP) stipulates a Q3 2022 deadline for approving a new Strategy based on previous stakeholder dialogue outcomes. In Bulgaria, the National Strategy for Development of the Forest Sector was active from 2013-2020 when it expired without renewal.

Hungary’s National Forestry Strategy 2030 was adopted in 2016 as a strategic planning document for the 2016-2030 timeframe. The first of nine identified challenges is climate change, defined both in terms of adaptation and mitigation needs. Specific goals were identified based on these challenges with recommendations for implementation in most cases. It supports increasing the share of non-energy utilization of harvested wood and its lifespan, while also supporting the energy utilization of non-industry quality wood. Related to the latter, it also aims to develop sub-regional heat plants associated with the establishment of logistical centres of state-owned forests. The document was developed before the LULUCF Regulation and the Hungarian Climate Law for 2050 climate neutrality and is lacking a carbon sequestration target.

National Energy and Climate Plans

The NECP is the central document determining the national contributions of each Member State toward the 2030 EU climate policy goals. It is mandated by the Governance Regulation, with obligated structure and elements. Below are short country summaries of NECPs regarding solid biomass:

Bulgaria

Biomass supply (incl. biofuel and biogas) should increase by 37% in 2030 compared to 2020. However, the relevant figure by source projects only a 25% increase, including waste.

The integrated impact assessment chapter provides detailed information about sourcing the additional demand from biomass and waste feedstock, with a projected increase of 17% for solid biomass, as the following:

- Lower biomass export from 1,2 TWh[1] due to higher inland demand.
- More logging under the National Action Plan for Energy from Forest Biomass (NPDEGB) for 2018-2027, building from the 2012-2016 period, using different approaches with different logging rates, landing the energy equivalent of the harvested volume for energy utilization between 9.2 – 12.3 TWh.
- Utilization of an additional 2,8 TWh of wood waste according to the NPDEGB 2018-2027.
- Other sources of biomass including waste and residues from biological origin from agriculture, forestry and related industries, fisheries and aquaculture, and biodegradable waste of biological origin divided between industry and municipal. (the energy quantity of these feedstock is not specified).
- Afforestation is not mentioned the NECP does not include any plan the increase the area of existing forest.

The NPDEGB and impact assessment admits that further studies are needed to determine the exploitable share of harvested residues, acknowledging growth of the harvesting could exceed the annual increment. The impact assessment indicates that higher levels of harvesting are not expected in consideration of the LULUFC Regulation requirements. Yet, the main conclusion is that a projected 17.7 TWh biomass can be covered without increasing the harvesting level. As described above, the document draws this conclusion without quantifying feedstock beyond wood waste. Therefore, it remains to be seen how the projected growth can be covered sustainably.

The European Commission (EC) has not made any recommendations on the draft version for biomass supply[2], only stating that plans for biomass utilization are supported with high agricultural, forest residues and waste potential. It does state that in order to meet the sustainability criteria laid down in Renewable Energy Directive (RED II)[3] more concrete measures or guarantees could be provided.

[1] The impact assessment applies heating value of 10.3 GJ/m3

[2] Available at: https://ec.europa.eu/energy/sites/default/files/documents/staff_working_document_assessment_necp_bulgaria_en.pdf

[3] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)

Hungary

In the Hungarian NECP biomass supply appears incomplete, with just three short paragraphs describing state and privately-owned forest management and the future risk of increased mortality due to climate change. Apart from this, there are only three tables covering the projected carbon sink of existing forestry, projections for additional forest land, and energy plantations. The trajectory for the forestry carbon sink in the NECP is based on the same modelling presented in the National Forest Accounting Plan (NFAP) but does not include afforestation. Of the scenarios presented - the Forest Reference Level (FRL), increased logging rate, and logging held at a lower level, equivalent to the NFAP – there is no indication as to which scenario should be implemented. The only signal is from the NFAP, which implies that the low-level harvesting scenario is the most likely since currently there is no desire to increase the volume of harvesting.

The NECP envisages a conservative rate of afforestation. According to the WEM (with existing measure) scenario, the ~850 ha yearly afforested area will increase to 2500 ha/yr and remain at the same level until 2030. On the other hand, the more ambitious WAM (with additional measures) scenarios increase by 3600 ha/yr from 2025 and 3800 ha/yr by 2030. Afforestation plans are only presented in a table format without any explanatory text concerning discrepancies between the planned afforestation rate and the other relevant governmental plans. For reference, the Climate and Environmental Action Plan envisages 20,000 ha/yr land covered by trees (not necessarily forest) on average until 2030, while the National Afforestation Plan envisages 15,000 ha/yr new forest in average until 2050.

The same gap is present in the planned new energy plantations. According to the WEM scenario, 1,000 ha of new energy plantations will be added to the existing ~6,000 from 2021-2030. For the WAM, scenario, it is 1 500 ha/yr. This is a small fraction compared to the forestry area, and there are no detailed measures for achieving the goal. The NECP is also missing an assessment of future biomass supply from energy plantations.

In its assessment of the draft NECP[4], the EC requested detailed measures to ensure sustainability of biomass supply and use in the energy sector but classified it as "fully addressed". Nonetheless, the above specified shortcomings need to be addressed in the 2023-2024 revision process.

Romania

In the Romanian NECP, the relevant chapter spans only two short paragraphs, referring to the modelled volume of living biomass until 2025 and the estimated potential (in million t) of agricultural residues. The chapter for GHG emissions and removals (3.1.1), anticipates growth in forested areas, but does note providing any further details or financial measures. The NECP mentions the identification of land unfit for agricultural use and its afforestation, promoting measures to establish forest on degraded lands.

The EC find's Romania's NECP to be lacking – despite their earlier recommendations on the draft version - assessment of its sourcing and impact on the LULUCF sink and biodiversity, which is especially important given the prominent role of bioenergy in the final plan. It is also mentions that there is no indication of biomass supply by feedstock and origin, and "a system

[4] Available at:https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576058180537&uri=CELEX:32019H0903(17)

of certificates of origin is in place for biomass from agriculture and forestry but is not linked to LULUCF and no sustainability criteria are set out".

The Energy Strategy for 2020-2030 could fill in some of the gaps on projected biomass supply, but it has not been adopted yet.

To conclude, the main shortcoming identified in Romania's NECP for planned biomass supply is a failure to provide details on feedstock covering stipulated growth demand and the trajectory of the carbon sequestration of the existing forest, this is similarly absent in Bulgarian and Hungarian NECPs. This should investigate the planned harvesting level, how it affects stored carbon, and to which extent other feedstock or newly afforested areas could be applied. It is recommended that governments address these gaps in the 2023-2024 revision

National Forest Accounting Plans

In 2018, the EU adopted (EU) 2018/841 Regulation (LULUCF Regulation) requiring Member States to balance greenhouse gas (GHG) emissions from land use, land use change, and forestry (LULUCF) by at least an equivalent accounted removal of CO_2 from the atmosphere in the 2021 to 2030 period ("no-debit" rule). As of December 2021, the Regulation is under revision to fit the enhanced 2030 climate goals. This assessment applies the original version of the Regulation and touches on the new proposal currently under discussion at the end of the chapter.

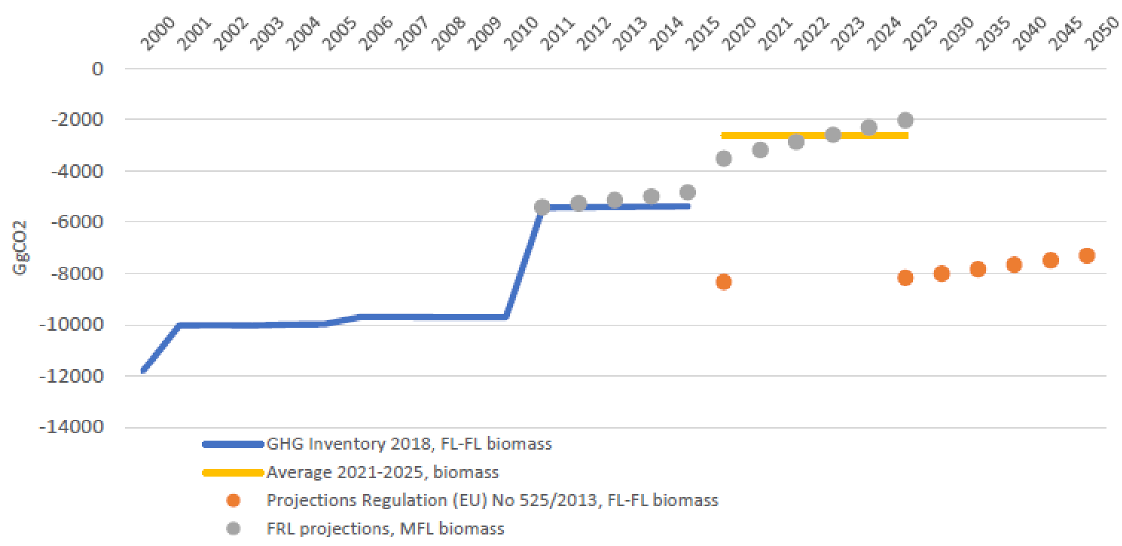
Due to the dynamics of the distribution of forest stands in terms of age, species, area, and yield, the future sequestration of forest land varies year-by-year, and will also be affected by changes in forest management practices.[5] This is the rationale behind the Forest Management Reference Level (FMRL), introduced under the second commitment period of the Kyoto Protocol, and its modified version (the so-called Forest Reference Level, or FRL) imbedded in the LULUCF Regulation. The FRL is a forward-looking benchmark for accounting net emissions from existing forests based on the continuation of sustainable forest management practices from 2000 to 2009.

FRL accounting for forest carbon sequestration dictates that any accounting of forests that excludes afforestation (accounted in the so-called land converted to forest land category) has to be done comparatively. The Regulation splits this decade into two commitment periods, the first of which Member States are obliged to calculate their FRL as the estimated average annual net emissions or removals resulting from managed forest land from 2021 to 2025. National Forestry Accounting Plans (NFAPs) were to be completed by the end of 2018.

The **Bulgarian** FRL envisages a steep fall in carbon sequestration potential. Compared to the volume of sequestered CO_2 in the early 2000s, 10 M t, the modelled average carbon sequestration for the first reporting period is about 3 M t CO_2, excluding the carbon pool of harvested wood product.

[5] Besides forest land, the LULUCF Regulation also includes arable land and grassland (and also wetlands as of 2026).

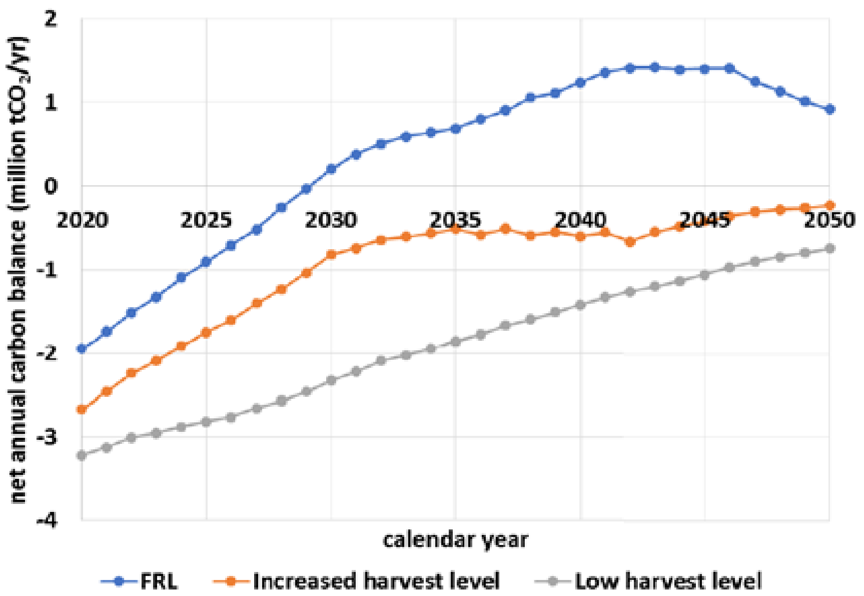
Figure 1 Forestry Reference Level in the Bulgarian NFAP



Source: Bulgarian NFAP

Similar to the Bulgarian NFAP, the Hungarian model projects huge decline in sequestration. The average yearly removal of the LULUCF sector over the last 5 years was around 5.2 M t compared to the FRL's 0.3 M t CO_2, falling to 0.05 M t CO_2 with the harvested wood product (HWP). The document models to 2050 as part of the long-term climate strategy, projecting forests which existed in 2010 to be net emitters after 2029 before stabilizing between 2040-2045, at 1.5 M t CO_2, after which emissions decrease.

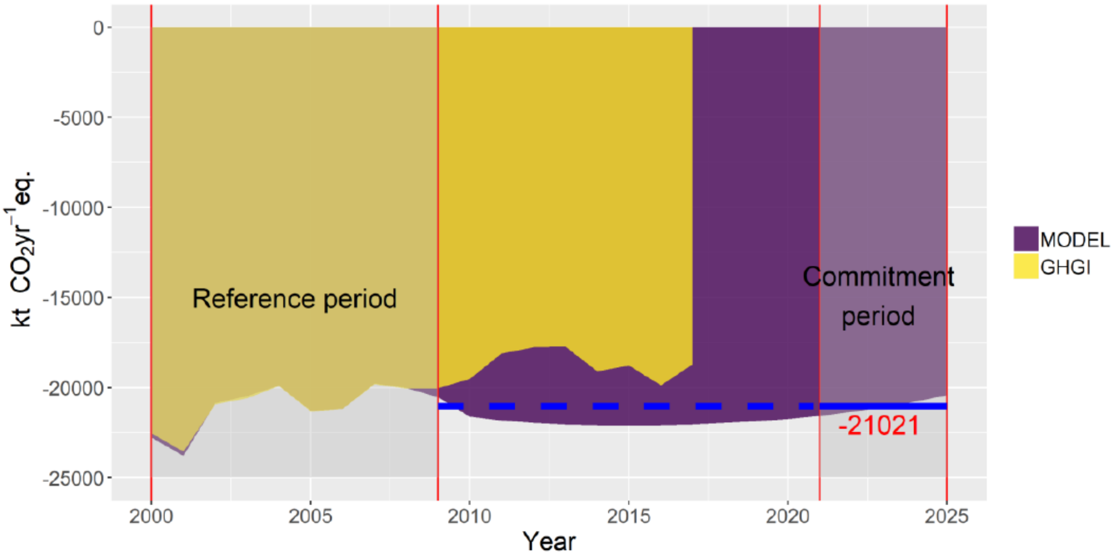
Figure 2 Forestry Reference Level in the Hungarian NFAP



Source: Hungarian NFAP

Romania's FRL also anticipates a significant decline in carbon sequestration, but less so than the other two countries. Compared to average annual removal over the past five years, some 25.9 M t CO_2, the FRL for the reference period is 21.5 M t, and 24 M t with the HWP.

Figure 3 Forestry Reference Level in the Romanian NFAP



Source: Romanian NFAP

Under the revised LULUCF Regulation proposed by the EC, the current accounting system would be simplified by 2025, based on the actual level of reported emission and removals instead of the "no-debit". It aims for an EU target of removing 310 million tons of CO_2 equivalent by the LULUCF sector by 2030, with national targets based on average level of recent (2016-2018) net emissions in the LULUCF sector and their share of the EU's total area of managed land.

Bulgaria and Hungary used their respective forestry databases for their NFAPs and FRLs while Romania used its forest inventory (as of 2008-2012). None of the three NFAPs include a soil and litter carbon pool since they are typically small carbon sinks difficult to approximate. Both Bulgaria and Romania included natural disturbances but only Romania's NFAP made corrections regarding illegal logging. While the calculated ratio of energy utilization rate (as opposed to harvested wood products (HWP)) is similar in Bulgaria and Hungary (89% and 80% respectively), in Romania it is only 47%.

To conclude, there is a massive information gap between planned biomass energy use and supply and climate neutrality sequestration requirements are missing from the relevant documents. Detailed assessments should balance i) future needed carbon sequestration ii) planned biomass-based energy use iii) future trend of harvesting volume based on the existing management regime. Also, the potential of afforestation and other wooded land should be evaluated according to their ability to relieve biomass use and improve sequestration of existing forestry.

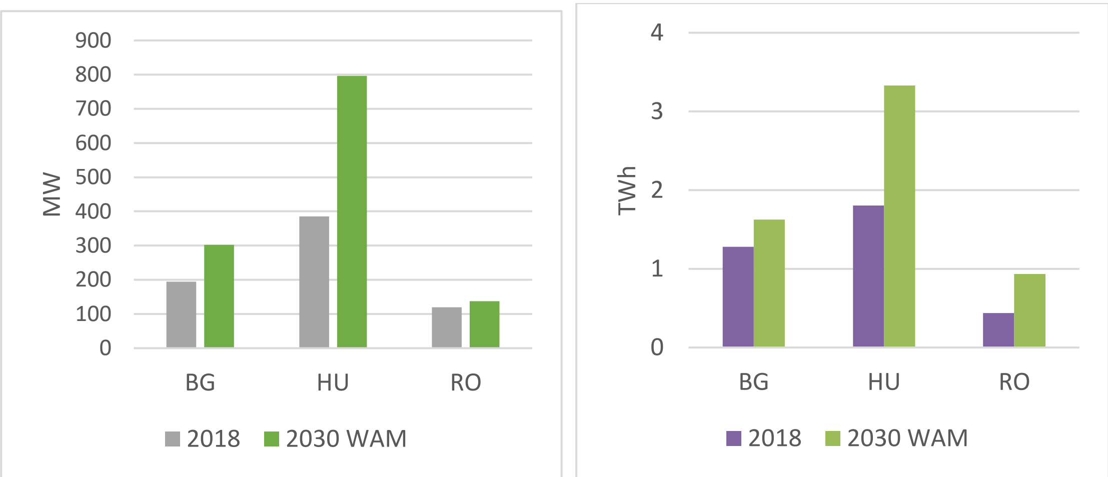
National energy strategies

National Energy and Climate Plans

This chapter focuses on NECP's biomass related content. The figures presented use and compare the latest available data with the projected values for biomass utilization in the electricity and heating sectors. The value for 2030 is a result of market modelling as presented by the NECPs, where additional policy measures (with additional measures – WAM) are implemented next to the already existing ones.

Bulgarian capacity data for 2018 presents a state which is in the middle of a quite high capacity expansion until 2019/20, reflected in the growth of model-based results for biomass based generation. Hungarian biomass capacity will grow by almost 50% and biomass-based generation even more. Romania's capacity is set to grow marginally while production grows significantly to 2030 according to modelling results.

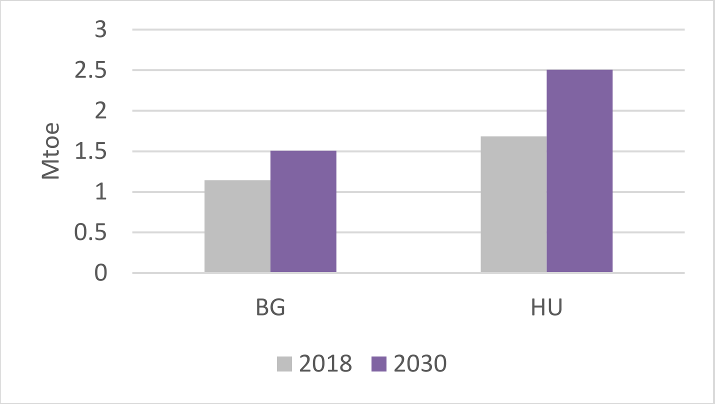
Figure 4 Biomass-base installed capacities (MW) and electricity production (TWh)



Source: EUROSTAT SHARES, NECPs, (Capacity data for Bulgaria is from Bulgarian RES Progress Report)

Data for the heating sector was unavailable in the Romanian NECP. Only Bulgaria provides a sectoral breakdown including household consumption. All three NECPs project biomass for heating to grow - in Bulgaria by 32% and in Hungary 50%.

Figure 5 Biomass heat production in 2018 and 2030 WAM, Mtoe



Source: NECPs

A summary of NECP biomass profiles is presented below.

Bulgaria

The pillar of decarbonisation in the electricity sector is growth in renewable energy production (around 50%). Three-quarters of this would be a results of new solar PV capacity, with only a marginal role for biomass capacity (220 MW).

The heat sector will deliver the majority (70%) of Bulgaria's emission reductions, which includes a 34% increase in renewable heat production based almost entirely on biomass-based cogeneration. In contrast household biomass, the largest consumption profile in the sector, is expected to increase by only 11%. That is in line with the intention to replace solid fuels with natural gas in domestic heating.

The Bulgarian NECP also sets "Biomass and waste" mix targets, but they are not properly disaggregated, making it difficult to estimate the pressure on forest biomass production. Achieving renewable targets requires an increase in "Biomass and waste" use of some 25%, from 1600 ktoe to 2000 ktoe. About 75% of demand growth comes from the transformation sector (electricity and heat production) and the industrial sector while residential and commercial growth have a relatively small impact.

Nearly half (45%) of the above-mentioned demand growth is expected to come from sources other than forestry solid biomass: „unutilised potential of the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal matter from forestry and related industries, including fisheries and aquaculture, and the biodegradable fraction of waste, including industrial and municipal waste of biological origin".

Solid biomass supply is expected to increase by 17% (up to 1522 ktoe), which remains just below the biomass potential identified in the 2011 Energy Strategy and above the forestry wood potential (1056 ktoe) cited in the National Action Plan for Energy from Forest Biomass. As the NECP puts it: „solid biomass is expected to be mostly derived from residues", mainly wood waste generated by the timber processing and furniture making industries.

Hungary

The NECP sets out to diversify the current Hungarian renewable energy mix, mainly through additional solar PV capacities, which will reduce the current dominant position of solid biomass from 80% to approximately 66% in 2030 under the WAM scenario. It explicitly acknowledges that biomass use for energy purposes poses environmental risks, stating that "it is important to satisfy growing demand for energy from biomass with the lowest possible environmental impact, taking into account optimal conditions for energy, forestry, soil science, agriculture, nature conservation and transport."

Despite these reservations, biomass utilisation is expected to grow this decade. While only bioenergy demand is projected, based on the current status of biogas is can be assumed that most of this bioenergy will be sourced from solid biomass. In the WAM scenario, bioenergy in the electricity sector is expected to increase from the 2092 GWh in 2019 to 3328 GWh in 2030 (+60%), and installed capacities from 453 MW in 2019 to 796 MW in 2030 (+75%). Such a dramatic increase does not appear to be backed by policy measures. The current feed-in-premium support scheme for new renewable electricity installations awards support via technology neutral tenders under which biomass must compete with lower-cost solar PV. The brown premium which provides special eligibility for depreciated biomass plants only prevents the shutdown of existing biomass capacities after the feed-in tariff support period expires.

Policy measures for increasing bioenergy use in the heating sector will be developed under the Green District Heating Program, including support for energy communities and efficient biomass boilers and heat pumps (as alternative to individual heating with biomass). This Programme commonly deferred to in both the energy strategy and the NECP, but recent district heating investment support schemes have largely failed due to high investment costs and an insufficient price regulation regime.

There is no quantification linking the growth in bioenergy and its supply, nor its effects on GHG emissions, LULUFC removals, or air quality. Furthermore, there is no description of non-forestry biomass use and its prospects.

Romania

The Romanian NECP presents little information as to the role of biomass. It defers to the NFAP projections of 9% growth from 2015 and 2025, while its own modelling outcomes project solid biomass capacities to fall from 180 GW in 2020 to 137 GW in 2030.

There isn't much information in the NECP on biomass usage for heating purposes which accounts for the overwhelming majority of Romanian biomass usage. The share of renewable sources in heating and cooling (RES H&C share) is expected to grow to 33% in 2030, also considering the sustainable use of biomass in the energy sector. The forest biomass supply by feedstock represents the trend in living biomass volume without any disaggregation by forest products or consideration of the cascading use of wood principle.

The difference between the 2030 the H&C sector RES share in scenarios with current and additional measures is 4.2%, with additional growth mainly from heat pumps, solar panels, and RES expansion in the district heating systems (without indicating the source of energy), supplemented with the decrease of the overall energy consumption of the sector.

Romanian's decarbonization path will be based mostly on the expansion of non-biomass of renewable energy.

Further strategic documents

The final version of Romania's National Energy Strategy is expected to differ significantly from prior drafts. The latest version envisages a 20% reduction of biomass usage in 2030 compared to 2018 without explicit policy support, as a result of energy efficiency measures such as building insulation and efficient heating installations. This is in contrast to an earlier version that projects a significant increase of biomass and waste consumption, leaving much uncertainty.

Hungary's National Energy Strategy (NES) and the long-term strategy (LTS)[6] are both relevant. The NES does not attach an important role for biomass in coming decades. Electricity sector decarbonisation is achieved largely through solar PV and the greening of the transport sector. For heating, the strategy focuses on natural gas demand reduction, both in district heating and individual heating of households.

Inefficient and polluting use of firewood (and often waste) in rural areas is an important issue in Hungary, so the strategy mentions the need to modernise poor energy efficiency rural households that burn biomass and waste to ease the living standards of vulnerable households.

The Hungarian LTS projects biomass consumption will be marginally reduced in 2030 compared to 2016 in the 'early action' scenario but will remain significant (75 PJ/year) in 2050. This assumes that current biomass household consumption will almost entirely disappear with the shift to RES-based electric heating and energy efficiency measures. Biomass will be directed to the electricity sector where CCUS (BECCS) technology allows not only for accounting zero but even negative emissions. If households are slow to shed biomass in heating *and* if the government is quick to launch effective support schemes for BECCS investments, a tight market for solid biomass resources could cause a significant demand stress which can lead to serious social consequences for households slow or unable to switch to other heating solutions.

The Bulgarian National Energy Strategy does not contain any additional information regarding the future role of biomass.

Summary

The three countries have different attitudes and strategies for biomass-based energy production. While Hungary and Bulgaria envision significant growth in biomass consumption of approximately 35% and 25% by 2030, in Romania it is marginal.

However, current Hungarian and Bulgarian support systems are unlikely to deliver the envisioned growth. Biomass-fired power plants are uncompetitive in technology-neutral Hungarian renewable tenders, while in Bulgaria the support system is limited to all renewable technologies. Without targeted support or legislative measure put in place, a rapid increase in biomass use for these countries is not feasible. If measures are put in place to realize

[6] https://cdn.kormany.hu/uploads/document/6/66/666/666e0310ef20606fba9f96f4fbf0d74bbaa1638e.pdf, download: December 13, 2021

these targets, a growing practice of biomass and coal cofiring will put pressure on biomass resources in the next decade.

For all three countries air pollution is the motivating factor for reducing residential firewood consumption rather than the sustainability of biomass resources, yet they face infringement procedures for failure to comply with EU clean air regulation. While cases against Romania and Bulgaria are ongoing, in February 2021 the European Court of Justice ruled that Hungary broke EU law on ambient air quality by systematically and persistently exceeding the daily limit value for particulate matter PM10.[7] Bulgaria faces the same allegation [8] while Romania is being tries for failing to adopt a national air pollution control programme[9].

Solid biomass consumption trends

Biomass is the most widely used renewable energy resource in **Bulgaria** – mainly as wood for domestic heating in combination with coal. According to EUROSTAT data, there has been an extraordinary leap in biomass-based electricity and district heating generation, which can be credited to a surge in biomass co-firing rather than targeted regulatory or support measures.

Biomass-to-energy plays a key role in the **Hungarian** renewable energy sector as well. The majority of solid biomass is used for household heating but also district heating. Solid biomass is also widely used for generating electricity. Several coal-fired power plants switched at least partly to biomass after the introduction of a feed-in-tariff scheme in 2002. The new brown premium aims to keep biomass installations in operation after the feed-in tariff support period ends (see more on the topic in Chapter ”Support schemes”).

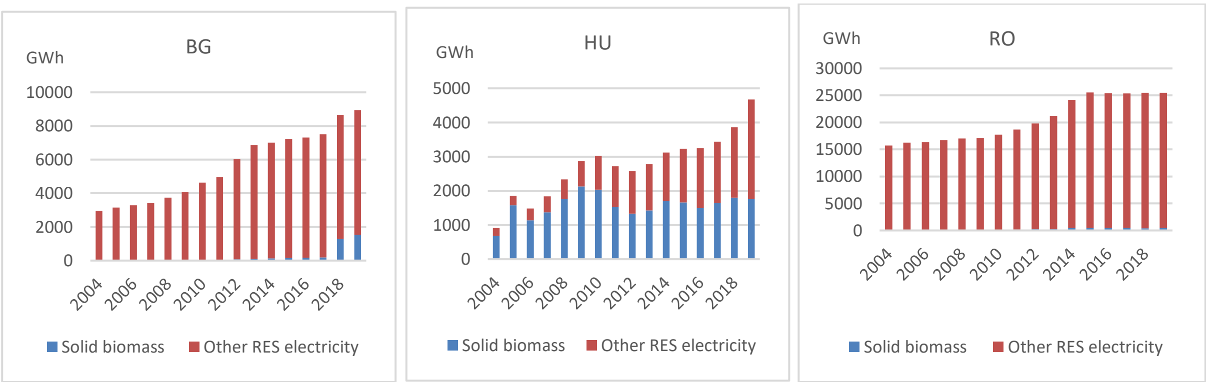
In **Romania**, biomass is used mainly for heating purposes. Along with the household segment, solid biomass is used by 9 of 55 district heating systems according to 2019 data. The 119 MW of biomass power plant capacity represents less than 1% of the total electricity generation.[10]

Solid biomass-based electricity generation

In 2019, 38% of Hungary’s renewable electricity (RES-E) was produced from solid biomass compared to only 2% in Romania, and after the recent surge, 20% in Bulgaria.

[7] Source: https://curia.europa.eu/jcms/upload/docs/application/pdf/2021-02/cp210012en.pdf download: 7 March 2021.
[8] https://ec.europa.eu/commission/presscorner/detail/EN/IP_20_2150
[9] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6264
[10] Source: EUROSTAT SHARES

Figure 6 Electricity generation from solid biomass and other renewable energy sources in Bulgaria, Hungary and Romania (2010 – 2019, GWh)

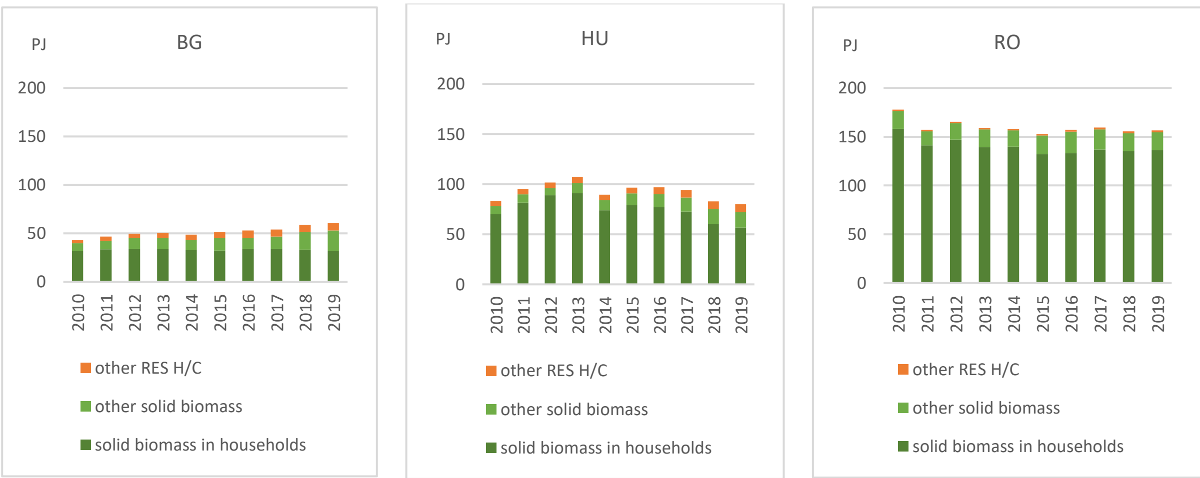


Source EUROSTAT SHARES

Solid biomass-based heat

Across all three countries, solid biomass is the main source for renewable energy for heating - 99% in Romania according to 2019 SHARES data.

Figure 7 RES in the heating sector for Bulgaria, Hungary and Romania (2010 – 2019, PJ)

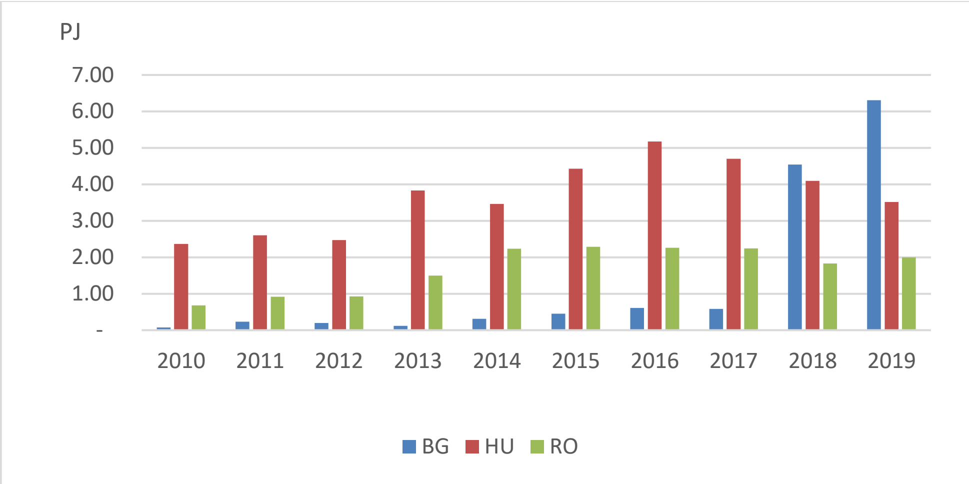


Source: EUROSTAT SHARES

Solid biomass is present in the district heating segment of all three countries, exhibiting a rising trend in Bulgaria while declining in Hungary and Romania.[11]

[11] Data inconsistencies can be found in terms of solid biomass consumption for district heating. The annual report of the HEA and the Association of Hungarian District Heating Companies (MATÁSZSZ) shows an increasing trend in recent years. Source: http://tavho.org/tudaskozpont/statisztika

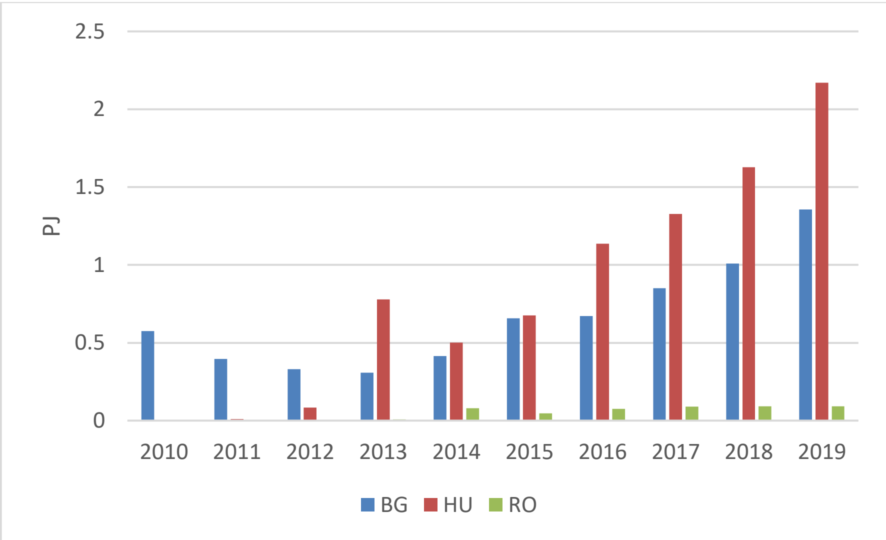
Figure 8 Solid biomass consumption in district heating in Bulgaria, Hungary and Romania (2010 – 2019, PJ)



Source: EUROSTAT SHARES

According to EUROSTAT data, the role of renewable municipal waste (the biodegradable part of municipal waste) is on the rise in Hungary and Bulgaria due to the increased mixing of waste derived fuels in lignite, coal or solid biomass fired thermal power units.

Figure 9 Renewable municipal waste use for heating in Bulgaria, Hungary and Romania (2021-2019, PJ)



Source: EUROSTAT SHARES

Co-firing of biomass

Several thermal power plants in the region have been retrofitted to co-fire biomass and waste. In Hungary, the process began in 2004 using mainly firewood. In Bulgaria, fuel change and transition to biomass gained momentum only in the last few years purely on a market basis, without a certificate of origin scheme or financial subsidy from the government.

Little information is available for the source of the biomass used in power plants. In Hungary round (solid) wood and wood chips are eligible for feed-in tariff or premium payments. Solid wood is a high-quality fuel with mature and reliable combustion technology, far more expensive than wood wastes, forestry and agricultural residues.

Agricultural residues are an affordable and attractive alternative, but cannot fully replace wood due to difficulties in collection, storage and transport. In addition, herbaceous biomass combustion may be technically problematic, leading to higher operating costs.

From an economic point of view, waste incineration is considered to be the most favourable alternative owing to the disposal "gate" fee", effectively making it a negatively priced fuel. Based on information from Hungarian market participants, the negative price paid to the recipient of the most common grade of waste - the refuse-derived fuel (RDF) – ranges from 20 to 50 €/tonne, depending on the composition of the waste. In Bulgaria it might be even higher according to local media, in the 120-150 €/tonne range excluding transport costs.[12]

In addition to the negative fuel price, the biodegradable part of the waste qualifies as a renewable biomass, exempted from the carbon quota obligation, and providing additional revenue to the generator.[13]

Some 27% (60 million tonne) of municipal waste generated in Europe is incinerated, accounting for 1% of electricity and 10 % of heat production, half of which are considered renewable. Supervision of EU waste shipments fall under the Regulation 1013/2006/EC, with 15-30% of the 70 million tonnes of annual waste shipped between EU countries estimated to be done so illegally.

Although official statistics show depict stagnant waste to electricity or heat production, industry sources and press reports suggest it is becoming an increasingly attractive investment in all three countries. The largest lignite-fired power plant in Hungary, which started co-firing biomass in 2004, also began mixing waste processed at the power plant site in 2014.[14] In 2019 another biomass fired CHP unit announced it plans to replace about a quarter of the fuel used in the woodchip block with Solid Recovered Fuel ("Mecsek Mix"), consisting of pre-selected paper, textiles and PVC-free plastic.[15]

The Bulgarian press has been reporting on illegal waste import and incineration activities which led to the dismissal and prosecution of deputy environmental minister.[16] They accused Bulgarian authorities of secretly allowed several coal power plants to burn huge quantities of waste, alongside coal, without the required permits. According to the letters obtained by

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[12] https://www.mediapool.bg/vnosat-na-bokluk-za-gorene-se-obvarzva-s-mestnite-rdf-otpadatsi-news323345.html

[13] According to he International Energy Agency: „If it is not possible to distinguish between renewable and non-renewable municipal solid wastes, then the total quantity should be divided equally between both categories." See: IEA (2004): Energy Satistics Manual, p. 117

[14] https://gyongyostv.hu/8798-geosol-uzemavato-az-eromu-ipari-parkjaban/

[15] https://www.veolia.hu/hu/hirek/ujabb-lepes-korforgasos-gazdasagert-specialis-tuzeloanyag-mix-pecsi-eromuben

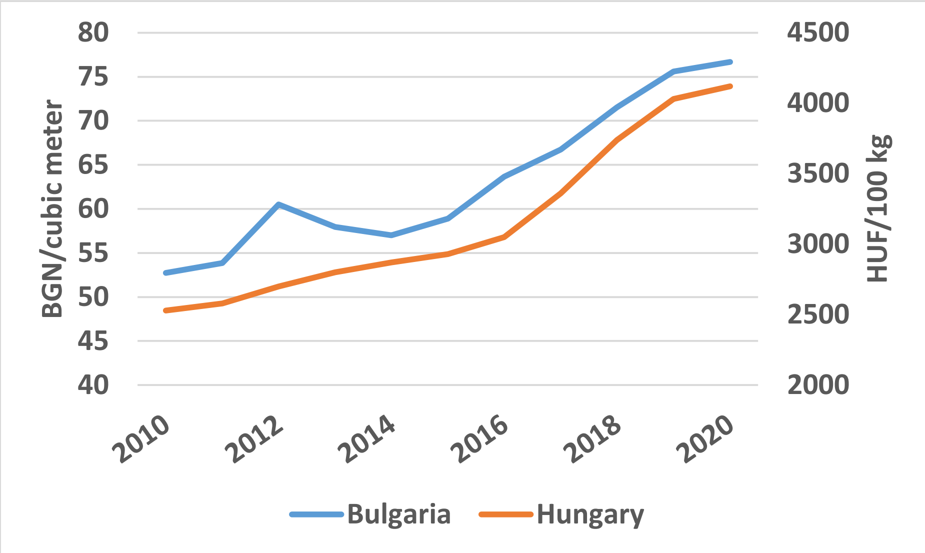
[16] See: „How does junk imports start in Bulgaria" (by Nikolay Stoyanov, Velina Gospodinova, 13 september 2019) https://www.capital.bg/politika_i_ikonomika/bulgaria/2019/09/13/3962426_kak_zapochva_vnosut_na_bokluci_v_bulgariia/ and „Bulgaria's deputy enviroment minister, facing criminal charges, dismissed" (by Sofia Globe, June 1. 2020) https://sofiaglobe.com/2020/06/01/bulgarias-deputy-environment-minister-facing-criminal-charges-dismissed/

Greenpeace, the Ministry of Environment allowed Bobov Dol Thermal Power Plant to burn up to 500,000 tons of waste for “experimental purposes”.[17]

There is no precise and reliable information on the amount and the proportion of (illegal) waste incineration in Bulgaria.

Although recent scandals might postpone growth in waste combustion, it is undoubtedly a very attractive alternative for old coal-fired power plants. In the last decade the price of firewood in Hungary and Bulgaria increased by 45% and 63% respectively, which is presumably raising the costs of biomass co-firing power plants.

Figure 10 Price of firewood in Bulgaria and Hungary (2010 – 2020)



Source: National Statistical Institute (Republic of Bulgaria), Hungarian Central Statistical Office

According to a Polish advocacy group, “there is very strong pressure and a lucrative market for new waste combustion energy plants” in Central Eastern Europe.[18] Sandbag estimates Bulgarian biomass co-firing potential over the next decade to be 11 PJ, some of which can come from waste.[19]

The potential for biomass co-firing is determined by the size of the available coal and lignite-fired power plant capacities. As coal is phased out, there will be less opportunity for co-firing and fuel switching. However, there remains uncertainty over the ability and willingness of these governments to develop and implement phase out plans. For now, the Bulgarian energy strategy plans to hold onto coal and lignite-fired power plants in the long term for security of supply purposes. Although coal capacity will decline significantly over the next decade, it will still account for over 30% of total electricity supply in 2030. The WEM scenario in the Bulgarian

[17] „Challenging Bulgarian coal plants’ new waste burning obsession” (by Dominique Doyle and Janek Vähk and Meglena Antonova; March 2, 2020) https://www.euractiv.com/section/air-pollution/opinion/challenging-bulgarian-coal-plants-new-waste-burning-obsession/ and „According to the disclosed secret correspondence, Bobov Dol Thermal Power Plant burns thousands of tons of garbage” (by Greenpeace, 13th October 2020) https://cee.press.greenpeace.org/bobov-dol-burns-thousands-tons-of-garbage/

[18] „In Europe, a Backlash Is Growing Over Incinerating Garbage” (by Beth Gardiner, April 1, 2021) https://e360.yale.edu/features/in-europe-a-backlash-is-growing-over-incinerating-garbage

[19] EMBER (2019): Playing with fire. An assessment of company plans to burn biomass in EU coal power stations

NECP, which is not significantly different from the WAM scenario, foresees 60% of current coal and lignite capacities (2500 MW) would still operate in 2030, leaving significant room for manoeuvre for the conversion of these capacities to biomass.

By contrast, the closure dates set in the operating licenses would result in a faster drawdown of capacities, leaving barely 400 MW of coal-fired power plants in 2030. Press reports seem to confirm the possibility of an accelerated phase out, with Balkan Green Energy News reporting the "combination of measures and investments from the current version of the National Recovery and Resilience Plan may lead to a rapid coal exit in Bulgaria".[20]

Sustainability regulations

Until the 2018 introduction of RED II, only few Member States rigorously applied sustainability criteria as part of its renewable energy production strategy (Richter, 2016). RED II laid out sustainability and GHG criteria for solid (and gaseous) biomass fuels in order to minimize negative environmental impacts (e.g., deforestation, degradation, biodiversity) of bioenergy use, including biogenic emissions under the LULUCF Regulation, applying to installations with a total rated thermal input equal to or exceeding 20 MW that receive financial support. The four core criteria are harvesting, LULUCF, efficiency, and GHG emissions. (see Figure 11 Summary of the new criteria set by RED II)

[20] Bulgaria hints at possible closure of all coal-fired power plants by mid-2025 (Igor Todorovic, August 2, 2021) https://balkangreenenergynews.com/bulgaria-hints-at-possible-closure-of-all-coal-fired-power-plants-by-mid-2025/

Figure 11 Summary of the new criteria set by RED II

Harvesting criteria – RED II, Article 29(6)

The country in which forest biomass was harvested has national or sub-national laws applicable in the harvest area as well as monitoring and enforcement systems in place ensuring the following criteria for sustainable harvesting:

- Legality of harvesting operations
- Forest regeneration of harvested areas
- Areas designated by international or national law, or by the relevant competent authority for nature protection purposes, including wetlands and peatlands
- Harvesting is carried out considering maintenance of soil quality and biodiversity with the aim of minimising negative impacts
- Long-term production capacity of forests.

LULUCF criteria – RED II. Article 29(7)

Economic operators need to ensure that the following criteria are met from the country of origin:

- the country is a Party of the Paris Agreement, and has submitted a nationally determined contribution (NDC) to the UNFCCC, covering emissions and removals from the LULUCF sector, and
- has legislation in place to conserve and enhance carbon stocks and sinks and providing evidence that reported LULUCF-sector emissions do not exceed removals.

Efficiency criteria – RED II. Article 29(11)

The efficiency criteria set efficiency standards for new power plant, with the following ranges and minimum efficiency:

- no efficiency requirement for new plants of less than 50 MW thermal capacity
- for installations with a capacity of 50 - 100 MW, high-efficiency cogeneration, or in the case of cogeneration is not cost-effective (electricity-only mode), meeting the best available techniques requirements
- for new plants above 100 MW, cogeneration, or efficiency of at least 36% in the case of cogeneration is not cost-effective
- no requirement for power plants applying biomass CO_2 capture and storage (CCUS).

GHG criteria – RED II. Article 29(10)

RED II. requires accounting for CO_2 emission from fossil fuels burned during biomass harvesting, manufacturing, and transport, as well as non-CO_2 emissions from biomass combustion.

Calculated emissions are compared to the following standard values:

- 80 g CO2eq/MJ for heat,
- 183 g CO_2eq/MJ for electricity
- for heating, in the case of coal substitution, the comparator is 124 g CO_2eq/MJ.

Dedicated criteria for agricultural biomass – RED II. Article 29(2) and 29(3)

- Operators or national authorities have monitoring or management plans in place to address the impacts on soil quality and soil carbon. Information about how those impacts are monitored and managed shall be reported.
- Agricultural biomass should not have originated from land which was (before 2008) primary of highly biodiverse forest or other wooded land, or land designated to nature protection purposes of highly biodiverse grassland.

Source: own summary of the related section of Article 29 of the RED II

Although the deadline for RED II transposition was 30 June 2021, there is little information in any of the three countries about the legal framework designed to ensure compliance with the new criteria.

Hungary

One of the main roles of the Hungarian Forest Act[21] is to ensure sustained wood production by regulating and setting limits for timber harvesting and prescribing forest regeneration. The founding principles of **sustainable forest management** in Hungary can be traced back to the 18th century. The current legislation is still focused on sustainable wood *production*, with sustainable management of species composition, age structure, microhabitats, natural

[21] Act No. XXXVII of 2009 on forests, on the protection and management of forests

processes, etc. being newly incorporated. These compositional and structural elements are covered in the Forest Act, but certain subcategories – notably preservation of native tree species, residual trees after harvest, leaving dead wood, use of close-to-nature silviculture methods in special areas – are covered in adjacent legislation. The point being, a comprehensive approach is still missing.

The core challenges are the widely used and maintained non-natural forests and plantations, the dominance of clear-cut and shelterwood management methods resulting in relatively young, even-aged native forest stands and general lack of microhabitats (veteran trees, hollow trees, deadwood, etc.). Several forest dwelling animal, plant, and fungi species suffer from the altered habitats, and can only be found in a few areas of Hungary today. According to the Hungarian Country report (Ministry of Agriculture, 2019) of biogeographical assessments of conservation status of species and habitats under Article 17 of the Habitats Directive (2), forest practices such as removal of dead and dying trees including debris, logging, conversion to other types of forests including monocultures, clear-cutting of Hungarian Natura 2000 forest habitats, are threatening factors to habitat preservation.

Hungary's previous KÁT renewable support scheme did impose safeguards for sustainable biomass-to-energy in the form of a requirement for eligible biomass to be sourced from sustainable forestry verified by the forestry authority or an FSC certificate for third country imports. However, this was omitted from the new Government decree 299/2017 (METÁRR) that now regulates the premium support scheme METÁR. This might have been considered redundant with the Forestry Act putting sustainability first. Also, government decrees 389/2007 and 299/2017 both state that biomass used for electricity generation cannot be suitable for food purposes and impose efficiency requirements on installations using biomass. Furthermore, the Hungarian Electricity Act states that operational support for renewable electricity cannot be provided for illegally sourced woody biomass or sourced from sawlog or higher quality wood. However, the law contains no direct reference to the source of non-forestry biomass, which leaves the source and sustainability of agricultural biomass unregulated until the transposition of RED II is completed. Currently most biomass-to-electricity plants receive feed-in tariffs, while Mátra power plant (which co-fires lignite and biomass) qualifies for the brown premium[22]. Those that do not receive financial support are outside the sustainability criteria.

The District Heating Act[23] does not refer to biomass or any renewables source, leaving any sustainability criteria outside of its scope. there are no such eligibility requirements to receive the preferential 4.5% rate of return.[24]

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[22] Within the scope of the METÁR support scheme operating renewable energy installations using solid biomass or biogas may apply for the brown premium, which serves as a successive support to the feed-in tariff or the green premium (i.e. after depreciation). The brown premium aims to ensure economic viability of the operation of biomass plants and is calculated either based on biomass fuel costs of these installations or opportunity costs which arise from the decision to avoid using fossil fuels.

[23] Act 2005/18 on district heating

[24] In Hungary, district heating prices are regulated and set annually by the energy regulator HEA. Prices for all district heating operators are based on annual natural gas prices due to the "least-cost principle", independent of the energy source used. Also, profit rates of district heating producers and service providers are capped according to District Heating Act 2005/18. Decree 50/2011 of the Ministry of National Development sets a

Ministerial Decree NFM 55/2016 sets technical specifications for renewable energy installations receiving EU funds and domestic financial resources. Annex 1 of the Decree contains requirements for biomass heating installations (e.g., min. 85% boiler efficiency, threshold for particulate matter emissions, documentation of emissions to be verified by accredited laboratories, several technical specifications), while Annex 7 deals with electricity generating biomass installations and their requirements (e.g., 37% min. electric efficiency for electricity only installations and min. 75% efficiency in the case of CHP plants.).

While the district heating legislation does not cover sustainability, cogeneration electricity plants participating in FiT or FiP schemes must meet sustainability criteria. In 2019, 63% of the solid biomass district heating capacity was eligible for feed-in tariff support.[25]

Traders selling firewood to **households** must provide an information leaflet containing information about suitable species for firewood, a recommendation to buy firewood by volume rather than by weight, and advice on energy efficiency measures. No information is given to buyers about the source and sustainability of the firewood.

The modification of the Biofuels Act transposed the term ”solid biomass fuels” and requested that the Minister of Agriculture issue a governmental decree on the new sustainability criteria for agricultural biomass per RED II. This decree was issued on 6 October 2021 but still does not provide monitoring and enforcement systems [26] and omits efficiency and GHG emission criteria.

Bulgaria

All **forest** area timber in Bulgaria is harvested sustainably according to forest management plans and programs that monitor the resource use. All forestry activities are planned over a 10 year period, and more than 55% of Bulgaria's state forests are FSC certified.[27]

The 2012 Bulgarian Forest Act introduced certain restrictions for wood used for **electricity** production, from Art. 213. (2): "The use of unprocessed timber from the categories of large construction timber and medium construction timber - III class of assortment for production of energy from biomass is prohibited."

With relatively few biomass installations in comparison to solar PV and wind booms, sustainable sourcing of biomass for electricity is not yet considered a sustainability challenge in Bulgaria. However, this could change with the sudden uptick in biomass co-firing in recent years.

Ordinance № 6 from October 7, 2019 of the Executive Forest Agency regulates wood used for **household heating** primarily by prohibiting more valuable assortments to be used for energy. The ordinance does not apply to combustion plants larger than 0.5 MW or those

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maximum rate of return in the initial book value of assets at 2% in the case of non-renewable generation and 4.5% for renewable generation (and CHP producers). Despite the higher cap on profit rates, the cap itself and the annual price regulation based on natural gas prices serves as a burden for preparing long-term business plans and for securing financing for renewable energy DH investments.

[25] Source of data: MEKH/MATÁSZSZ, http://tavho.org/tudaskozpont/statisztika

[26] 34/2021. (X. 6.) AM rendelet a megújuló energia előállítására szolgáló biomassza fenntartható termesztésére vonatkozó egyes szabályokról

[27] FSC is a global forest certification system established for forests and forest products to promote better forest management.

using pellets and wood briquettes. Accordingly wood for domestic heating must be dry, must not be surface treated with paints, varnishes, resins and glues, must not be impregnated or have undergone other chemical treatment, must not be mixed with other substances and materials, including textiles, plastics, tires or other petroleum products.

Control activities over the use of wood for domestic heating is carried out by the mayor of the municipality or persons authorized and by the Regional Inspectorate of Environment and Water. When carrying out inspections on the use of wood for domestic heating, the persons and bodies referred to above may involve representatives of other competent authorities. No criteria for the sourcing and sustainability of the woody biomass used in domestic heating apply.

Despite its growth, no information pertaining to biomass sustainability criteria in the **district heating** sector could be obtained. Also, no information could be obtained on the implementation of **RED II**, either in terms of new legislation introduced or in preparation.

Romania

In Romania, national laws establish the **forest** management system (forest regime) that are binding for forest owners. The Forest Law (Forest Code) and subsequent legislation and norms (additional FSC certification) comply with the requirements of RED II regarding sustainable harvesting practices, while the Environment Protection Law (GEO no. 195/2005) and the Habitat, Species and Protected Areas Law (GEO no. 57/2007) provide for nature protection and seek to minimize adverse impacts on soil quality and biodiversity.

Research for this project did not uncover additional sustainability criteria for biomass-to-energy use. The support scheme will be changed from green certificates and a mandatory quota system to a contract for differences scheme, as a new energy law is expected to enter into force from 2023. But neither establish criteria for the sustainability of biomass sources according to research.

Other than harvesting criteria for inland forestry biomass, information on the transposition of RED II is also unavailable.

Summary

Sustainability in the forestry sector is assured by forestry regulations in all three analysed countries. Hungary and Romania went beyond sustainable harvesting levels, taking into account the biodiversity of forests.

Such measures are, however, often missing for biomass-to-energy, with the exception of Hungary. Still, in Hungary the standards only apply to plants receiving financial support and have weak control mechanisms. For now households, district heating and industry remain outside of any sustainability criteria in all three countries. In fact the EU still has not defined sustainable criteria for households. In Bulgaria and Hungary the only progress has been an effort is to inform households about the proper use of firewood to minimize air pollution.

While regulations assuring sustainability on the supply side of solid biomass fuels is key, they need to be accompanied by demand side legislation to prevent the use of unregulated biomass sources for energy production (e.g. imported biomass or non-forest biomass).

RED II aims to strength the sustainability criteria for biomass by including efficiency and GHG emissions criteria on the energy demand side while also setting criteria for agricultural biomass on the supply side. It has been speculated that uncertainty surrounding the Fit for 55 proposal is the reason behind several Member States failing to transpose RED II by the deadline while awaiting and expecting stricter rules to emerge.

The **Fit-for-55 Package** published by the EC on 14 July 2021, contains a huge set of proposals to revise and update EU legislation. The aim is to make sure that the Member States get on track to reach the new 55% GHG emission reduction target by 2030, needed for climate neutrality by 2050. The package includes (among others) a proposal to revise the Renewable Energy Directive, the LULUCF Regulation, and the legislation for alternative fuels, which aim at strengthening sustainability criteria for biomass use. The proposal for RED III introduces the following important amendments compared to RED II:

- Applying existing land criteria (e.g. no-go areas) for agricultural biomass to forest biomass (including primary, highly diverse forests and peatlands).
- Reduction of the capacity limit for agricultural and harvesting criteria to a total rated thermal capacity of 5 MW.
- Exclusion of saw logs, veneer logs, stumps, and roots to produce energy from public subsidy.
- GHG saving thresholds for electricity, heating, and cooling production from biomass fuels would also apply to existing installations (not only new installations).
- From 2026 on, support shoudl not be given to electricity-only plants using forestr biomass, with the exception for teh Just Transition Regions or installations using biomass CCUS technology.

Certification schemes

This chapter analyses the national schemes for tracking the origin and route of solid biomass in Bulgaria, Hungary and Romania, and, where available, certification of sustainability.

Hungary

In Hungary, KÁT and METÁR are the schemes providing operating support for **renewable electricity** installations and, as such, stipulate the sustainability of solid biomass. The Hungarian Energy and Public Utility Regulatory Authority (HEA) is the competent authority for administering and verifying the eligibility of projects under the schemes. The HEA asks biomass power plant operators to self-declare compliance with the regulations for the sourcing of biomass and carries out regular inspections to check eligibility for operational support. However since 2017, there is no public information available on HEA's website about the methodology and results of these inspections.

Electricity generators are able to certify guarantees of origin (GOs) for electricity generated from renewable and high efficiency cogeneration once prequalified by HEA. In Hungary the certification of GOs is voluntary. The prequalification by HEA only certifies that a generator site is capable of generating electricity from renewable sources and no sustainability criteria apply.

There is no legal basis for verifying the origin and sustainability of biomass in **district heating** systems.[28]

The KÁT Gov. Decree 389/2007 established that the Forestry Authority is responsible for certifying that biomass in energy originates from **sustainable forest management**.

[28] Cogeneration plants that besides producing district heating receive KÁT or METÁR support for electricity generation face the sustainability criteria and control schemes on the electricity side.

Stakeholder consultations revealed that the Forestry Authority issues this certification annually upon request from biomass plant operators, yet there is currently no legislation outlining the criteria or procedures for it. There also does not appear to be any legislation ensuring that biomass sources originating from unsustainable forest management do not count towards the renewable energy target or must pay back operating support.

The **delivery note** is an important document that keeps track of harvested timber issued under the EU Timber Regulation (Regulation EU No. 995/2010 – EUTR) and prohibits illegally harvested timber or timber products derived from such timber on the internal market. The EUTR competent authority is the NÉBIH[29]. Member States must ensure that timber and timber products are traceable by holding players in the timber value chain responsible for keeping records of traded and carried timber. The delivery note issued to the trader contains all relevant data concerning the biomass material which must be presented by the carrier in the event of an inspection by the competent authority. While forestry biomass is well tracked and verified, solid biomass from land outside of the scope of forestry regulation is much less rigorously tracked. For species covered under the Forest Law harvested outside of forests, the authority or municipality must be notified, but no authority allowance and no operation sheet with technical details are issued. For those species not covered by the Forest Law (e.g. azarole, blackthorn), harvesting can be executed without any notification, leaving only estimates about their production volume. Delivery notes do, however, keep track of their inland transport, self-reported by the carrier of the biomass fuel.

The National Tax and Customs Administration (NAV) keeps records of timber freights as part of the Electronic Public Road Trade Control System (EKÁER)[30], implemented in 2015 to minimize VAT fraud. Firewood and other solid biomass fuels are categorized as "risky products" by their customs registration codes, and any freight volumes above 500 kg or valued at more than 1 million HUF must request a EKÁER registration number. An exemption is possible for distances under 20 km.

No certification of sustainable origin or EKÁER registration is required for solid biomass sold directly to **households** as firewood. It carries a delivery note under the EUTR obligation and an information leaflet for the purchaser.

According to data from HEA, a significant part (31%) of solid biomass comes from agriculture. Its value chain is less documented than forestry, until RED II sustainability criteria is transposed.

EUTR and EKÁER systems focus on the prevention of illegal logging and tax fraud rather than sustainability. Furthermore, the Forest Authority's certificate for sustainable management is a weak instrument for assuring sustainability since it is issued ex-post. Moreover, this certificate is issued annually, and it is not directly tied to wood shipments. There does not appear to be any legislation regulating the consequences of biomass usage from unsustainable sources in Hungry.

[29] https://portal.nebih.gov.hu/
[30] https://ekaer.nav.gov.hu/

Bulgaria

The Bulgarian Renewable Act (Article 33-35) stipulates that GOs for renewable energy sources (RES) including biomass are a precondition for premium payments under the Electricity System Security Fund (ESSF). The application and issuance process for GOs by the responsible authority SEDA does not require any proof of origin or sustainability for the source of biomass. SEDA, the agency responsible for issuing the GOs, would have been stretched thin to verify the biomass sourcing and sustainability of logging for the However, for the recent upswing in biomass co-firing no certificates were required because it was achieved without public subsidies. The verification of origin of raw materials is within the scope of competences of the Ministry of Agriculture, Food and Forestry.

The Forestry Act prohibits use of high quality assortments for electricity production[31], but there is not much information about the control mechanisms. The EUTR regulation was implemented through an amendment of the Forestry Act in 2012 under the Executive Forests Agency. Client Earth[32] and WWF[33] report that penalties and criminal sanctions could be strengthened to prevent from illegal logging.

Romania

In Romania timber is traced by a wood tracking system called SUMAL, implemented in 2008 under the Forest Guard. It is regulated by Government Decision no. 497/2020 and Minister Order no. 118/2021.

SUMAL tracks wood from harvesting to the final consumer including the transformation processes, registering all owners operations in the process. It calculates timber volumes based on inventory data from the field for harvested areas. The updated version of SUMAL released in early 2021 digitized several components (downloading documents online directly from devices, electronic storage registers etc.), reduced the risk of double counting, provides real-time stocks and visualization (through the above mentioned application "Forest Inspector") of data, volumes, locations of harvest plots, and transports underway. Nonetheless retrieving origin information of chips and pellets requires significant time and effort. Furthermore, this updated SUMAL has not been able to address wood transport trucks being overloaded beyond their permits, a problem identified by WWF.[34]

Biomass power plants applying for green certificates must hold certificates of origin but sustainability criteria does not apply. One of the forms delivered to the Environmental Agency requires information on where and when the firewood was bought. Another form asks for further information which can be reached via SUMAL. The heating and transport sectors, which together account for 99% of biomass usage, do not have any proof of origin obligation or sustainability requirement.

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[31] Art. 213, para 2 of the Forest Act (of March 12, 2021) prohibits the large assortments to be used for burning: ,, The use of unprocessed timber from the categories of large construction timber and medium construction timber - III class of assortment for energy production from biomass. "

[32] https://www.documents.clientearth.org/wp-content/uploads/library/2017-02-23-info-brief-eutr-enforcement-in-bulgaria-ce-en.pdf, download: Nov 28, 2021.

[33] https://wwfeu.awsassets.panda.org/downloads/bulgaria_country_assessment_sheet.pdf

[34] Source: https://wwfcee.org/news/wwf-romania-launches-new-tool-in-fight-against-illegal-logging, download: 2021.12.13

SUMAL is created to upload information about wood that is sold and purchased rather than extract information.

The EU Timber Regulation requires assurances of origin for wood entering the market for the first time in the electricity and the heating sector.

Summary

Effective schemes that assure and verify the sustainable use of solid biomass fuels are rare in all the three countries. Certification schemes for renewable energy are linked to financial RES support schemes, which is a sliver of total biomass use. In Bulgaria and Romania the certificates of origin are obligatory, but not subject to any criteria regarding the source or sustainability of solid biomass. In Hungary KÁT and METÁR schemes require biomass plant operators to prove conformity with applicable regulations. These require that woody biomass is sourced sustainably and legally, is not block-wood or higher quality wood and is not suitable for food purposes. Despite these requirements, the practice of self-reporting and weak control mechanisms do not effectively safeguard the sustainability of biomass sources in Hungary.

We also see a risk of circumvention of sustainability rules if biomass is burned on a market basis, i.e. not under support schemes.

Tracking schemes of timber (as requested by the EUTR Regulation) need to be strengthened in the three countries, to be able to keep track of the value chain of solid biomass fuels and to gain data on the amounts and volumes of traded biomass.

The prerequisites for effective certification and verification schemes are: clearly defined sustainability criteria, tracking mechanisms for all types of of solid biomass (not only forest), responsible authorities with effective control mechanisms, and more transparent, publicly available information and data.

Support schemes

This chapter provides an overview of RES support schemes in power and heating sectors, examines the biomass position, and provides an outlook for individual heating.

Support for electricity generation

Bulgaria

Bulgaria introduced a RES support scheme in 2007, providing priority connection and feed-in tariffs with limited annual adjustments and long-term (15-25 year) power purchase agreements (PPAs) signed with National Electricity Company (NEK) and public suppliers. The generous support triggered a boom in renewable investments (wind and solar capacities grew 677 and 1013 MW) increasing the share of total RES electricity generation/consumption to 16.1% in 2012, far ahead of schedule for its 16% 2020 target.

This pace of expansion threatened grid stability and was very costly for the National Electricity Company (NEK). Extra costs were transferred to consumers, causing social tensions, until all forms of support for installations above 30 kW were closed in 2015, resulting in very small RES growth (61 MW for wind and solar) between 2012 and 2018.

In 2018 FiTs were replaced by fixed premiums for existing installations and the mandatory buy-out of renewable electricity by NEK was terminated for renewable energy and cogeneration installations above 4 MW. This threshold was reduced to 1 MW in 2019 and 0.5

MW in 2020. PPAs were replaced by Contracts for Compensation with Premiums (CfCPs) signed with ESSF (Electricity System Security Fund), the successor to NEK.

Currently RES installations over 30 kW are not eligible for premium or feed-in tariffs and are expected to succeed on a market basis. They benefit from indirect support in the form of tax reduction, exemption from transmission and distribution fees, or exemption from the “obligation to society fee”, in certain cases. Currently there are no plans to introduce renewable auctions or support measure beyond the above mentioned, but the NECP notes that tenders may be executed if necessary to reach targets after 2025.

Most of the biomass power plants commissioned before 2015 (totalling 54 MW) managed to lock in the old support mechanism under 20-year PPAs and preferential feed-in-tariff offtake of the electricity output. For these producers the certificates of origin remain necessary to receive the premium component of the FiT.

Partial conversion of existing lignite or coal fired blocks to biomass or waste (co-firing) took off in 2018-2019 without subsidies and may continue on a market basis, driven by carbon quota savings and negative waste fuel prices.

Hungary

Solid biomass-fuelled power plants mainly receive feed-in-tariffs under the so-called KÁT-support as regulated by the Electricity Act and the Gov. Decree No. 389/2007. Tariffs are differentiated according to installed capacity, the date of the support decision and peak and off-peak periods, granted for a period of 20 years. The scheme was closed for new applications at the end of 2016, but installations that received support decision prior to that date are eligible for the feed-in tariff till the end of their support period.

As of January 1st 2017 the new support scheme METÁR and the referring Gov. Decree No. 299/2017. (X. 17.) apply. METÁR introduced a premium support scheme where renewable electricity installations sell electricity on the market and receive an additional premium for up to 20 years. Three technology-neutral METÁR auction rounds have been organised for installations over 0.3 MW without any bids from solid biomass, probably due to the low chances of winning in a joint auction with solar PV.

Solid biomass or biogas installations in operations can apply for the so-called brown premium, which serves as a support extension post feed-in tariff or green premium, after depreciation. The brown premium aims to ensure the economic viability of existing biomass plants and is calculated either based on the biomass fuel costs or the opportunity costs which arise from the decision to avoid the use of fossil fuels. The HEA grants brown premium support upon request by the operators for 5 years, which can be extended for 5 years. In 2020, the Mátra power plant was the only to receive a brown premium.

In October 2021 a new METÁR auction was announced specifically for renewable power plants in operation undergoing major renovation. According to the application form, bidders need to have been in operation at least 20 years before the date of the call and have been in operation for at least 14 years, and those entitled to a feed-in tariff or feed-in premium at the date of the call are not eligible. While this call is technology neutral, solid biomass and co-generation plants are expected to participate. The auction was withdrawn after the application deadline before being announced again in November 2021.

Romania

RES support is in a transitional phase in Romania. The current green certificate and mandatory quota system framework has been in place under Law No. 220/2008 for more than a decade. According to the national Recovery and Resilience Plan (RRP) agreement with the European Commission, Romania will adopt a CfD scheme under the new Energy Law by the second quarter of 2023. The new law will be elaborated with support from the European Bank for Reconstruction and Development.

Eligible RES based producers receive certificates after every unit of electricity delivered to the network. Suppliers must possess a certain number of certificates according to the mandatory quota, from RES producers or the secondary market. Certificate values differ by technology, with wind and solar PV worth more than biomass, and thus dominating RES-E capacities.

The scheme has been modified several times since its inception because higher than expected investments resulted in an oversupplied certificate market. It was formally closed to new applications in 2017, but the expansion of new capacities grinded to a halt in 2014 when the government reduced the quantity of green certificates available for new entrants.

The new CfD scheme announced in 2019 will support not only renewables but nuclear (Unit III and IV Cernavoda) and fossil fuel-based power plants supplemented with CCS. Winning bids will be allocated by the auction rounds according to the strike price determined by producer technology costs, determined on a case-by-case basis for nuclear and CCS.

The ‘reference price’ is set annually on the basis of average day-ahead prices. If the reference price is below the strike price, the counterparty (the market operator OPCOM) compensates the producer with the difference, and if it is above, the producer pays back the difference. The duration of the CfD will be adjusted according to the lifetime of the specific investment, a change from the standard 15 years under the green certificate system. Until the NRRP makes its proposal for the 2023 Energy Law, auction design details and favoured technologies will remain unknown. Assuming a technology neutral auction is chosen, technologies with LCOE (levelized cost of electricity) values lower than biomass will have an advantage.

Support for heating

Bulgaria

In Bulgaria, the use of renewable energy for heating and cooling is promoted through financial grants from the Energy Efficiency and Renewable Sources Fund (EERSF), grant assistance from EU Operational Programmes, and a property tax exemption for building owners.

Operational Programmes active in the 2014-2020 programming period supported several project type, including energy efficiency, renewable energy in buildings, and cogeneration, totalling EUR 10-15 million annually. Use of renewable energy in buildings is also promoted through tax incentives varying between 3 - 10 years, depending on the age of the building and classification of energy performance certificate.

Modernisation and reconstruction of district heating cogeneration systems is supported by the European Structural Fund, including cogeneration projects using biodegradable waste

[and] sludges from water treatment plants and a highly efficient CHP plant in Sofia using municipal waste.

Generation of heating energy could be supported indirectly through the support of cogeneration facilities where mandatory buy-out is applied, but such support is not observable in Bulgaria.

Hungary

Hungary's national support scheme does not specify any special provisions for district heating or RES in district heating. Natural gas is the dominant fuel in the sector, followed by biomass with a 14% share in the recent years[35]. District heating end user prices are regulated based on natural gas prices, independent of the energy source, and district heating heating rate of return is capped at 2% of the initial book value of assets and 4.5% for renewable generation and CHP. Despite the higher cap on profit rates, the cap itself and the price regulation are problematic for securing long term financing.

In recent years significant funding has been allocated to RES from the operative programs (OPs) of the EU Cohesion and Regional Development Funds, co-financed by the Hungarian government in the form of non-refundable support and preferential loans. Most of these applications included solar PV projects, with solid biomass projects only contracted among the Regional Development calls open to municipalities.

In the new programming period (2021-2027), the Hungarian government plans to earmark additional funds for RES via the KEHOP+, the GINOP+ and TOP+ programs and the Just Transition Fund (eligible counties are Heves, Baranya and Borsod-Abaúj-Zemplén). While the structural funds provide significant RES support, project development is hindered by inconsistent open calls.

Romania

In Romania, biomass is used mainly for heating purposes. Policies that incentivize biomass and other renewables in the heating sector are much less structured and support is not continuous. There is investment support available for renewable fuel (bioenergy and geothermal) in district heating, which accounts for a small portion of sectoral biomass. Municipalities are responsible for a share of the operating costs for each district heating system, which results in a subsidized pricing. Operating support have never been in force in this subsector. By far the most significant demand is found in households, yet in place of a targeted national policy for improved energy efficiency there is a general social fuel subsidy for all heating types.

At the end of 2020, a state aid scheme was introduced to support biogas, biomass, and geothermal energy investments in district heating systems. A 150 million euros budget (could be increased to 180 million) was provided to the state aid scheme mostly from European funds. This program is not expected to stimulate significant biomass investment because the overall volume is small and it is competing with biogas and geothermal projects, the latter of which has great potential in Romania. Due to its design, with no more than 20% of the funds going towards transmission networks, which excludes some potential beneficiaries, the program might result in undersubscription. National strategies do not envisage the new

[35] Source of data: HEA

transportation systems, leaving any growth in the number of district heating households to new builds connecting to the already existing networks. This limited growth prospects in the sector can possibly build on biomass but neither confirmatory nor rebuttal information is available regarding the fuel mix of these possible developments.

Prior to this a similar scheme was attempted in 2017, but without EC approval the permitting process did not move forward and it was not implemented.

Renewable heat can be cross-subsidized with CHP plants but Romania's biomass-based electricity generation is so low that it will not be a factor anytime soon.

Support for individual heating and social support

Bulgaria

Household gasification receives far more attention than RES in the new energy strategy along with energy efficiency based on concern over local air pollution caused by burning of wood and coal in old, inefficient heating devices.

In addition, household energy poverty is a major challenge for Bulgarian energy policy. High share of energy costs in household expenditures, arrears on energy/utility bills and inability of poor households to keep their home adequately warm are the conventional indicators of energy poverty.

The main instrument for alleviating fuel poverty is a heating allowance (subsidy in cash) granted to low-income families during the heating season (from November to March). In 2019-2020 more than 200,000 households (7-8% of the Bulgarian families) benefited from this allowance, amounting to €50 million, equal to the annual budget of the EERSF. With more than 90% of beneficiaries using solid fuel (coal or firewood), allowances worked against gasification: social policy concentrating on social cohesion get into conflict with energy policy aiming at decarbonisation.

The National Air Pollution Control Programme introduced a mandatory decommissioning (accelerated discontinuation) from 2020 to 2024 for the use of solid-fuel stoves and boilers. In addition, several standards have been introduced for firewood, including maximum humidity, moisture and ash content, and calorific value. Ordinance № 6/07.10.2019 imposes limitations to the moisture content of firewood used in residential heating and obliges end-users to meet the requirements for storage and drying. Nevertheless, according to a World Bank analysis, it „seems unlikely to be effective as a legal instrument" as it „does not provide the controlling authorities with any practical tools to enforce the requirements for the quality of firewood".

Hungary

Since 2011, the Hungarian government has used the Social Fuel Programme to assist small settlements affected by (energy) poverty. Municipalities with less than 5000 inhabitants can apply to the Ministry of Interior for this non-refundable support, which can be spent on providing firewood or lignite to low-income inhabitants. In 2019 the Hungarian governmental budget earmarked 5000 million HUF (approx. 14 million EUR) for the Social Fuel Programme of 2020.

More than 70% of Hungarian municipalities have benefited from the programme in recent years despite a low budget and disproportionate distribution that provides higher average support to more affluent communities. Use of firewood and lignite in low energy efficient homes causes serious air pollution and health risks in rural areas. In 2019, 90% (approx. 12,8 million EUR) of the funds went to the purchase of firewood (with an amount of 205 685 m3) and the remaining 10% (1.5 million EUR) to lignite (accounting for 14637 tons).[36]

Romania

Low-income consumers can receive social aid for all types of heating, including firewood. The level varies from EUR 4 to 11 per month from the national budget which can be supplemented by local authorities. Mayors can decide the payment method and often chooses direct provisions of firewood. For other heat inputs such as natural gas, electricity and district heating, part of the monthly bill is compensated directly to the service provider. A 2011 census determined that 3,5 million households heat with firewood, of which 17% in 2013 and 4% in 2020 received support. The year-on-year decline is attributable to a rising minimum wage that left many households ineligible even though they are still in poverty.

All municipalities with district heating systems cover some portion (20-50%) of production and transportation costs with subsidies, regardless of the source of production, effectively subsidizing all consumers.

Currently there is no targeted program to incentivize household fuel switching. The Ministry of Environment does manage a program called “Green House,” which supports the purchase of heat pumps and solar panels, but it is not popular and does not address energy poverty. The updated “Green House Plus” is expected to support household energy optimization but the program does not yet have a budget.

Building renovation is led by local authorities applying European funds under the 2014-2020 Regional operational program Priority axis 3, but there is no support for individual households using firewood, for building insulation, or to fuel switch.

Existing programs support energy efficiency in public buildings through thermal insulation, thought the vast majority are left only partially modernization, i.e., thermal insulation but without any further improvements. There are only scarce initiatives of the local authorities to insulate individual households.

Summary

Although Hungary and Bulgaria have relatively ambitious targets for biomass-based energy production, adequate support schemes are missing. In Hungary, the technology-neutral auction system, in Bulgaria the limited overall support system, and in Romania the underdeveloped future support system blocks new biomass-to-energy investments. Some partial coal and lignite fuel switching is happening and conceivable on a market basis, due to rising CO_2 quota prices, as evident in Bulgaria, but the negative fuel price makes the incineration of biomass-containing waste more economic than more "expensive" firewood. In Hungary the growth of waste mixing is attributable to reducing fuel costs.

[36] Source of data: Ministry of Interior, Department for Municipal Affairs

District heating systems are supported mostly through European structural funds in all the three countries, but there is no targeted operational support for biomass.

Bulgaria and Romania support low-income households regardless of heating fuel while Hungary supports applies regulated prices supplemented with social support in small municipalities for the direct purchase of firewood or lignite. In the domestic heating sector Hungary's RES programme can support biomass, but air pollution concerns are a limiting factor, similarly to the other two countries.

Status of biomass compared to other RES technologies in European renewable auctions

According to the EC State Aid Guidelines, renewable support schemes are to be replaced by competitive auctions starting in 2017. These competitive auctions help reveal true costs of renewable technologies and provide comparable data among European countries.

Auctions should be open to all RES technologies, but some flexibility is allowed, in many cases some level of technological differentiation is observed. When all technologies are competing with each other it is possible that all winner projects will be based on the same RES fuel with the lowest unit cost compared to others. Creating different baskets for specific technologies allow for more RES diversification and capitalize on most favourable country specific attributes. The AURES II project[37] examined European RES finding that the role of biomass is not very significant compared wind or photovoltaic. The following short brackets present those few examples where the role of biomass was more significant, at least considering the auction design and the intention of the regulator.

In the Netherlands, technology neutral SDE+ auctions designed to reach 2020 targets differentiates technologies according to specific ceiling prices but in practice compete under the same budget, with the exception of offshore wind. Under this system, 5 GW biomass-based capacities representing one fifth of total awarded capacities was achieved. Support required for biomass was the lowest compared to other technologies in 6 of 12 auction rounds between 2011 and 2019 and was generally lower than support level for PV in this decade long period. The average support level varied between approximately 32 EUR/MWh in the fall of 2018 fall and 62 EUR/MWh in 2014, following an exceptionally high 100 EUR/MWh in the first round in 2011.

Germany uses a dedicated basket for biomass open to existing installations that compete on a different ceiling price. The maximum yearly capacity for new biomass was set at 150 MW in 2017 and 200 MW in 2020. Number of auction rounds was also scheduled, one round per year was held in 2017 and 2018, two was planned from 2019 and onwards. The biomass basket for 615 MW was undersubscribed through four rounds, with only 186 MW awarded capacity where most of the winning bids were already existing installations. The average price of successful bids was near the ceiling price which does not provide much incentive for already existing installations. Local biomass plants appear costly compared to other RES-E installations because of the limited availability of feedstocks and high operational costs. The average successful bid price was between 120-150 EUR/MWh in the four auction rounds between 2017-2019, with 150 and 170 EUR/MWh ceiling prices respectively.

[37] Project website: http://aures2project.eu/

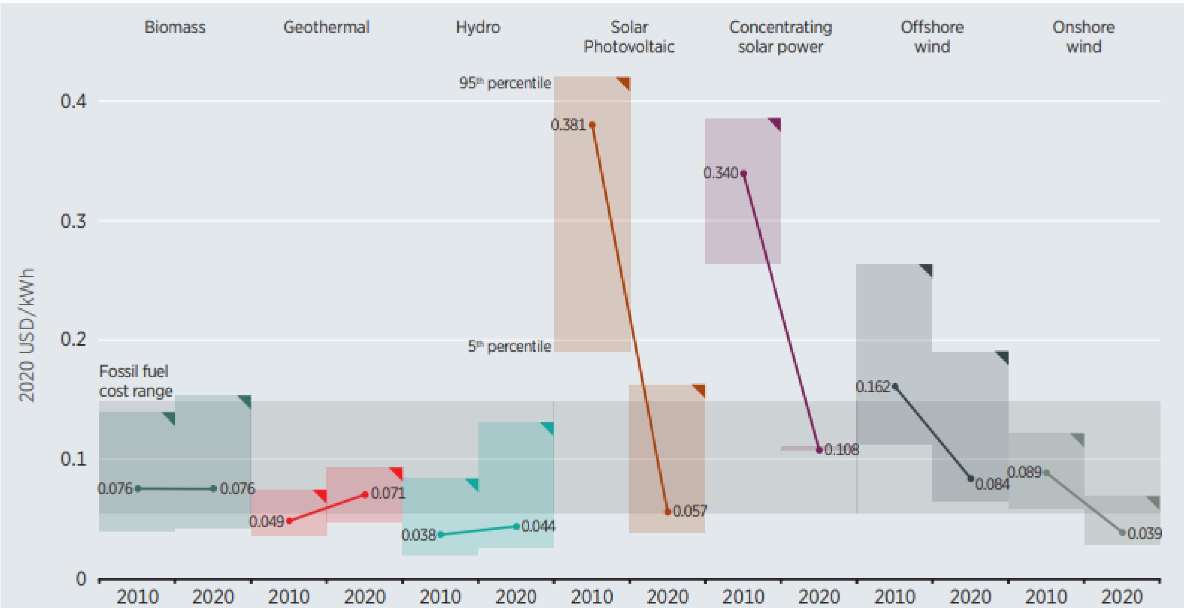
In Polish auctions it is a priority to create opportunity to installations which are not able to compete with the cheapest wind or PV projects, so a separated basket is created for biogas and biomass installations. The 2017 auction for biomass under 1 MW was not considered successful, and for larger installations over 1 MW one successful bid was awarded at 93.65 EUR/MWh. Overall, 6 of the first 9 auctions were unsuccessful due to lack of participation. Auctions in 2018 for existing biomass power plants were also considered a failure, because developers preferred the older scheme in which the maximum price of a green certificates equalled 70.6 EUR/MWh (SKLegal, 2018).

The United Kingdom has established a biomass basket but it has not yet been activated. Another technology basket awarded one 85 MW biomass CHP project.

In most other countries[38] biomass is barely mentioned in auctions, making it clear that the new EU support schemes are not prioritizing the role of biomass in their renewable capacity expansion so pressure on biomass demand is not expected from this aspect.

The low application and success rate of biomass installations is surprising when considering levelized cost for electricity (LCOE) between RES technologies. IRENA's global LCOE valuation shows the range and average values over the last decade, covering mature and less mature technologies. It finds that the unit cost of biomass-based electricity is very close to other technologies, depending on individual characteristics of the project. Furthermore, RES expansion could be achieved with a wider range of technologies, not only those with the lowest unit costs. It is evident that neither LCOE values or bidders themselves value the flexible production of biomass relative to other RES technologies.

Figure 12 Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



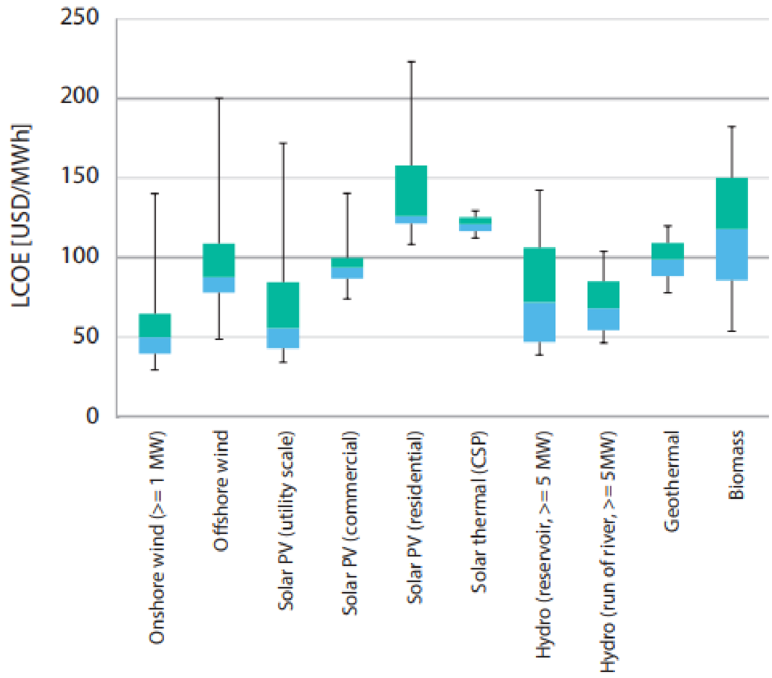
Source: IRENA Renewable Cost Database (2021)

IEA's calculations show that the cheapest biomass projects can be competitive against some solar or wind installations. Fraunhofer (2021) paints a similar picture for Germany. At the

[38] Denmark, Germany, Greece, Hungary, Portugal, Slovakia, Spain, Ukraine

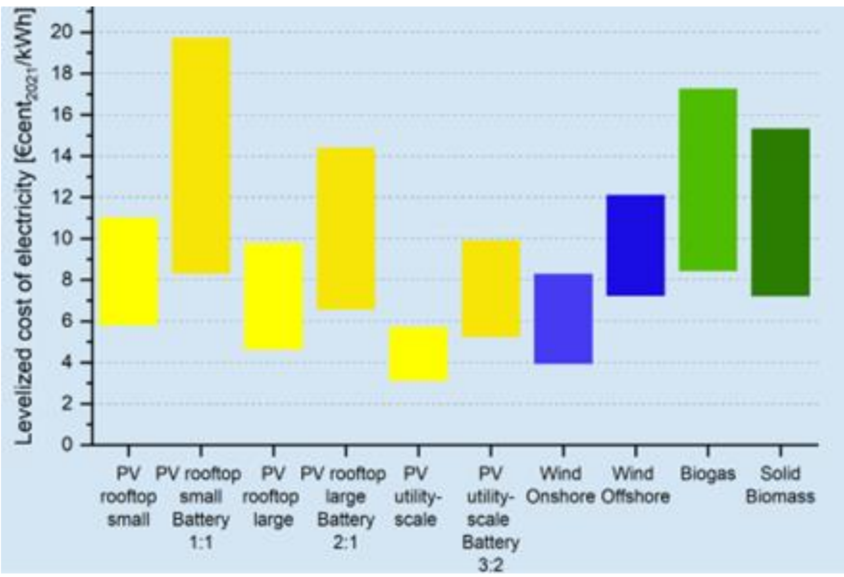
same time, while most RES technology costs are expected to continue to fall, this is not the case for biomass.

Figure 13 LCOE by technology



Source: IEA (2020)

Figure *14* LCOE of renewable energy technologies in Germany in 2021



Source: Fraunhofer (2021)

The unit costs of electricity shown above do not necessarily align with auction outcomes. In theory, biomass-based plants should be competitive with other technologies and win more bids but, as the German and Polish case studies reveal, they do not. One reason is that LCOE calculations do not factor in the availability of firewood, which can impose higher costs, uncertainties, and required features for a plant to operate profitably. For example, IRENA uses 20-50% cost band for feedstock which is a very wide interval representing high uncertainty. As described above, among the three analysed countries only Hungary organized renewable auctions so far, Romania is already committed to switch to this scheme but there is no such news in Bulgaria yet.

Current low popularity of biomass plants in the auction schemes across Europe does not necessarily mean that the role of biomass remains constant or will disappear from the RES-E sector in the future.

It is possible that new 2050 climate targets will require technologies that require higher premiums. Regulated biomass prices and/or investment as opposed to operational support can help to alleviate higher costs. Still, stricter forthcoming EU sustainability requirements make it questionable whether biomass will be classified as a carbon neutral fuel in the future.

2. Quantitative integration and comparison of forest wood for biomass energy in the region

Integrating forest wood supply data and demand for biomass energy data

This section assesses the supply – demand balance adequacy simply by comparing annual quantities of solid biomass entering the markets and annual data of their utilization for energy transformation or final energy consumption.

On the demand side, for consistency reasons, we exclusively rely on EUROSTAT Energy Balances. Transformation input indicates the energy content of the solid biomass utilized by electric power plants, heating plants and cogeneration plants. The final energy consumption of solid biomass occurs in industrial heating processes, household furnaces and stoves and in other sectors.

Official data on the supply side was gathered from an assortment of energy wood products of forest origin (firewood/fuelwood, wood chips for energy, etc.) and the net balance of official export – import data in all forest product categories. Own estimates for forestry residues to energy is added to this.

Official data on agricultural residues and side products utilized for energy in the transformation sector was researched but not fully available. Grey areas include illegal logging data where available, however, most experts can only agree that the magnitude of illegal logging is widely disputed. Another problematic data item is the biomass fraction of incinerated waste and waste products, which should not belong to the category of primary solid biomass, in theory. These calculations are made by the assigned national authorities, who often publicly acknowledge high uncertainty related to waste utilization for energy in both the transformation and final consumption sectors.

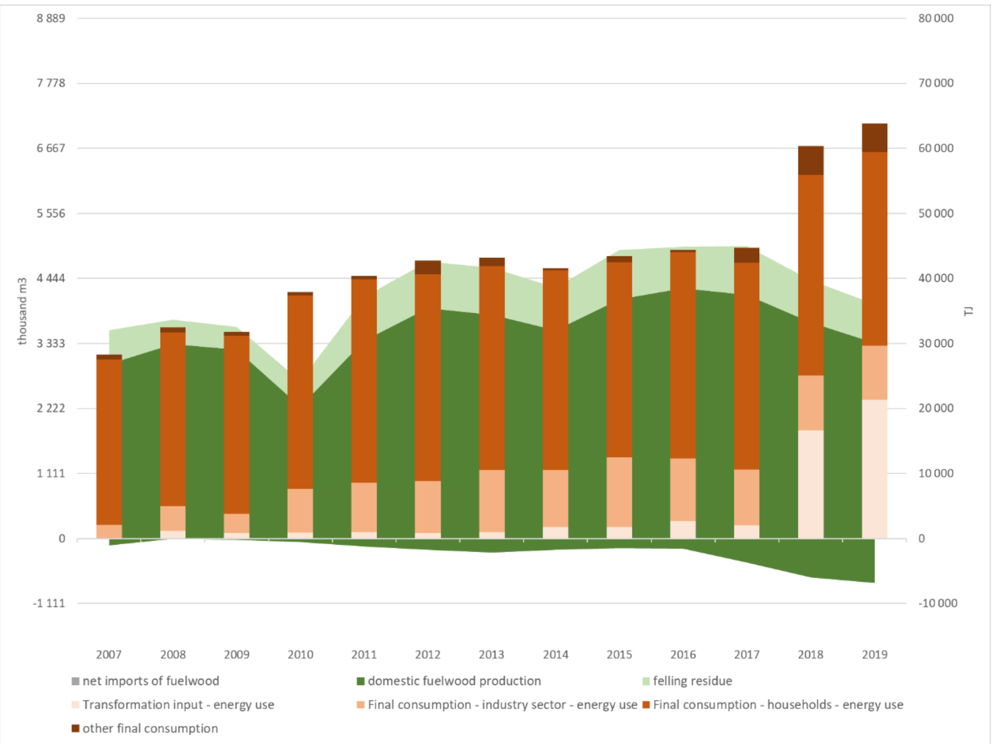
Unit transformations were made based on utilization technologies. For energy balances, the authorities assume a certain amount of energy recovered from the steam generated from the water content of biomass, thus the applied transformation of biomass volume to energy is made with factors higher than the Net Heating Value (but lower than the Gross Heating Value). Conversely, in the household sector the biomass heating facilities are suitable only for simple incineration of firewood with no technical capacity to recover the energy content of the water steam, which is assumed to be lost to the environment. Accordingly, the applied specific energy content of household firewood is the Net Heating Value of firewood[39].

In the followings we summarize country by country how closely solid biomass supply and demand matched in the past several years.

Bulgaria

In the 2010s biomass consumption in Bulgaria did not exceed the sum of domestic fuel wood production and residue, a situation that changed abruptly in 2018 when biomass use for power and heat generation increased sharply while supply of biomass suddenly subsided, creating a significant deficit. However, due to gaps in the available data, it is difficult to judge and explain the gravity of the shortfall. There are conflicting statistics on the volume of biomass that suddenly appears in electricity and heat production, the origin is unknown.

Figure 15 Gap between the supply and demand side of solid biomass energy consumption in volume (thousand m3) and in energy units (TJ) – Bulgaria, 2000-2019



Source: chart by REKK and WWF BG based on EUROSTAT and information from the Executive Forestry Agency of Bulgaria

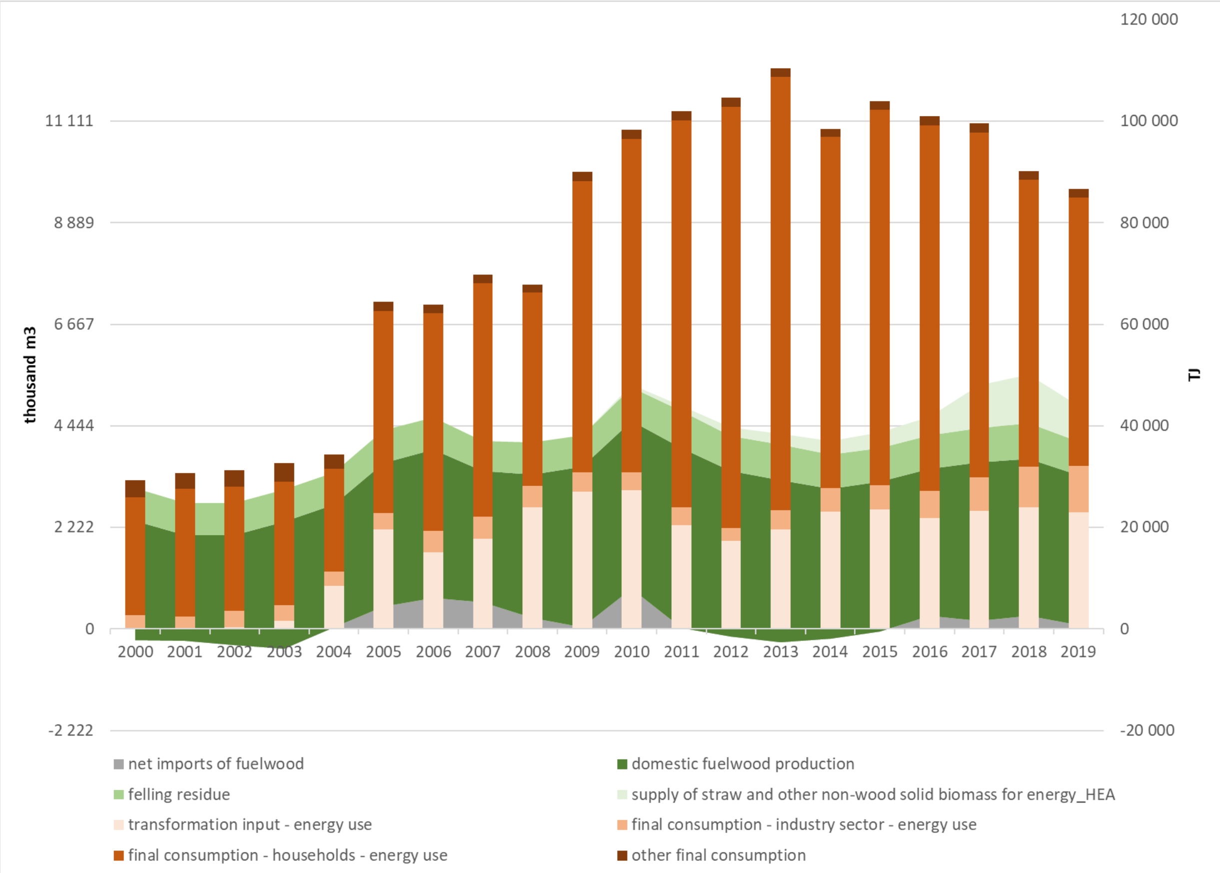
Hungary

Below official Hungarian figures for biomass supply and demand are compared. On the supply side, data from domestic fuel wood production is converted with logging residues and

[39]NHV: the heat of combustion less the heat of water condensation per unit mass of wood with observed moisture content. The parameters we use in our calculations are as follows: GHV: 19 MJ/kg, water moisture content: 30% v/v, ash content: 1% v/v, the latent heat of water evaporation: 2.2 MJ/kg. Calculation with these parameters returns a NHV of 12,5 MJ/kg. Basic wood density is set according to national assortments of firewood species, resulting heating values of 9-11 GJ/m3.

net imports into energy units and then added to straw and other non-wood solid biomass for energy. This arrives at an estimated 36.86 PJ solid biomass supplied in 2019, compared to 86.6 PJ of final consumption according to energy statistics. This leaves about 50% of the solid biomass use unexplained by official statistics in 2019 and raises questions about the source and typology.

Figure *16* Gap between the supply and demand side of solid biomass energy consumption in volume (thousand m3) and in energy units (TJ) – Hungary, 2000-2019



Own calculation based on data from HEA, Central Statistical Office, Eurostat, NLC

The calculation does not include any woody biomass outside the Forestry Act since the data is missing. In the absence of supply side data for agricultural biomass, HEA demand side data was used instead.

The remarkable leap in consumption from 2004 to 2005 can be explained by change in statistical methodology based on updated statistical procedures (see section 'Assessment of biomass energy data uncertainty').

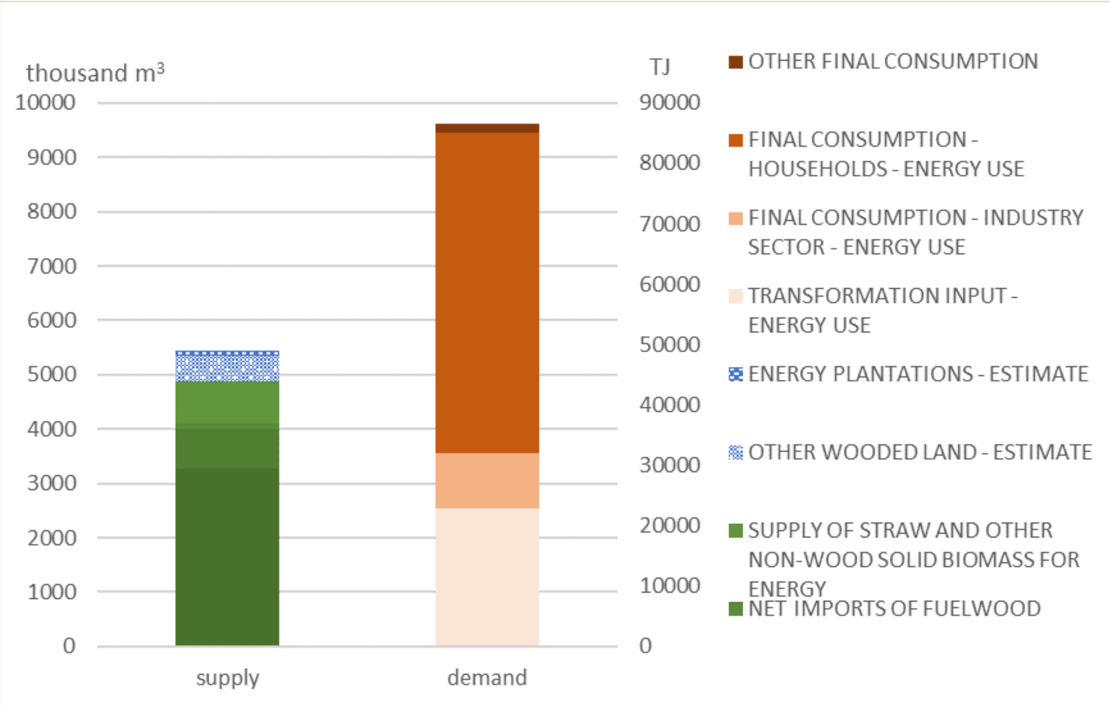
Estimations of other solid biomass supply sources in Hungary

Below estimations of the wooded land areas outside the National Forest Database (NFDB) and the short rotation plantations show the extent to which these biomass sources might cover the gap. The National Forest Inventory (NFI) estimated the growing stock of other wooded land categories outside of the NFDB to be 27.2 M m^3 from 2010-2014 and 33.3 M m^3 from 2015-2019. The average of these two figures, 30.2 M m^3 is the growing stock volume used in the calculations. The intensity of harvesting is assumed to be equal to the forest land within NFDB, which is likely an overestimate, and the same 1.85% average rate of harvested to growing stock is used. After correcting for the gross to net volume (factor: 0,16), the result is approximately 470 thousand m^3 of solid biomass for energy purposes from "other wooded land" sources.

According to the most recent available data in 2013, the total area of short rotation energy plantation was 2,340 ha (Posza, 2018). Considering significant yield variance according to site condition, a rough calculation was made using a 310 GJ/ha/yr lower yield average (Posza & Borbély, 2017; Barkóczy & Ivelics, 2008) and 20t/ha (based on interview with Z. Lontay in REKK 2020) higher yield, which would produce 80-94,000 m3 of solid biomass possibly sourced from energy plantations.

Yet, even after adding our estimations for wooded land outside of the scope of the Forestry Act and energy plantations to supply data, there is still a 43% gap to the solid biomass consumption 2019 official data. as the figure shows below.

Figure *17* Biomass energy supply-demand gap with estimated additional supply from energy plantations and non-forest wooded lands, in volume (thousand m3) and in energy units (TJ) – Hungary, 2019

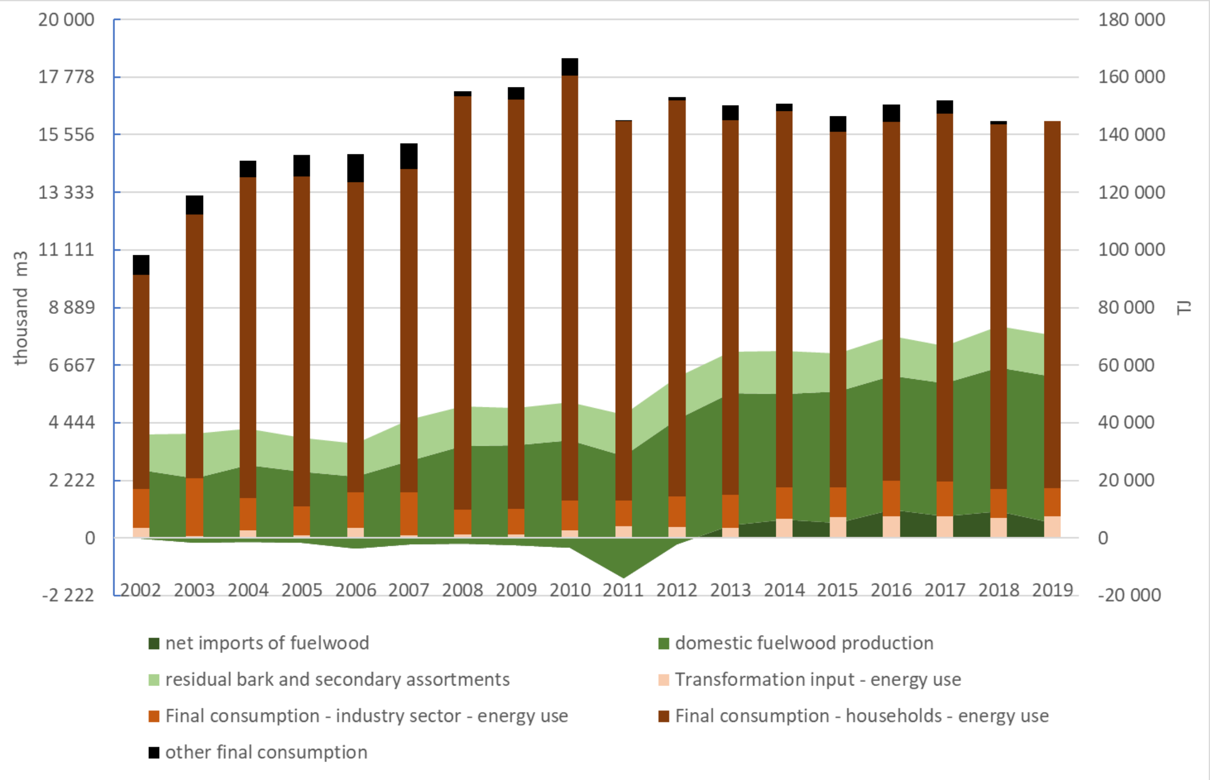


Own calculation based on data from HEA, Central Statistical Office, Eurostat, NLC

Romania

The total domestic production, net imports and felling residues utilized for energy are significantly lower than consumption. Outside of forests, there is no data available for agriculture, agriculture by-products and agricultural waste are categories (which are considered as primary solid biomass).

Figure *18* Solid biomass consumption supply and demand gap in volume (thousand m3) and in energy units (TJ) – Romania, 2000-2019



Own calculation based on data from the National Institute of Statistics, Eurostat

The gap can be partially explained by changes to the statistical estimation methodology for households, which is by far the largest in Romania, way bigger than the supply side. On the supply side, some volumes are not accounted for in the production statistics, possibly covering

- illegal logging from forests,
- unmonitored illegal imports,

Furthermore, household statistics are based on surveys, and people are unlikely to report waste-burning even with a clearly spelled out definition of firewood. The most optimistic assumption would be to fully explain the gap as unmonitored firewood rather than waste such as plastic and other materials that are far more polluting.

The gap is narrowing in the long term, from 70% in the early 2000's to 50% in 2019. The unavailable non-forest biomass data could lessen the gap in the time series, but it is impossible to estimate.

Summary

This analysis reveals a significant gap between biomass sources supplied and biomass consumed in the energy sector for all the three countries, with Bulgaria's starting later.

Underpinning this is the inadequacy of supply and demand statistics, which at times are estimated or missing, and will go a long way to explaining the discrepancy, with no bias to credibility of either data sources. Explaining the entire gap will require elimination of errors and misapprehensions on both sides, supply - demand alike.

On the supply side, official statistics are mostly available for fuel wood categories sourced from forests covered by the national forestry code. The net import balance statistics are also methodologically consistent. Fellings, energy plantations and agricultural waste products and by-products tend to fall outside of the scope of forestry laws. In the end, filling in with estimates of the missing datal still leaves a consistently wide gap.

On the demand side, data on biomass co-firing with coal and/or waste derived fuels tend to be incomplete. One reason is that authorities are hesitant to scrutinize the quantity and sustainability of solid biomass used in for heat and power. Where it is most prevalent for all three countries in the household sector, rigorous statistical methods are executed from a large sample and a lack of methodological coordination makes it very difficult to assess the margins of the statistics.

Assessment of forest wood data uncertainty

Data uncertainty in forestry statistics are not only important in terms of the volume for energy use but also to monitor long-term forest productivity, the cornerstone of the forestry legislation. There are two main sources of forestry data:

- The **forestry database** is the administrative framework for forest management planning, which is a 10-year period in all the three countries. In Romania, in place of a central database the National Institute of Statistics collects administrative data about the forest funds. Bulgaria and Hungary both maintain central databases, but in Hungary the net volume of the different wood types – the foundation of the biomass supply/demand balance – comes from a singular Statistical Data Collection Programme (OSAP) form. This is a yearly collection of stratified random samples from all state-owned forestry, national parks, and water agency and 500 other selected forest managers are data providers.
- The **forest inventory** is a statistical database of national forestry information using sampling grid typically by the FAO forest definition. Bulgaria is one of the few countries in Europe that does not keep this inventory. Romanian and Hungarian inventories are in their third cycles following the first two over the last decade.

Reliability of these datasets are highly questionable. In Bulgaria, according to the Executive Forest Agency, there are difficulties accounting for logging residues and forest resources at national level. Hungary is the only country where data from the forestry database and the National Forest Inventory (NFI) can be compared but pending data from the third cycle is needed to calculate incremental NFI since the first and second cycles targeted different grids. The difference between the two sources is significant: the average of the two NFI cycles quantified 38.4 M m^3 more growing stock in Hungarian forests subject to forest planning. An assessment would need to be carried out to determine how the two methodologies created the discrepancy.

Data uncertainty is also major concern with **illegal logging**. In Bulgaria, the Executive Forest Agency does not have a methodology for assessing illegal logging. Analyses of illegal logging are executed on the basis of administrative violations submitted to the prosecutor's office. Illegal logging can reach 20% of the total harvest. In Hungary, over the last four years of recorded data, illegal logging was between ~12-17,000 m^3.[40] There is no official data regarding the share of industrial wood and wood for energy use, but according to an interview with the responsible authority illegal logging mainly concerns firewood. As stated by the report on the EUTR monitoring, the amount reported is only a fraction of the actual volume of illegal harvest.[41] In Romania, illegal logging is assessed by the central authority through the Forest Guards. According to available data from the 2019 Forest Status Report, the illegal logging in the forest fund reached 256,100 cubic meters. However, the topic of illegal logging features prominently among stakeholder and media, especially in 2019 when the Minister labelled removed wood from forests as 'unauthorized cuts' totalling 20 million cubic meters per year, a figure higher than the reported legal logging. The situation was serious enough for the European Commission to start an infringement procedure in 2020 which remains open.

Assessment of biomass energy data uncertainty

Uncertainty about the exact value of biomass use arises from the fact that while the transformation sector is covered by a complete data service, the consumption of biomass in industry, tertial and household sectors is determined by sampling procedures. Meanwhile the household sector is the most difficult to survey despite accounting for the largest share of biomass consumption.

As a member of the official statistical service, HEA is the responsible body Hungary's for energy statistics as laid down by EU Regulation on energy statistics[42], the EU Directive on energy efficiency[43], the Act on Official Statistics[44], the national sectoral laws on electricity, natural gas supply and district heating, and the government regulation on the OSAP[45]. Data on energy supply and energy consumption are collected and processed separately, based on monthly and yearly data collection across sectors. Obliged parties submit data electronically via the Statistical Information Database (SIA) system, with explanatory notes provided on the HEA website.[46] HEA reports energy statistics regularly to national (Hungarian Central Statistical Office - KSH) and international (Eurostat, International Energy Agency) institutions.

For Romania the authority in charge of official energy statistics is the National Institute of Statistics, which gathers annual data for several domains including 'Energy, Gas and Water Statistics'. The biomass-to-energy is found in the energy chapter of the annual national

[40] Source of data: Source of data: National Food Chain Safety Office (NÉBIH)

[41] National Food Chain Safety Office (Nébih). (2021). Az illegális fakitermelés kockázatával apcsolatos 2016-2020. Évi statisztikai adatok, továbbá a faanyag kereskedelmi-lánccal kapcsolatosan végzett 2017-2020. Évi ellenőrzések végrehajtásának összefoglaló eredményei. https://portal.nebih.gov.hu/documents/10182/1655465/Az+illegalis+fakitermeles+kockazataval+kapcsolatos+2016+2020+evi+statisztikai+adatok.pdf

[42] Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics

[43] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

[44] Act CLV of 2016 on Official Statistics

[45] Governmental Decree 388/2017 (*XII.13.*) on the Mandatory Reporting of the *National Statistical* Data Collection Programme (OSAP)

[46] Available at: http://mekh.hu/statisztikai-informacios-adattar-osap

statistical program. Household energy data is collected using a questionnaire, "Household labor force survey - biomass consumption module".

The questionnaire methodology was established through the President of the National Institute of Statistics Order no. 394/2004 with the "Survey on the labor force in households – AMIGO", in line with EU regulations.[47]

The methodology remains unaltered and no information is expected to be subject to revision in the near future. Data is published in the dataset "Energy balance and structure of energy equipment" and used by the central authorities, research, media, EUROSTAT, International Energy Agency, an the UN.

Of the 3.5 million households listed in the NECP as using firewood, 28,080 are surveyed per quarter, some 3.2% from 2019. The 3.5 million appears to be taken from another statistic publication 'ENERGY CONSUMPTION IN THE HOUSEHOLDS IN 2009', tab.16. This is a large sample compared to other countries but still does not differentiate by type or source of firewood or the installation in the building. Authorities have this information and highlight the huge share of households that burn firewood inefficiently in strategic materials, but do not publishe it. We couldn't gather any further information on the sampling and upscaling methodology of the household survey, or if there is any modelling-based background calculation applied.

For Hungary's **household sector**, the statistical methodology for estimating solid biomass consumption is determined in collaboration with the Central Statistics Office (KSH) based on the results of an energy module added to the Household budget and living conditions survey (HKÉF) run by KSH, with building-energy calculations performed by HEA. This methodology was introduced in 2016 (affecting 2015 data) in response to EU Regulation 431/201448. The modification of the energy statistics regulation requires a separate calculation of household energy consumption according to function (for space heating and cooling, water heating, cooking, etc.). As a result, reported amounts of biomass consumed by households rose sharply. It also increased the RES share from 10% to 14% (Grabner, 2017) .

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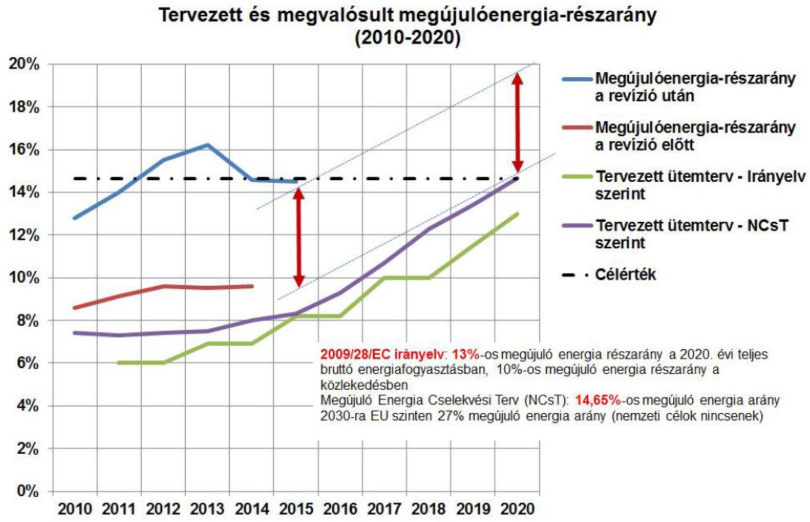
[47] These are specifically: (1) Regulation (EC) no. Council Regulation (EEC) No 577/98 of 9 March 1998 on the organization of a Community labor force sample survey, as amended; (2) Regulation (EC) no. Commission Regulation (EC) No 377/2008 of 25 April 2008 implementing Regulation (EC) No Council Regulation (EEC) No 577/98 on the organization of a Community labor force sample survey, as regards the coding used for data transmission since 2009, the use of a subsample to collect data on structural variables and the definition of reference quarters, with changes subsequent; (3) Regulation (EC) no. Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics, as amended.

[48] Commission Regulation 431/2014 of 24 April 2014 amending Regulation (EC) No 1099/2008 of the European Parliament and of the Council on energy statistics, as regards the implementation of annual statistics on energy consumption in households

Figure 19 Methodological revision effect on Hungarian RES share



Megújulóenergia-részarány a revízió után	Renewable energy share after revision
Megújulóenergia-részarány a revízió előtt	Renewable energy share before revision
Tervezett ütemterv – Irányelv szerint	Trajectory – according to RED
Tervezett ütemterv – NCsT szerint	Trajectory – according to NREAP
Célérték	Renewable energy target

Source: presentation of Péter Grabner, executive vice president of HEA at that time

The yearly HKÉF includes two questions related to biomass use of households: their consumption of biomass fuels and the corresponding expenditures. To be able to assess the used amounts of biomass fuels in depth, in 2016 HEA and KSH collaborated on adding an extra energy module to the HKÉF questionnaire. In 2016, the sample of the HKÉF survey included only 1350 respondents. Information derived from the energy module was being upscaled to the national scale by KSH. Data were cross-checked and adjusted based on building energy calculations based on the typology of residential buildings in Hungary. The HEA used the building typology developed during the Intelligent Energy Europe projects TABULA and EPISCOPE.[49]

The revision of data takes place every five years. Since 2016, the solid biomass consumption data of households have been extrapolated annually by HEA, based on household yearly consumption of other fuels (mainly natural gas and lignite) and temperature correction. In 2020, a new energy module with a new set of energy related questions was devised by HEA and added to the 2020 household survey.[50] The new set of questions shall ensure better data quality. Results and more information on the 2020 survey will be available at the end of 2021.

[49] Source: https://episcope.eu/fileadmin/tabula/public/docs/brochure/HU_TABULA_TypologyBrochure_BME.pdf

[50] Source: https://www.ksh.hu/docs/hun/info/02osap/onk/2154/d202154_2.pdf

In the **transformation sector data uncertainties are more manageable.** In Hungary data collection in the transformation sector is comprehensive, meaning companies that produce, stock, or trade energy sources, or supply electricity or district heating, provide regular data to HEA according to the OSAP Gov. Decree. In the **industry sector**, transport sector, and other sectors (excl. households), the list of organisations obliged to submit data is determined via sampling. Random sampling is based on the list of economic organisations provided by the KSH, considering the NACE codes[51] and number of employees. HEA prepares yearly sampling plans and assesses the samples regularly (Central Statistical Office, 2018).

Uncertainties arise from the reporting of biomass co-firing with coal and/or waste derived fuels used by power plants and heating plants.

For Romania, the data collection methodology for sectors other than households could not be sufficiently mapped in the course of the research for this project. For Bulgaria, no information related to statistical methodologies could be ascertained.

3. Estimating the regional economic supply potential of forest carbon sequestration

Introduction to the FOX model

Today's understanding of the role forests play in the global carbon cycle has been developing rapidly, allowing climate policy makers to begin to appreciate the vast potential of forest carbon sequestration that can contribute to go zero carbon emission goals by mid-century. There is a slowly unfolding demand for economic underpinning amidst the complexity of national carbon mitigation options that utilize and value forests beyond timber producing natural resources.

Governments must integrate forest sink optimization into national carbon mitigation policy as part of the lowest cost solution for reaching net zero-carbon emissions. Forest sink optimization must be made available among other mitigation options. Exactly how much additional forest carbon sequestration will be socially efficient is impossible to say without an economic instrument in place.

Carbon pricing instruments provide information about the cost of abating one ton of greenhouse gases in regulated sectors. In a socially optimal climate policy regime, marginal abatement costs are equal across the entire economy representing the lowest total mitigation cost for the society. Policy instruments must be designed and implemented to prevent the cost of carbon reduction in one sector to far outweigh another.

Economic models can help provide deeper insight for this difficult policy mission. Strategic management of forests with non-timber benefits, including but not confined to carbon sequestration, is complex enough in its own right. Adding biomass-to-energy schemes to the equation requires complex economic modelling to avoid inefficient allocation of natural resources.

The Forest Carbon Sink Optimization Model (FOX) developed by REKK for the BioScreen Project is designed to precisely do this. It is a bio-economic optimization model where production of forest wood is fuelled by biologically determined growth functions but decision making about harvesting or further growth is resolved by an economic profit maximization objective function. This introduces the potential for wood as a carbon instrument in addition to wood as a commodity. Besides the benefits of wood products there is an additional item in the FOX model: the potential benefit of a carbon, by providing a certain payment after the incremental carbon sequestration when harvesting is delayed by another period. Similarly, the model internalizes an equivalent level of carbon release cost in the time period when the final cut is realized.

The FOX Model determines the optimal harvest of forests on a national level based on the exogenous forest growth functions, timber and carbon prices. It is a dynamic, linear mathematical optimization model. The harvesting process includes both cutting and thinning of forests. The model allows the co-existence of multiple forest age classes. Timber and carbon prices are exogenously set for the model. The timber prices are defined for three main demand segments: 'sawlogs' for the timber industry, 'pulpwood' for the fibreboard and paper industries and 'firewood' for all energy purposes. The model can process up to 10 species/species groups in 10-year age classes and can be run for up to 220 years (with 10-year time periods). All characteristics can be further expanded upon based on the input data. The model is written in GAMS with Excel interface. Currently, the model is calibrated with country specific datasets collected from the forest authorities of Hungary and Romania, while the calibration of the Bulgarian model is suspended until all required input data becomes available

In the context of dynamic exogenous factors, model outputs can be computed for all modelled periods: forest stock changes (by species and age), forest final cutting (by species and age), forest thinning as a function of the available forest (by species and age), CO_2 sequestration and the impact of carbon price on forest stock, cutting, thinning and CO_2 sequestration. Ultimately, the model constructs forest carbon sink supply curves for different time periods.

Literature

In economic theory, we build upon the neoclassical literature. Bowes and Krutilla (1985) authored a seminal text on multiple use management of public forestland. Based upon their conceptual approach, economists have built several influential optimization models for forests with multiple benefits.

Development of this model is based mostly on works of Guo and Gong (2017, 2019) and Ekholm (2020). Guo, Gong (2017) models the potential and the cost of promoting forest carbon sequestration through a tax/subsidy to forest owners for reducing/increasing carbon storage, proving that a higher carbon price would lead to higher forest carbon stocks.

In a later paper Guo, Gong and Brännlund (2019) apply a partial equilibrium model of the Swedish forest sector to assess the impact of increasing bioenergy production on the timber harvest and forest growing stock. Their results suggest that increased bioenergy production will lead to a substantially higher harvests and a net loss of forestry carbon storage.

Using the production possibility frontier between harvests and carbon storage, Ekholm (2020) shows that significantly larger forests carbon stocks are achievable with lower harvest levels. The optimal position is determined by the interplay and changes in relative prices between timber, carbon and other commodities dependent on land-use.

From the international modelling stock, EFISCEN (EFISCEN 2021) and CASMOFOR Model (Somogyi, 2019) were consulted closely.

Model description

The model determines the optimal forest harvest area through dynamic linear optimization based on the different end-use prices and costs associated with forest cutting and plantation, as well as the implicit forest growth functions.

The objective function maximizes the net present value of the net benefits from timber production and the stream of net benefits from incremental carbon sequestration:

$$max\ PHI = \sum_t DF * \left(\sum_c pd_{c,t} * x_{c,t} - muc_t * \sum_c r_{c,t} - mup_t * \sum_{s,th} v_{s,tp,th} + PCAREX_t + PCARNEW_t \right) \qquad 1)$$

Where the objective function is subject to

$$pl * \sum_{t} w_{s,u,t} \leq land_{s,u} \qquad \forall s,u \tag{2)}$$

$$\sum_{th} v_{s,t,th} \leq \sum_{u} w_{s,u,t} + \sum_{tp} v_{s,tp,t} \qquad \forall s,t \tag{3)}$$

$$r_{c,t} = \sum_{s,u} w_{s,u,t} * yw_{s,c,u,t} + \sum_{s,tp} v_{s,tp,t} * yv_{s,c,tp,t} \qquad \forall c,t \tag{4)}$$

$$thnew_{t,c} = \sum_{t}^{T} \sum_{s} \sum_{tp} v_{s,tp,t} * ytv_{s,tp,t,c} \qquad \forall c,t \tag{5)}$$

$$thex_{t,c} = \sum_{s,u} \left(land_{s,u} - pl * \sum_{t=1}^{t-1} w_{s,u,t} \right) * ytw_{s,u,t,c} \qquad \forall c,t \tag{6)}$$

$$x_{c,t} \leq r_{c,t} + \frac{thex_{t,c}}{pl} + thnew_{t,c} \qquad \forall c,t \tag{7)}$$

$$PCAREX_t = \frac{\sum_s \{[(\sum_u (land_{s,u} - pl * \sum_{t=1}^{t} w_{s,u,t}) * yw_{s,c,u,t}) - (\sum_{s,u} (land_{s,u} - pl * \sum_{t=1}^{t-1} w_{s,u,t}) * yw_{s,c,u,t})] * nu_s\} * pc_t}{pl} \qquad \forall t \tag{8)}$$

$$PCARNEW_t = \sum_{s,tp} \{ [(\sum_{t+1}^{T} v_{s,tp,t} * yv_{s,c,tp,t}) - (\sum_{t}^{T} v_{s,tp,t} * yv_{s,c,tp,t-1})] * nu_s \} * pc_t \qquad \forall t \tag{9)}$$

$$DF = \frac{1}{(1 + rho)^{10(t-1)}} \tag{10)}$$

Indices	
c	commodity
s	species
u	tree age of „existing" forest
t	modelling period
th	period of final cut for „new" forest (th is part of the modelling period t)
tp	reforestation period (tp is part of the modelling period t)
Variables	
PHI	net present value of benefit from timber production and carbon sequestration
pl	length of a modelling period (measured in years)
DF	Discount factor
$pd_{c,t}$	commodity-specific price
$x_{c,t}$	quantity supplied for commodity c in time period t
muc_t	time dependent harvest cost in period t per m3
$r_{c,t}$	harvested quantity (m3)
mup_t	marginal plantation cost in period t per ha
$PCAREX_t$	net benefits from incremental carbon sequestration in case of "existing" forest
$PCARNEW_t$	net benefits from incremental carbon sequestration in case of "new" forest
$w_{s,u,t}$	area for final felling in existing forest (denoted by w)
$lands_u$	land area for specie s and tree age u
$v_{s,t,th}$	area for final felling for new forest (denoted by v)
$v_{s,tp,t}$	area of new forest for reforestation for species (s) for tree ages (tp) and for each year within the modelling period
$yv_{s,c,tp,t}$	standing volume of newforest
$ytv_{s,tp,t,c}$	exogenous increment of thinning for new forest
$thex_{t,c}$	thinning of existing forest (measured in m3)

$thnew_{t,c}$	thinning of new forest (measured in m3)
$ytw_{s,u,t,c}$	exogenous increment of thinning for new forest
$yw_{s,c,u,t}$	standing volume of existing forest
nu_s	species-specific carbon content coefficient
pc_t	carbon price
rho	discount rate

The objective function (Eq. 1) consists of the following four terms: the benefits from timber, as a perfectly elastic, linear demand "function" where the commodity specific (c) prices ($pd_{c,t}$) are exogenously determined for each period (t) and measured in 1000 € per m^3 timber demanded. The quantity supplied for each commodity ($x_{c,t}$) in each period (t) variable is measured in m^3 and determined by the model.

The objective function consists of the costs associated with harvest and plantation. The cost of harvest is calculated with exogenous and time dependent harvest costs (muc_t) measured in 1000 € per m^3 timber harvested and by the endogenously determined harvested timber quantity ($r_{c,t}$), given in m^3. The plantation cost is determined by the exogenous marginal plantation cost measured in 1000 € per hectare and the area of reforestation in period (tp). The last two terms of Eq. 1) describe the stream of net benefits from incremental carbon sequestration, discussed in detail in Eq. 9).

The supply of timber is determined endogenously and driven by area for reforestation ($v_{s,tp,t}$) and area for final felling ($w_{s,u,t}$) and ($v_{s,t,th}$). The model distinguishes between "existing" forests from the beginning of the modelled time horizon, represented by w, and "new" forests from reforestation activities during the modelled time horizon, represented by v. The final felling of existing forest ($w_{s,u,t}$) is a matrix which describes the area for final felling for species (s) for tree ages (u) and for each year within the modelling period (t) measured in 1000 hectares. Similarly, variable ($v_{s,tp,th}$) includes the area of new forest for reforestation for species (s) for tree ages (tp) and for each year within the modelling period (th) measured in 1000 hectares. Variable ($v_{s,tp,th}$) is a matrix that describes the area of reforestation for species (s) and for each year within the modelling period (tp) measured in 1000 hectares. Variable $v_{s,tp,th}$ describes the area of new forest for final felling for species (s) in the modelling period (th). Here tp and th are elements of t. Both ($w_{s,u,t}$) and ($v_{s,tp,th}$) are nonnegative variables.

The above-mentioned objective function is subject to the following constraints (introduced by Eq. 2)- 9)). Constraints (Eq. 2) and (Eq. 3) describe the maximum amount of area that is available for final felling. Eq. 2) sets the maximum amount of area for final felling of "existing" forest for each species (s) and each forest age (u) over the entire modelled horizon, given the exogenously determined land area for each species and tree age ($land_{s,u}$) and the length of the modelling period (pl). Furthermore, Eq. 3) defines the maximum amount of area for reforestation $\sum_{th} v_{s,tp,th}$ (left hand side, LHS) as a function of the sum of the area for final felling of „existing" $\sum_u w_{s,u,t}$ and „new" forest $\sum_{tp} v_{s,tp,th}$ (right hand side, RHS of Eq. 3).

The constraint introduced by Eq. 4) describes the supply of timber from final felling by demand segment (c) for the modelled period (t) which is the product of the variable area available for final felling $(\sum_{s,u} w_{s,u,t})$ and $(\sum_{s,tp} v_{s,tp,th})$ and the main standing volume $(yw_{s,c,u,t})$ and $(yv_{s,c,tp,t})$ for „existing" and „new" forest, respectively. The main standing volume is determined for each species (s), each tree age $(u$ and $tp)$, each demand segment (c) and each period (t).

Constraints (Eq. 5)) and (Eq. 6) define the timber available from thinning for "new" and "existing" forests respectively. For thinning, the model takes into consideration all afforested land, meaning forest areas still available for final felling, $\sum_t^T \sum_s \sum_{tp} v_{s,tp,t}$ and $\left(land_{s,u} - pl * \sum_{t=1}^{t} w_{s,u,t}\right)$ for "new" and for "existing" forests respectively, where (T) indicates the end of the modelling time horizon. Eq. 5) and Eq. 6) also include the exogeneous increment of thinning $(ytv_{s,tp,t,c})$ and $(ytw_{s,u,t,c})$ for "new" and "existing" forest. Thus, the thinning is calculated based on the land available in period (t) for each species and tree age and the associated yield of side stocks, and it is automatically harvested and supplied in each period.

Constraint Eq. 7) sets the market balance correlation where the demand side (LHS) is constrained by the supply side (RHS). The supply side consists of the timber production from final felling $(r_{c,t})$ and thinning of "existing" $(thex_{t,c})$ and "new" forest $(thnew_{t,c})$. The demand of timber $(x_{c,t})$ is determined for each time period (t) and each demand segment (c) ensuring that the perfectly elastic demand does not exceed supply at any time period and demand segment.

Equation 8) and 9) constraints describe the net benefits from incremental carbon sequestration for "existing" forest $(PCAREX_t)$ and "new" forest $(PCARNEW_t)$. Note that, from the forest manager's perspective, incremental carbon sequestration generates carbon benefits and loss of sequestration incurs carbon costs on growing stock. Thinning wood is produced and cut within the same time period, generating zero carbon benefit or loss. The RHS of these constraints consists of the following three main parts: the changes in the forest stock between period $(t-1)$ and (t), the species-specific carbon fraction coefficient (nu_s) and the – time dependent – carbon price (pc_t) in CO_2 equivalent. The changes in forest stock includes the changes in area available between period $(t-1)$ and (t) and the wood volume yield of side stocks for "existing" and "new" forests.

Country specific estimation of the regional economic supply potential of carbon sequestration by forests

The Forest Carbon Sink Optimization ('FOX') Model has been applied for Hungary, Romania and Bulgaria. The subsequent sections describe the model inputs and assumptions followed by the discussion of results for Hungary and Romania. The development of the model version for Bulgaria is currently on hold pending data acquisition.

Economic supply potential of carbon sequestration of forests in Hungary

Model input parameters and assumptions

The Hungarian Forest Carbon Sink Optimization model (FOX-HU) is mainly built on data provided in the Hungarian National Forest Accounting Plan NFAP-HU, 2019). The FOX-HU model consists of 10 groups of tree species based on the most widely used categorization of species in Hungary (NFK).

Land distribution of existing forest stock and median cutting age

The land distribution of existing forests is disaggregated between species groups and age classes in Table 1 (NFK). Given that the land distribution is split to 10-year age classes, the length of the modelling period is also measured in 10-year periods. Since age classes are not differentiated beyond 110 years, 11 age categories are used in the model for existing forest stock.

Taking into consideration the median cutting age for each species (NFK)[52], any existing standing stock that is older than the median cutting age is considered to be “protected stock”, assuming that its existence is not explained by the tight economic rationale of harvest optimization. Thus, we distinguished the pool of standing stock of overage status, and it is excluded from optimization as ‘protected forests’[53]. The trees in these forests, however, continue to grow and sequester carbon, which is accounted for in the model.

According to our definition of ‘protected forests’ (area of forests older than median cutting age), there are cca.135,000 hectares of forest exempt from optimization in the model. This figure matches the protected status definitions and interpretations of the Hungarian forest statistics.

- The NFAP-HU indicates that “Hungary…has landscape protected areas in more than 15% of the total forest area” which means cca. 270-280 thousand hectares. NFK (2020).
- The National Land Centre, Forest Authority Data Publications summarizes the territory of forests under various protection labels: National Parks, water resources protection, etc. with all areas adding up to cca. 134 thousand hectares

The median cutting age of different species is also one of the central features used to calibrate the model.

[52] The median cutting age for the analyzed species are the following: Oaks 101 years, Turkey oak 90 years, Beech 117 years, Hornbeam 89 years, Black locust 36 years, Other hardwood 75 years, Hybrid poplar 26 years, Poplars 43 years, Other softwood 65 years, Conifers 67 years.

[53] The standing volume of protected stock is assumed to stay unchanged throughout the modelling horizon.

Table 1. Land distribution of existing forests in Hungary by species and age classes, year 2019 (in 1000 hectares)

Age / Species	Oaks	Turkey oak	Beech	Horn-beam	Black locust	Other hardwood	Hybrid poplar	Poplars	Other softwood	Conifers
10	22.7	9.5	3.5	2.0	81.3	6.1	20.3	22.1	3.6	4.6
20	59.7	25.1	14.5	8.1	133.6	18.6	44.1	23.4	8.0	9.4
30	32.4	16.8	9.0	7.9	123.9	17.9	30.2	14.7	10.9	19.4
40	31.5	17.7	5.2	11.1	73.8	15.8	9.3*	11.5	20.2	41.7
50	27.8	19.3	4.6	10.4	21.1	12.8	3.1*	6.7	19.3	52.2
60	31.0	17.5	5.3	7.8	12.9*	11.1	1.9*	4.7*	16.3	27.6
70	38.7	17.9	6.9	8.4	6.4*	11.2*	0.5*	2.9*	8.6*	20.1*
80	35.6	28.7	11.5	13.3	1.4*	7.8*	0.1*	1.2*	5.1*	6.1*
90	37.4	24.4	12.7	11.6	0.3*	5.7*	0.0*	0.4*	2.6*	4.9*
100	26.0	15.8*	11.8	7.8*	0.1*	4.0*	0.0*	0.1*	1.4*	2.6*
110+	45.7*	19.4*	27.1	8.7*	0.1*	6.7*	0.0*	0.0*	2.0*	2.9*

* Areas for protected stock (stock with an age above the median cutting age).

Increments of the standing and thinning stock

Besides the land distribution of existing forests and the median cutting age, another central input is the volume increment of the main standing stock and of the thinning stock, both measured in m^3/ha. Volume increment of the main standing and thinning stocks is based on the biological growth of a particular species - for the FOX-HU model based on the SOPP database (Sopp, L. 1974), a well acknowledged source in Hungary. However, this data set only includes forests up to the 110-year age class, making data extrapolation necessary as input parameters for the model for age classes above 110 years. This extrapolation exercise is carried out based on a regression analysis presented in the EFISCEN model of the European Forest Institute (EFI) by Pussinen et al (2001)[54]:

The growth function is assumed to be quadratic with coefficients based on the following formula:

$$I_{Vf} = a_0 + \frac{a_1}{T} + \frac{a_2}{T^2} \qquad 11)$$

, where
I_{Vf} is the ten-year volume increment,
T is the age of the stand in years, and
a_0, a_1, a_2 are the coefficients,

Given these estimated coefficients, the extrapolation of the volume increment is calculated for the older stand age (up until 600 years). Since the estimated volume increment deviates from the observed values, some correction must be made, given the following formula (Pussinen et al (2001)):

[54]Pussinen, A., Schelhaas, M.J., Verkaik, E., Heikkinen, E., Liski, J., Karjalainen, T., Paivinen, R. and Nabuurs, G.J. 2001. Manual for the European Forest Information Scenario Model (EFISCEN 2.0). Internal Report No. 5. European Forest Institute, Finland. Available: https://www.researchgate.net/publication/268203003_Manual_for_the_European_Forest_Information_Scenario_Model_EFISCEN_20

$$I_{Va} = I_{Vf} * \left(\frac{a_1}{T}\right)^{beta} \qquad \forall\, V_a \leq V_m \tag{12}$$

$$I_{Va} = \frac{I_{Vf} * V_m}{V_a} \qquad \forall\, V_a > V_m \tag{13}$$

. where
I_{Va} is the ten-year volume increment for observed standing increment,
I_{Vf} is the ten-year volume increment for estimated standing increment,
V_a is the observed standing volume (measured in $m^3/_{ha}$),
V_m is the estimated standing volume (measured in $m^3/_{ha}$), and
$beta$ is the correction parameter, that is the relationship between the relative standing volume and the relative volume increment (Nilsson et al. 1992) [55].

The volume increments of the main standing and thinning stocks in the FOX-HU are calculated and applied along the above methodology (see **Table 9** and **Table 10** in Appendix A).

Carbon content

The carbon fraction of the stand is calculated by the ton of carbon stored in a cubic meter of wood. This measure deviates between species, given their carbon content – ton of carbon stored in a ton of wood – and their wood density (or their weighted average wood density in case of grouped species), the mass of a cubic meter of wood[56]. We apply the weighted average of the carbon fraction to compute the mass of carbon sequestered in the forest (see Eq. 8. and 9.). The carbon content and the weighted average wood density input data are based on reference values by Somogyi (2008), NIR-HU (2021) and IPCC (2006).

Table 2. Average carbon fraction, carbon content and weighted avg. wood density by species for forests in Hungary

	Oaks	Turkey oak	Beech	Horn-beam	Black locust	Other hardwood	Hybrid poplar	Poplars	Other softwood	Conifers
Average carbon fraction (ton carbon/m^3)	0.28	0.31	0.28	0.28	0.28	0.26	0.16	0.17	0.21	0.22
Carbon content (ton carbon/t)	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.51
Weighted average wood density (t/m^3)	0.59	0.64	0.59	0.58	0.59	0.54	0.34	0.36	0.43	0.43

Share of demand segments

The FOX model can distinguish between different forest product demand segments. In the FOX-HU settings, three demand segments are identified: firewood, pulpwood and sawlog. The previously mentioned main standing volume and thinning increment input parameters

[55] Nilsson, S., Sallnäs, O. and Duinker, P. 1992. Future forest resources of Western and Eastern Europe. International Institute for Applied Systems Analysis. A report on the IIASA forest study. Parthenon Publishing Group, UK. 496 p. Based on the discussion in Nilsson et al. (1992) and Pussinen et al. (2001), in our calculation a specie-independent 0.4 value is applied for beta parameter.

[56] The carbon fraction is calculated as the product of carbon content and weighted average wood density.

must be further divided among these demand segments. In case of the main standing volume, the share of these segments is a function of age class, while in case of thinning increment the share of the demand segments is constant. As such, the demand segment ratios for thinning volumes are applicable to all thinning regardless of the age of the forest. Lastly, thinning does not generate any sawlogs. The demand segment ratios for final felling apply to mature forests at least as old as the median cutting age (displayed in italics in the following table). The final cut of younger forests produces a lower share of sawlogs and a higher share of pulpwood and firewood, and below a certain age (specified independently for each species group), no sawlogs can be harvested.

Table 3. Share of harvested timber according to demand segments, species groups and harvesting type, Hungary

Demand segment	Oak	Turkey oak	Beech	Horn-beam	Black locust	Other hard-wood	Hybrid poplar	Poplars	Other soft-wood	Coni-fers
Thinning										
Sawlog	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pulpwood	4.8%	3.5%	16.4%	7.9%	3.9%	4.3%	70.2%	66.6%	27.4%	80.1%
Firewood	95.2%	96.5%	83.6%	92.1%	96.1%	95.7%	29.8%	33.4%	72.6%	19.9%
Final felling of mature forest										
starting at age	*110*	*90*	*120*	*90*	*50*	*90*	*30*	*40*	*70*	*70*
Sawlog	46.3%	5.8%	38.0%	12.4%	19.9%	25.9%	88.3%	54.4%	33.6%	43.7%
Pulpwood	2.6%	3.3%	10.2%	6.9%	3.1%	3.5%	8.2%	30.3%	19.2%	45.1%
Firewood	51.2%	90.9%	51.8%	80.7%	77.0%	70.6%	3.5%	15.2%	47.2%	11.2%

Source of data: NFK[57]

Costs, prices, discount rate

The cost and price input parameters are assumed to be nominal and constant over the modelling horizon.

There are two major cost items in the model: harvesting costs and regeneration costs. Ministry of Agriculture (2021) publications provide a very detailed cost structure including all cost items occurring in the harvesting and regeneration processes. Stakeholder interviews were conducted to determine more granularly the most typical harvesting and regeneration cost figures for the purposes of the modelling.

[57] https://nfk.gov.hu/download.php?id_file=41487 and https://nfk.gov.hu/download.php?id_file=41505, accessed on 15 Dec. 2021

Harvesting in FOX-HU includes all types of cutting that produce wood, thinning and final cutting alike. Stakeholder input suggests that about 60% of the harvesting costs are actual cutting costs and 40% logistics. Cutting costs can be labour intensive in challenging terrains and might evolve into capital intensive cutting if the forest manager invests into heavy machinery. Labour intensity of cutting highlights an interlinkage with the construction industry: the two sectors compete for unskilled workers.

Natural and artificial regeneration are two different methods of restarting forests after harvest. The former has low upfront labour and material costs but requires 'operational' skilled labour over the next decade or two to complete a selection for the natural regrowth and select the required structure and species distribution (pre-commercial thinning). Artificial regeneration begins very labour and material intensive with purchase and planting of seedlings in the plot, and even prior to that, soil preparation. The discounted cost flows of each method turn out to be quite similar with low positive discount rates (3-5%), something most experts interviewed agree with.

The following cost parameters are used for the model runs:

- species-independent cutting cost: 10 thousand HUF/m^3
- regeneration cost: 1000 thousand HUF/ha.

The latter can be adjusted to each different species but considering current data availability uniform regeneration costs were applied.

The demand side of the FOX model can be characterized by perfectly elastic demand curves (i.e., market prices) for each demand segment (measured in HUF/m^3), i.e., at the pre-set prices all forest wood products are taken by the market.

We determined the product prices in FOX-HU based on the price statistics of the Ministry of Agriculture[58] Statistical Service (2021). We combined price statistics with marketed volumes, also from the Ministry of Agriculture, to understand drivers of prices. Eventually, we identified three distinctive product categories: sawlogs, pulpwood and firewood. Weighted averages were calculated with the most 'typical' products on the market (products with the highest marketed volumes within each product category.

The following price parameters are used for the model runs:

- sawlogs: 40 thousand HUF/m^3
- fibre- and pulpwood: 13 thousand HUF/m^3
- firewood: 16,6 thousand HUF/ m^3.

The discount rate is one of the main exogenous parameters with a significant impact on modelling results. This study applies a 3% discount rate, which is most common in forest economics literature for long-term modelling (Tietenberg, 2018, Perman et al, 2011). This is

[58] The agricultural administration of the Hungarian government initiated an obligatory reporting scheme about selling prices of forest wood products by state owned forestries in 2019. The same year, a similar survey was launched for privately owned forestries. The statistics got published for year 2020 as well. See link in References.

the rate that has been applied in all FOX models (FOX-HU, FOX-RO and FOX-BG). The following table displays the cost, price and discount rate parameters by source.

Table 3. Input parameters and sources for FOX-HU model

	Planting costs for all species (1000 HUF/ha)	Cutting costs for all species (1000 HUF/m^3)	Market prices by demand segments (1000 HUF/m^3)			Discount rate (%)
			Firewood	Pulp	Sawlog	
Input data	1000	10	16,6	13	40	3

Source of data: Ministry of Agriculture, Statistical Service (2021)

Given the input data and the associated assumptions, the FOX-HU model is run for 18 periods (180 years) but only the first 13 periods (130 years) are evaluated[59]. Period-1 is the 2019 base period with the most recent data on record.

Modelling results of FOX-HU

Reference scenario

Under the FOX-HU Reference scenario no carbon payments are made, net sequestration is not rewarded, just as net emissions are not penalised. Thus, the reference scenario reflects the current policy landscape whereby forest harvest decisions are not influenced by carbon prices. Forests are harvested when they generate the highest net present value of timber benefits minus costs. Figure 20 shows a net decline in timber stock over the first five periods, following latest NFAP projections (NFAP-HU, 2019) due to an ageing standing stock, greater harvest intensity and a slowdown in afforestation. The rebound in timber stocks between periods 5 and 7 is an outcome of the large-scale reforestation following the harvests of the first few periods. Between periods 1 and 5, beech and other hardwood exhibit the largest declines both in percentage and absolute terms. Among short rotation species, hybrid poplar declines the most because of the timing of the harvest, followed by conifers and black locust.

[59] As it has been introduced in the previous section, the FOX model aims to maximize the net present value of net benefit from forestry over a limited time horizon, between 0 and T. The current model cannot assign a residual value to the forest after the end of the horizon (e.g. in $T+1$), thus the last periods of the extended time horizon are impacted by this limitation. Therefore, the first 13 modelling time periods are considered out of the 18 periods.

Figure 20. Main standing stock (optimized and protected) throughout the modelling horizon in Hungary (million m³)

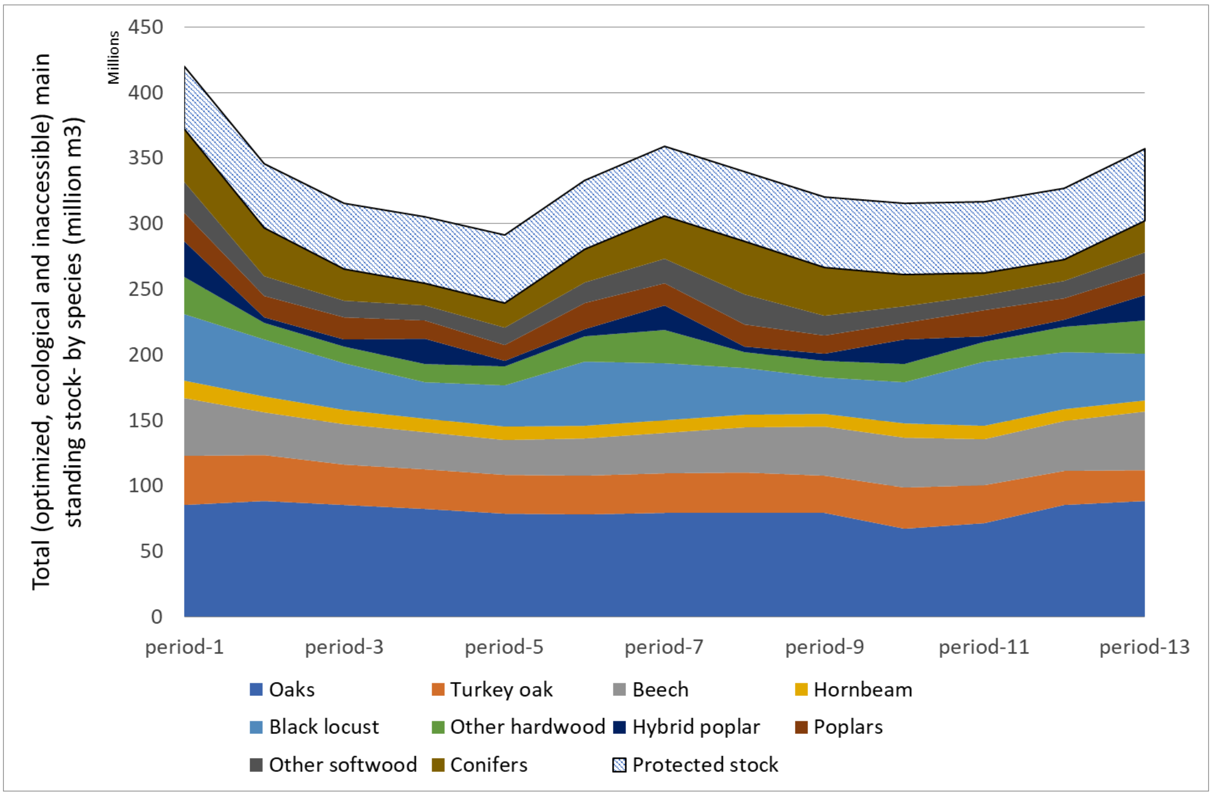
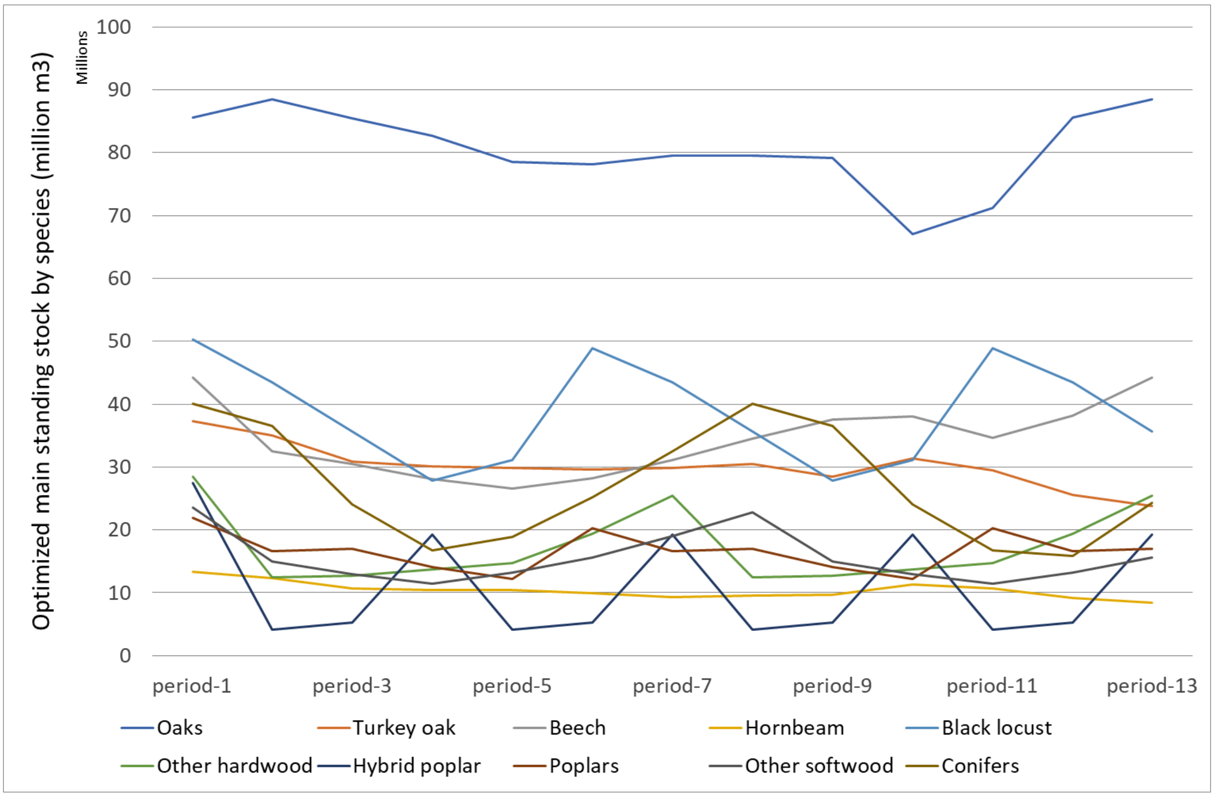


Figure 21 below offers a more nuanced illustration of how the optimised standing stock changes over the 130 years modelled. Some species exhibit a clear cyclic pattern, especially hybrid poplar, (regular) poplar and black locust. The longer cycles of species such as conifers, other softwood and other hardwood would require a longer time horizon, while for the rest of the species current results are not yet indicative of a cyclic pattern.

Figure 21. Optimized standing stock by species in Hungary (million m³)



. The most harvested timber is oak and black locust, as depicted by **Figure 22**. Depending on their starting age composition, individual species exhibit a cyclic pattern, the total harvested volume per period is less volatile (**Figure 23**) than the cyclical patterns of different species that balance each other to some degree.

Figure 22. Timber harvest (final cut + thinning) by demand segment in Hungary (million m³)

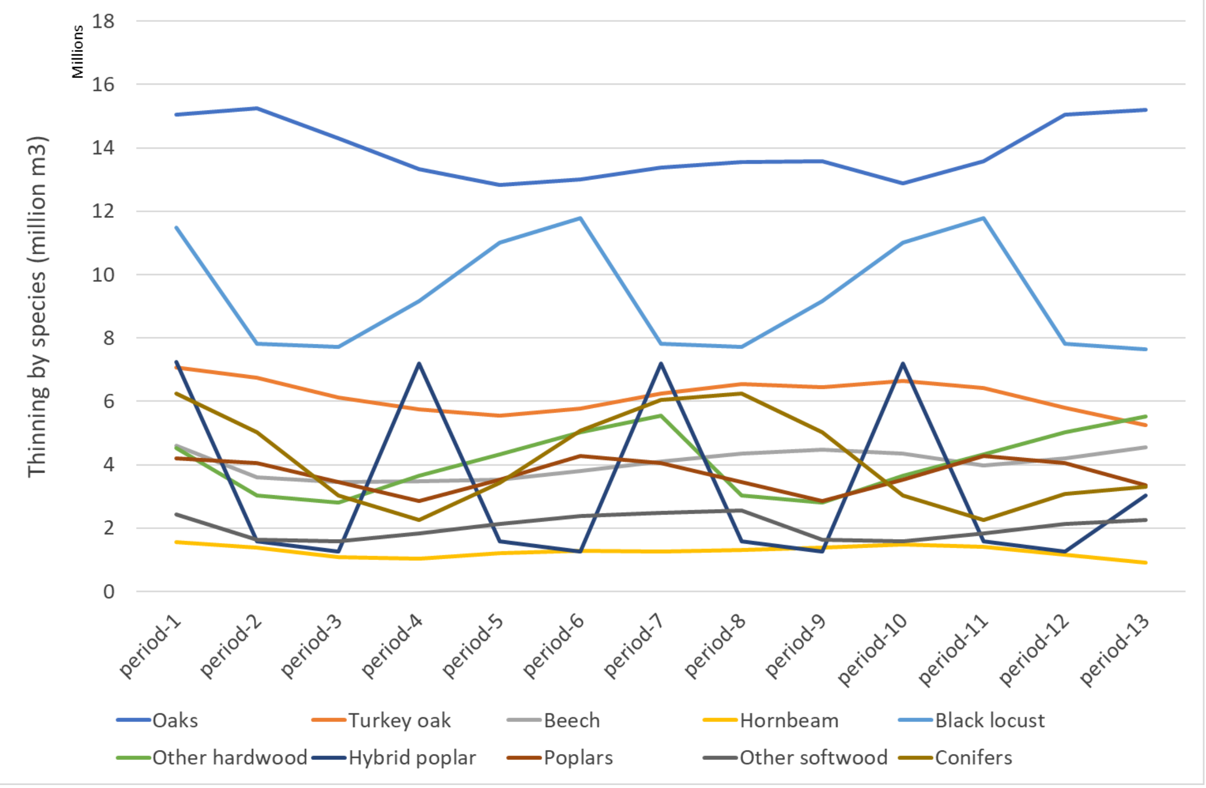
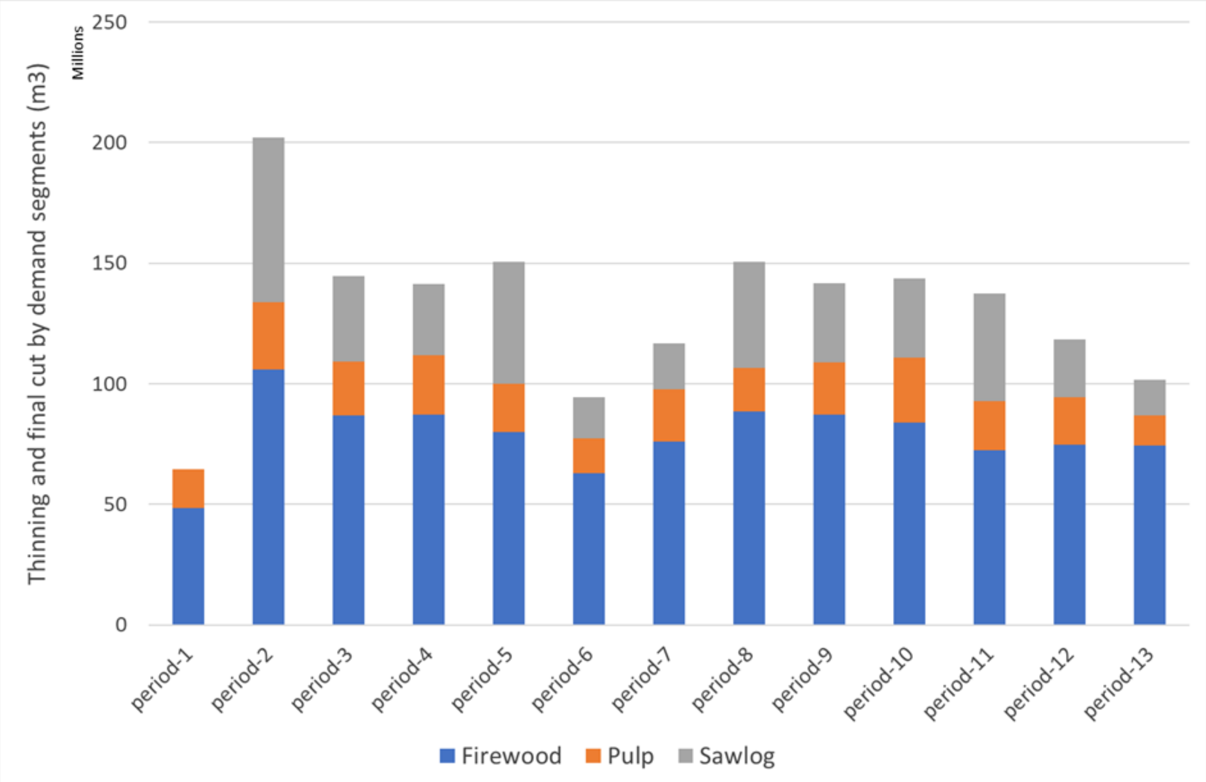


Figure 23 shows the composition of harvested timber for both final cut and thinning. Period 1 volume is the lowest because the model optimises for final harvest only starting from period 2. In period 2, however, it makes up for the absence of harvesting in period 1, with more forests reaching economically rational harvest age.

Thinning occurs automatically as a function of forest composition and age, making it a relatively stable component of the overall timber harvest. Its value ranges between 45 and 65 million m^3 per period, with 71-84% firewood and the rest pulpwood. Period 1 is the best representation of thinning volumes as in all the other periods the additional harvested volume is a result of the final cut, because all of the sawlog originates from final cut.

Figure 23. Total harvest (thinning plus final cut) by demand segments in Hungary (million m^3)



Note that total harvest is taken decade to decade, meaning the quantities are the sum of 10 years of harvest. The average annual harvest across the modelled period is 13 million m^3, the historical annual harvest in the past decade was 7.5 million m^3, and the current annual increment (CAI) has been 13 million m^3. CAI is the technical potential of the economic production possibility frontier in terms, in other words the maximum sustainable yield that can be harvested without depleting the renewable capacity of forests. Hungarian policy documents (NECP-HU, NFAP-HU) anticipate continuous growth in total harvest from the current 7.5 – 8 million to 9 million m3 in 2025 and exceeding 10 million m^3 by 2050.

Scenarios with carbon price

The following section presents the alternative scenario results as we initiate a carbon pricing instrument within the FOX-HU model. Consider a linear carbon tax-and-subsidy scheme rewarding every additional ton of carbon sequestered in the subsequent period by a flat rate subsidy payment (e.g. 20 EUR/t of CO_2) and penalizing each ton of carbon released from harvesting by a flat rate tax payable after total released carbon.

This instrument has the potential to substantially change cost – benefit dynamic over the model horizon. Note that the direction of carbon payments is the inverse of timber payments: carbon subsidies are payable only if timber production is delayed by another period and, similarly, when timber is produced and sold the carbon tax is payable at the same time, after the release of carbon.

In Figure 24, the reference scenario featuring zero carbon payments is denoted with p-0 and the other scenarios factor CO_2 sequestration with carbon payments between 10 EUR/t and 100 EUR/t. In the reference scenario, the sequestered CO_2 stock falls in line with the forest stock. A carbon price of 30-40 EUR/t is enough to counter intensive harvesting and loss of sequestered carbon, with higher prices. Above that price level we see remarkable growth in additional carbon sinking.

Figure 24. Sequestered CO_2 stock at different carbon prices in Hungary (million tons CO_2)

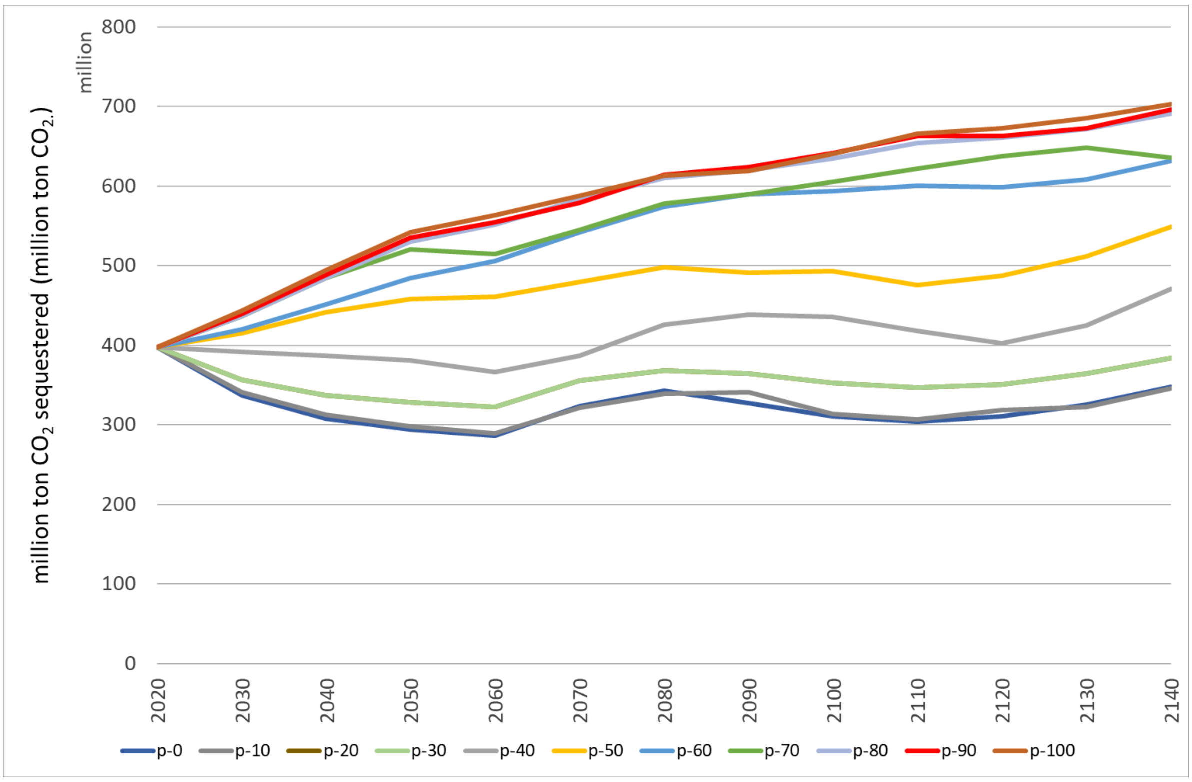
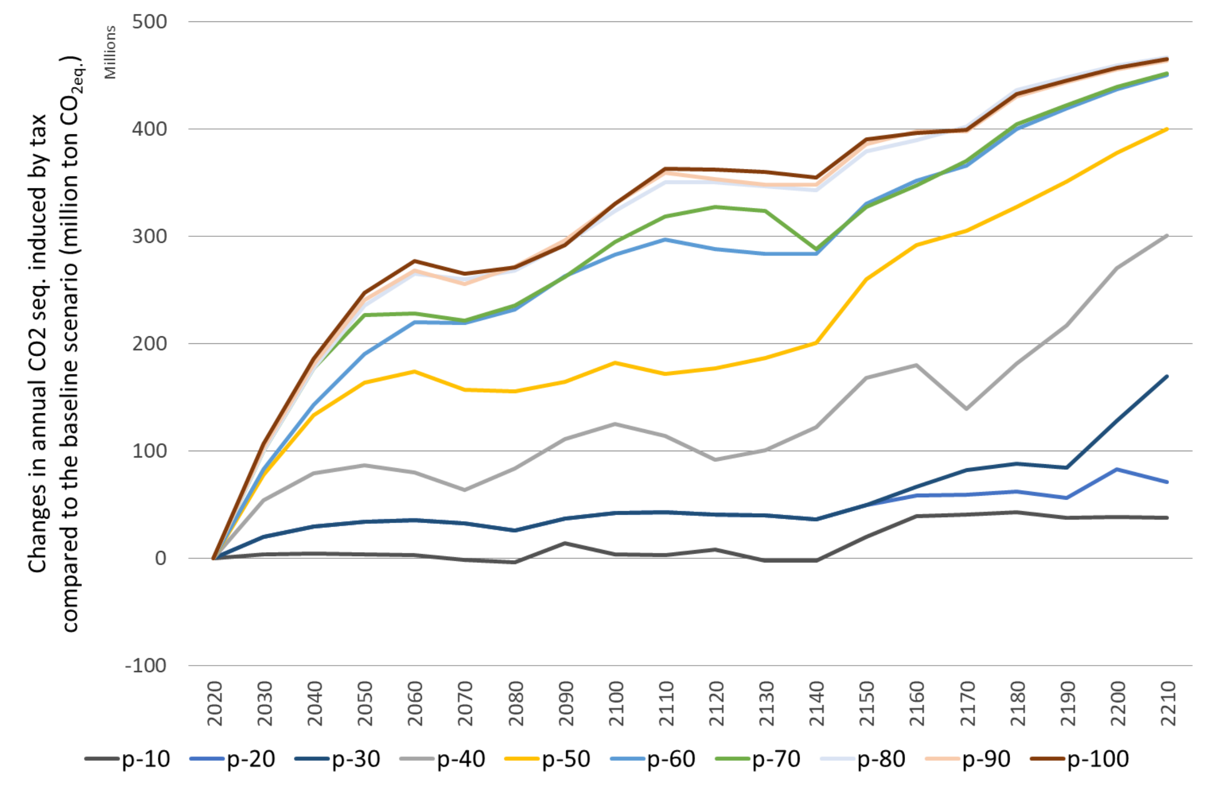


Figure 25 compares growth in sunk carbon at various prices. While CO_2 at 10 EUR/t causes only a minor change in forest management, 20-30 EUR/t leads to net CO_2 sequestration of 34 million tons. As the price of CO_2 keeps increasing through the scenarios, sequestration clearly gathers pace. At 50 EUR/t 164 million tons more CO_2 gets sequestered by 2050 than without carbon payments, and a price of 100 EUR/t generates 247 million tons higher sequestration than in the reference scenario.

The greatest gain is observed when the price jumps from 20 to 60 EUR/t: carbon price becomes game changer at 20-30 EUR/t and it induces a huge amount of additional sequestration as it inflates gradually to 40, 50 and 60 EUR/t and triggers 86, 164 and 190 million tons of additional sequestration, respectively until 2050. Above 60-70 EUR the carbon sinking potential of the forest territory appears to be fully exploited. We further raised the price in FOX-HU up to 80-90-100 EUR in subsequent model runs but only marginal further sequestration could be induced.

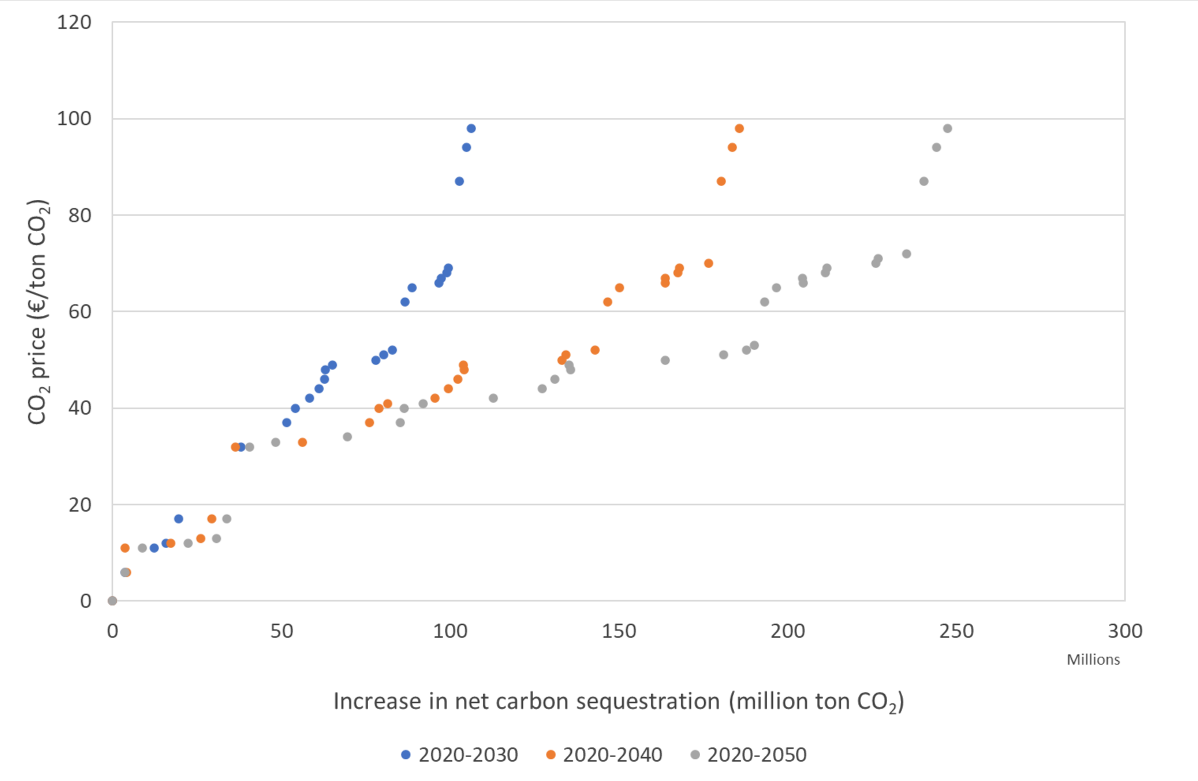
Figure 25. Changes in sequestered CO_2 stock at different carbon prices, compared to the baseline (Reference) scenario in Hungary (million tons CO_2)



The following chart on

Figure 26 translates our results into economic terms. We present carbon sequestration supply curves for forests in Hungary in the first half of the century. These are inverse supply curves, depicting prices in terms of quantities. Inverse sequestration supply curves can be interpreted as either as how much CO_2 is sequestered at a certain CO_2 price or the price for an additional ton of sequestration. The X axis is cumulative sequestration for one, two and three decade-long carbon pricing at certain fixed prices from 2020 through 2030, 2040 and 2050 respectively.

Figure 26. Rise in net aggregated carbon sequestration at different CO_2 prices in Hungary, 2020 to 2050

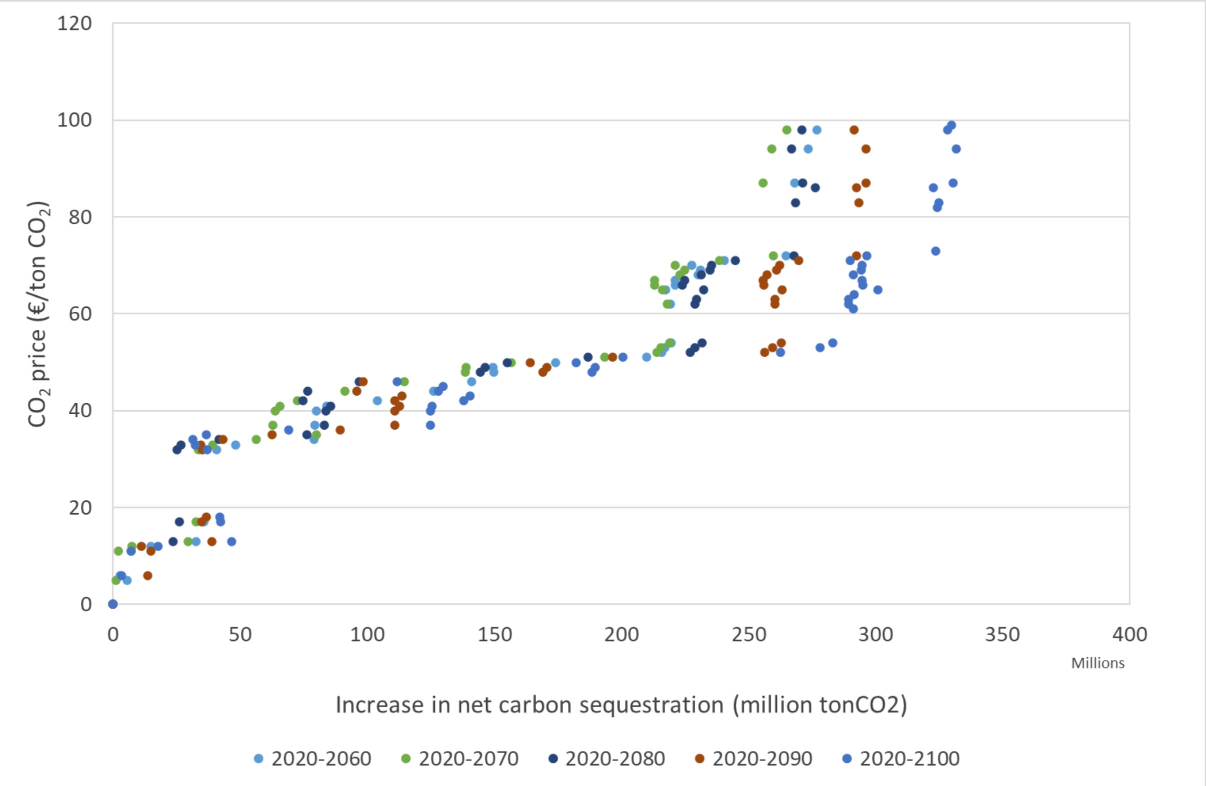


These 'short-run' supply curves are useful to provide insight into the coherence of results. A carbon price of 40 EUR/tCO_2 from 2020 to 2030 leads to a cumulative 54 million tCO_2 additional sequestration (that is 5.4 mt/yr additional annual sequestration on average over 10 years' time). If the regulator can maintain this carbon price for another decade, the cumulative sinking grows to 79 million tons – reaching 86 million tons if the same carbon price prevails until 2050.

The total additional sequestration is not evenly distributed across the decades. Figure 20 illustrated a gradually declining yet very pronounced trend in the baseline scenario for harvesting an aging stock over the first three decades, mostly the first, with a lower drop in the second, and even lower in the third. This means that a carbon price of 40 EUR/t has the most impact on the slope in the first decade (5.4 mt/yr average), with a lower effect impact over two decades (3.9 mt/yr average) and yet lower over three decades (2.9 mt/yr average).

Figure 27 presents cumulative supply curves for the second half of the century. The picture for these 'long-run' supply curves is not as clear as the first part of the century, especially for prices below 50 EUR/t. Recall that the total growing stock rebounds after the 5th decade for reasons other than carbon pricing: after decades of intensive harvesting the forests are allowed to regenerate and we experience rapid growth of the standing stock. So, the carbon price incentive should be stronger to deliver additional sequestration through the latter half of the century.

Figure 27. Rise in net aggregated carbon sequestration at different CO_2 prices in Hungary, 2020 to 2100



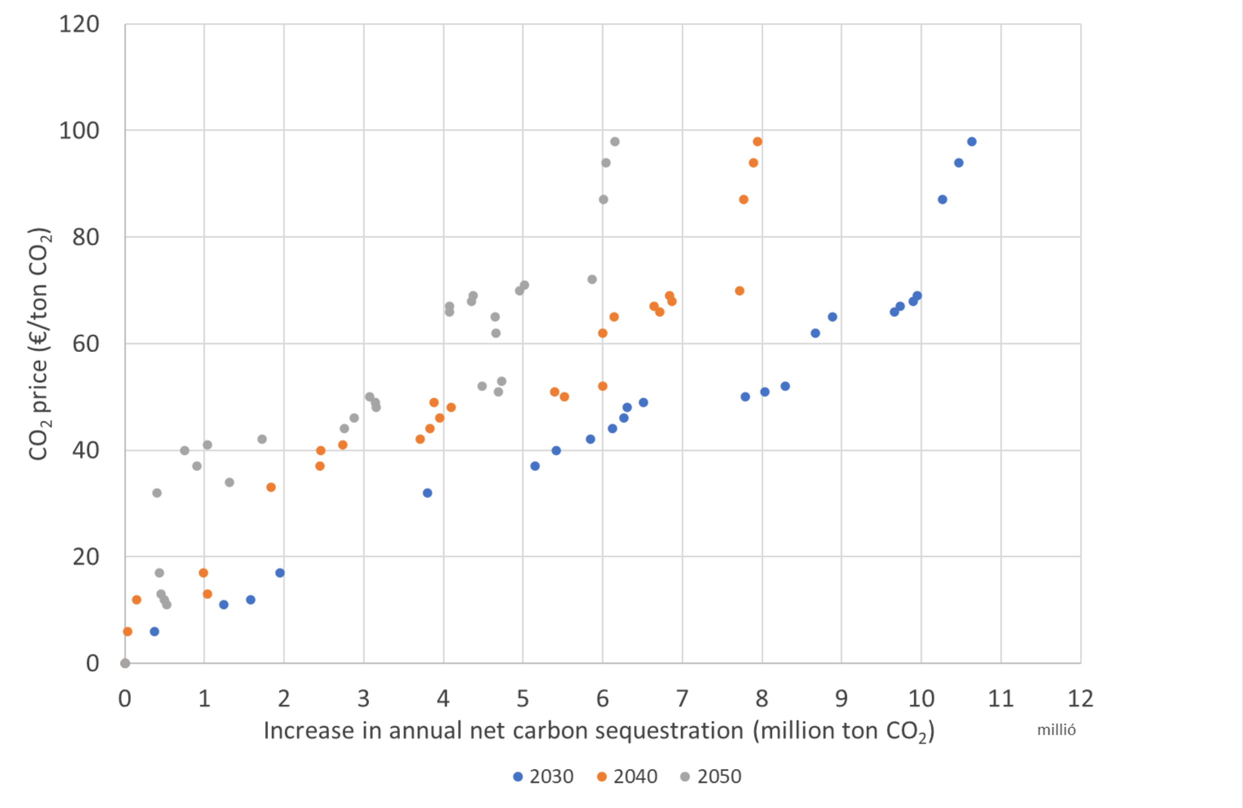
Once the price goes beyond 60 EUR/t the working of the carbon price is intuitive: it prompts more sequestration over a longer period than in the shorter run. For example, at 60 EUR/t, the model returns 265 million tons by 2060 and 324 million tons by 2100, which are 6.6 million t/yr and 4.0 million t/yr average annual sequestrations over 40 and 80 years, respectively.

Figure 28 shows the modelling results in the form of Marginal Abatement Cost (MAC) curves. These conceptually represent the cost of avoiding one more unit of emission at any emission level and are widely used by policy makers to develop optimized, least-cost decarbonisation strategies.

The correlation between rising CO_2 prices and forest sequestration fits with national abatement cost curves, breaking down the task to annual emission reductions. On the downside, we must note that this concept is misleading to the extent that forest-based carbon sequestration cannot be switched on and off like a wind power plant to the grid. Making forests sink additional carbon is not only a slow response, long run option, but, moreover, the cumulative growth of the live stands is a prerequisite to any given year's carbon abatement option. So however useful these may look, the annual forest carbon MAC curves must be carefully interpreted with the more realistic cumulative supply curves in mind as well, as shown in

Figure 26.

Figure 28. Rise in annual net carbon sequestration with CO_2 prices (i.e. marginal abatement costs) in different milestone years in Hungary



In Figure 28 we present milestone years only, to make marginal cost of carbon sequestration by forests comparable to other abatement options. The benefits of carbon pricing for forest sequestration are greatest in the earliest period through 2030 and already declining by 2040 and 2050. Intensive harvesting is also rising to 2030 before subsiding in the later decades. Therefore, a certain surplus sequestration target can be achieved at lower marginal cost in 2030 than in 2050. For example, if the regulator aims for 6 million tons of extra sequestration in the milestone years the carbon price would need to gradually increases from 40 EUR/t to 70 EUR/t by 2050.

FOX-HU has identified significant economically efficient sequestration potential in Hungary's forest sector. Even moderate carbon prices would reverse the loss of sequestered carbon for intensive harvesting in the decades to come. With current EU ETS prices Hungarian forests could sink 5 – 8 million tons more CO_2 than the Reference Scenario, more than double rate over the past decade. As a result, the forest sector could sink 9 – 13 million tons more of CO_2 annually. The real magnitude of this finding is in the context of Hungary's total GHG emissions, representing 14% - 20% of the 64.4 million tons of total GHG emissions in 2019 without Memo Items and LULUCF.

Economic supply potential of forest carbon sequestration in Romania

Model input parameters and assumptions

The Romanian Forest Carbon Sink Optimization model (FOX-RO) is mostly based on data provided by the Romanian National Forest Accounting Plan (NFAP-RO, 2019). The FOX-RO model consists of 5 groups of tree species using the NFAP aggregation.

Land distribution of existing forest stock and median cutting age

The land distribution of existing forests is disaggregated between species and age classes in Table 5 (Ciceu et al., 2019). The land distribution data is provided in 20 year age categories so for the modelling it is evenly split between the two 10 year age groups for 180 years.[60]

The standing stocks older than the median cutting age[61] are considered to be the sum of ecological reserves and inaccessible stocks, since their existence cannot be justified by the tight economic rationale of harvest optimization. This led to the creation of a new category for 'inaccessible and ecological stocks' from the existing forests above median cutting age and exempted from optimization[62].

Table 4 provides the area covered by stocks beyond their median cutting ages.

Table 4. Area and volume of protected and inaccessible forests, Romania

beyond median cutting age	Coniferous	Oak	Beech	Mixed Hard	Mixed Soft	Total	% of forest fund
hectare	487 940	155 080	121 700	78 840	276 740	1 120 300	17.2%
1000 m^3	218 142	79 010	64 319	24 568	85 234	471 273	24.2%

Source: NFAP-RO

Over 17% of the total forest fund representing close to 25% of the total standing stock is overage. FOX-RO classifies 21% of the land area and 28% of the total volume of the forest fund as protected or inaccessible.

In Romania forest management has long turnover cycles, especially for ecological reasons. For some ecological reserve areas (virgin and old-growth forests or quasi-virgin forests) non-intervention is the very goal. Yet, there are several other criteria for identification beside the age: inaccessible areas, lack of roads, lack of labour force, lack of clear ownership, difficult terrain, etc. In these situations, management plans allow for non-intervention.

The median cutting age is used to calibrate the model for different species.

[60] For example, in case of 100-year-old oak, 152 thousand hectares appeared in the original dataset, but, because the preceding observation is the 80-year-old age class, land was not distributed among the 90- and 100-year-old Oak stocks. Given the assumption from the Romanian NFAP, the assigned value is distributed evenly between the 90- and 100-year-old stocks, therefore 76 and 76 thousand hectares are assumed for the 90- and 100-year-old Oak, respectively.

[61] The median cutting age for the analyzed species are the following: Coniferous 70 years, Beech 120 years, Oak 100 years, Mixed hardwood 110 years, Mixed Softwood 30 years. Source: Virstele exploatabilitatii technice pentru arboretele gospodarite in codru regulat functie (prioritara) de productie (received from expert consultation)

[62] The standing volume of ecological reserve and inaccessible stocks is assumed to stay unchanged throughout the modelling horizon.

Table 5. Land distribution of existing forest by species and age in Romania, year 2010 (in 1000 hectares)

Age / Specie	Coniferous	Beech	Oak	Mixed Hardwood	Mixed Softwood
10	110.9	132.3	69.8	85.7	27.5
20	110.9	132.3	69.8	85.7	27.5
30	178.5	212.9	112.3	138.0	44.2
40	178.5	212.9	112.3	138.0	44.2*
50	156.5	186.7	98.5	120.9	38.8*
60	156.5	186.7	98.5	120.9	38.8*
70	158.3	188.8	99.6	122.3	39.2*
80	158.3*	188.8	99.6	122.3	39.2*
90	120.7*	144.0	76.0	93.3	29.9*
100	120.7*	144.0	76.0	93.3	29.9*
110	72.2*	86.2	45.5*	55.8	17.9*
120	72.2*	86.2	45.5*	55.8*	17.9*
130	30.7*	36.6*	19.3*	23.7*	7.6*
140	30.7*	36.6*	19.3*	23.7*	7.6*
150	13.9*	16.6*	8.8*	10.8*	3.5*
160	13.9*	16.6*	8.8*	10.8*	3.5*
170	6.4*	7.7*	4.0*	5.0*	1.6*
180	6.4*	7.7*	4.0*	5.0*	1.6*

* Areas for ecological reserve and inaccessible stocks (stock with an age above the median cutting age).

Increments of standing stock and the thinning stock

The Romanian NFAP provides aggregate standing volume data for every 20-year age class based on the observations of the National Forest Inventory. Without the Giurgiu & Draghiciu yield tables, we attempted to estimate the net increment of the standing and thinning stocks, but some of the derived increments turned out to have improper (negative) values.

Therefore, net increment of the main standing stock and thinning was modelled by input data from the FOX-HU estimates in the FOX-RO model. In case of Coniferous, Beech and Oak data is directly applied, while in case of mixed hardwood and mixed softwood main standing volume and thinning increment are calculated as the arithmetic average of the Hungarian Turkey oak, Hornbeam, Black locust and Other hardwood yield data, and of Hungarian Hybrid poplar, Poplars and Other softwood yield data, respectively.

We calculated the main standing volumes and thinning increments in the FOX-RO model based on the assumptions described above (see Table 11and Table 12 in Appendix B).

Carbon content

The average carbon fraction of the stand is measured by ton of carbon stored in a cubic meter of wood. This measure varies between species according to their carbon content – ton carbon stored in a ton of wood – and their weighted average wood density – the mass of a cubic meter of wood[63]. The average carbon fraction measure is applied to calculate carbon sequestered in the forest (see Eq. 8. and 9.). Carbon content and weighted average wood density input data are based on Romania's Greenhouse Gas Inventory Report 1989-2019 (NIR-RO, 2021)

[63] The carbon fraction is calculated as the product of carbon content and weighted average wood density.

Table 6. Average carbon fraction, carbon content and weighted avg. wood density by species

	Coniferous	Beech	Oak	Mixed Hard	Mixed Soft
Average carbon fraction (ton carbon/ m^3)	0,20	0,26	0,27	0,19	0,27
Carbon content (ton carbon/t)	0,51	0,48	0,48	0,48	0,48
Weighted average wood density (t/ m^3)	0,39	0,55	0,57	0,41	0,55

Share of demand segments

Like the FOX-HU model, the FOX-RO model uses three demand segments: firewood, pulpwood and sawlogs. The main standing volume and thinning increment input parameters are further divided among these demand segments. In contrast to the Hungarian model, the share of these segments is a function of age class for both the main standing volume and the thinning increment. In the FOX-HU model the share of demand segments is age specific only for the main standing stock but not for thinning. This is because in Romania a significantly larger share of timber is used as sawlog than in Hungary. Table 7 shows the demand segment shares applied in the model for median harvest age forests.

Table 7. Share of harvested timber according to demand segments, species groups and harvesting type, Romania

Demand segment	**Coniferous**	**Beech**	**Oak**	**Mixed Hard**	**Mixed Soft**
Median harvest age	70	120	100	110	30
Thinning (at median harvest age)					
Sawlog	43.3%	0.0%	35.0%	21.7%	2.3%
Pulpwood	29.7%	23.7%	6.5%	12.9%	40.7%
Firewood	27.0%	76.3%	58.5%	65.4%	56.9%
Final felling of mature forest (at median harvest age)					
Sawlog	90.0%	72.3%	80.0%	80.0%	80.0%
Pulpwood	5.2%	6.6%	2.0%	3.3%	8.3%
Firewood	4.8%	21.1%	18.0%	16.7%	11.7%

Source of data: Institutul National de Statistica, Round wood volume exploited by categories and species group.

Costs, prices, discount rate

In FOX-RO cost and price input parameters are assumed to be nominal and constant over the modelling horizon. The following cost parameters are considered: species-independent cutting cost (unit: 1000 lei/m3) and the species-dependent regeneration cost (unit: 1000 lei/ha). The demand side of the FOX model is constructed with perfectly elastic demand curves (i.e., market prices) for each demand segment (measured in 1000/m3). A discount rate of 3% is applied in the FOX-RO model. Table 8 summarizes these inputs.

Table 8. Cost price and discount rate input parameters and their sources for FOX-RO model

	Planting costs for all species (1000 lei/ha)	Cutting costs for all species (1000 lei/m^3)	Market prices by demand segments (1000 lei/m^3)			Discount rate (%)
			Firewood	Pulp	Sawlog	
Input data	2.83	0.13	0.21	0.28	0.52	3

Source: Statistica Activitatilor din Silvicultura, 2019

Given the input data and the associated assumptions, the FOX-RO model is able to cover 28 periods (280 years), but only the results for the first 22 periods (220 years) are used in the study. Period-1 is the baseline period with the most recent historic data on records, that is 2010).

Modelling results of FOX-RO

Reference scenario

The Reference scenario of FOX-RO captures the optimal harvesting pattern and the resulting felling and regeneration cycles of forests in Romania under the parameters and constraints discussed above. In the Reference scenario there are no carbon payments, net sequestration is not rewarded, just as net emissions are not penalised. Thus, forest harvest decisions are not influenced by carbon prices, they are driven by the net benefit considerations of forest managers on the basis of product prices, management costs and discount rate, i.e. the highest net present value of timber production.

As Figure 29 shows, the FOX-RO Reference scenario starts with an intensive harvesting period followed by several periods of plateaus and moderate overall harvesting activity up until period 10, which corresponds with the NFAP projections of increased harvesting (Ch. 4.2., NFAP-RO) for better technology and higher demand in the wood market.

After period 10, FOX-RO recovers the existing volume of total standing stock. Throughout the modelling horizon, species exhibit their typical felling and regeneration cycles.

Figure 29. Total standing volume (main stock and thinning) in Romania (million m³)

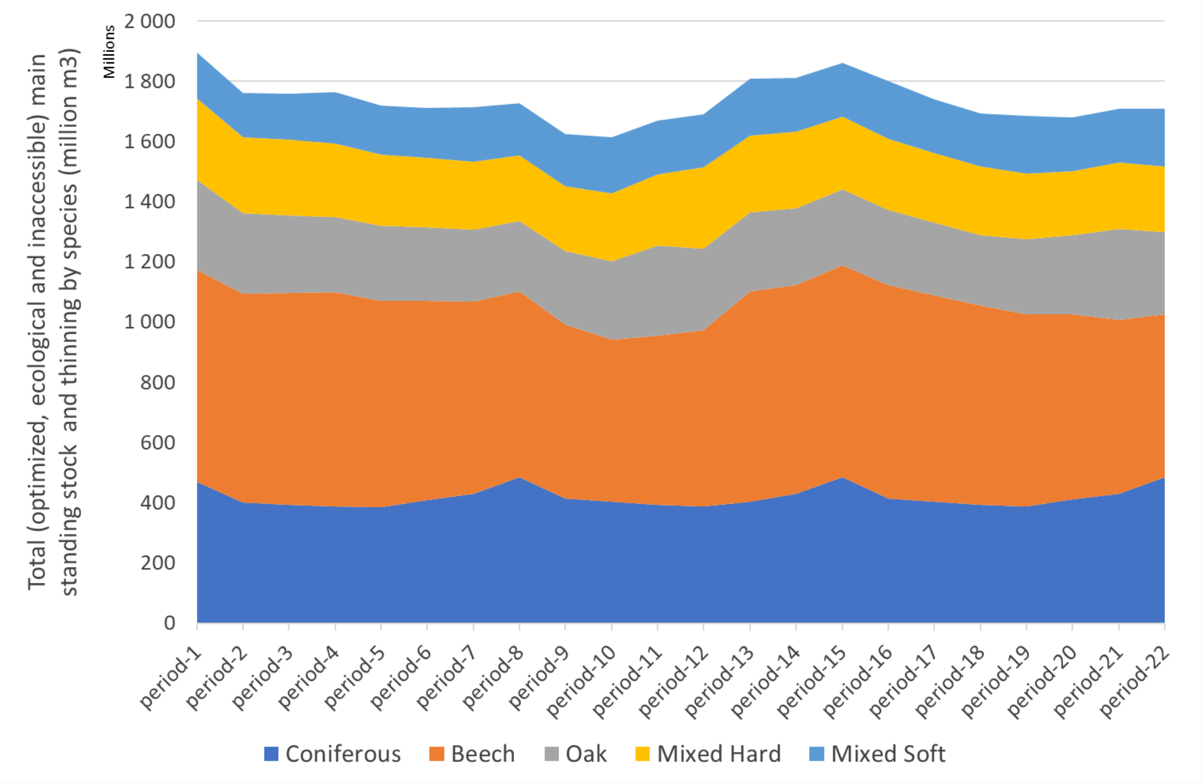


Figure 30 adds the volume of protected and inaccessible forests to the baseline scenario. About 25% of Romania's total volume of standing stock of protected and inaccessible forests are not part of the optimization algorithm in FOX-RO.

Figure 30. Main standing stock (optimized and protected) in Romania (million m³)

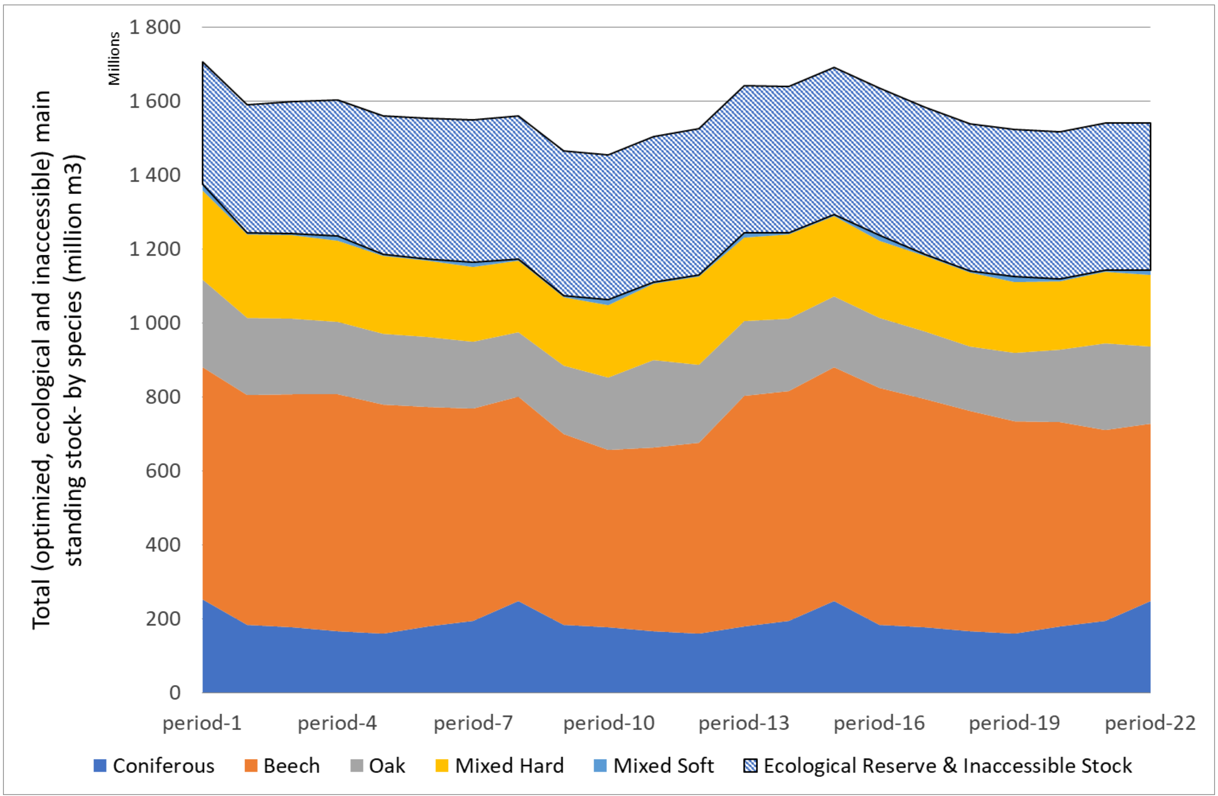


Figure 31 reveals how the standing stock changes through the 220 years of the modelling period species by species. We can observe clear, species-specific cyclic patterns, from the short rotation Mixed softwood category, through the mid-length rotation of Conifers to the long rotation Oaks and Beech. Each species recovers its full initial volume of standing stock. So, the swaying pattern observed for the total standing stock is only the add-up result of asynchronous fluctuations of the species stocks.

Figure 31. Changes in optimized standing volume by species in Romania (million m³)

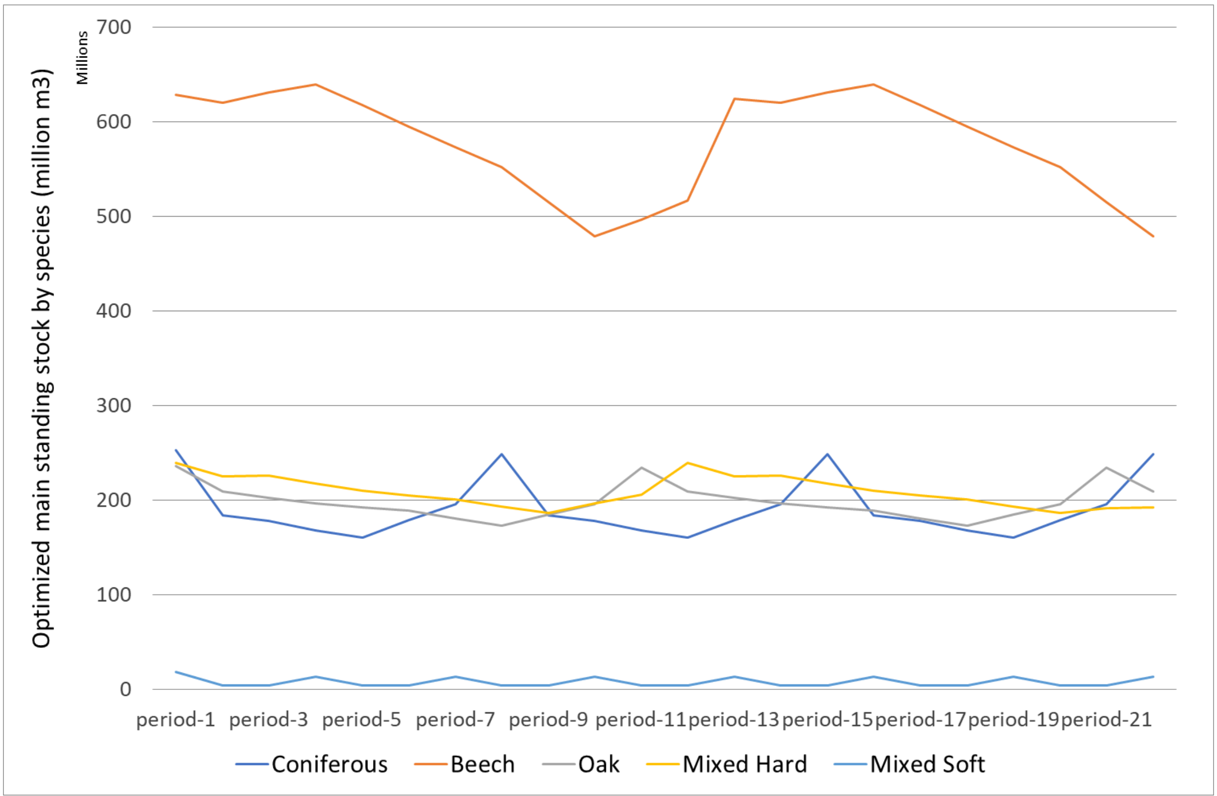


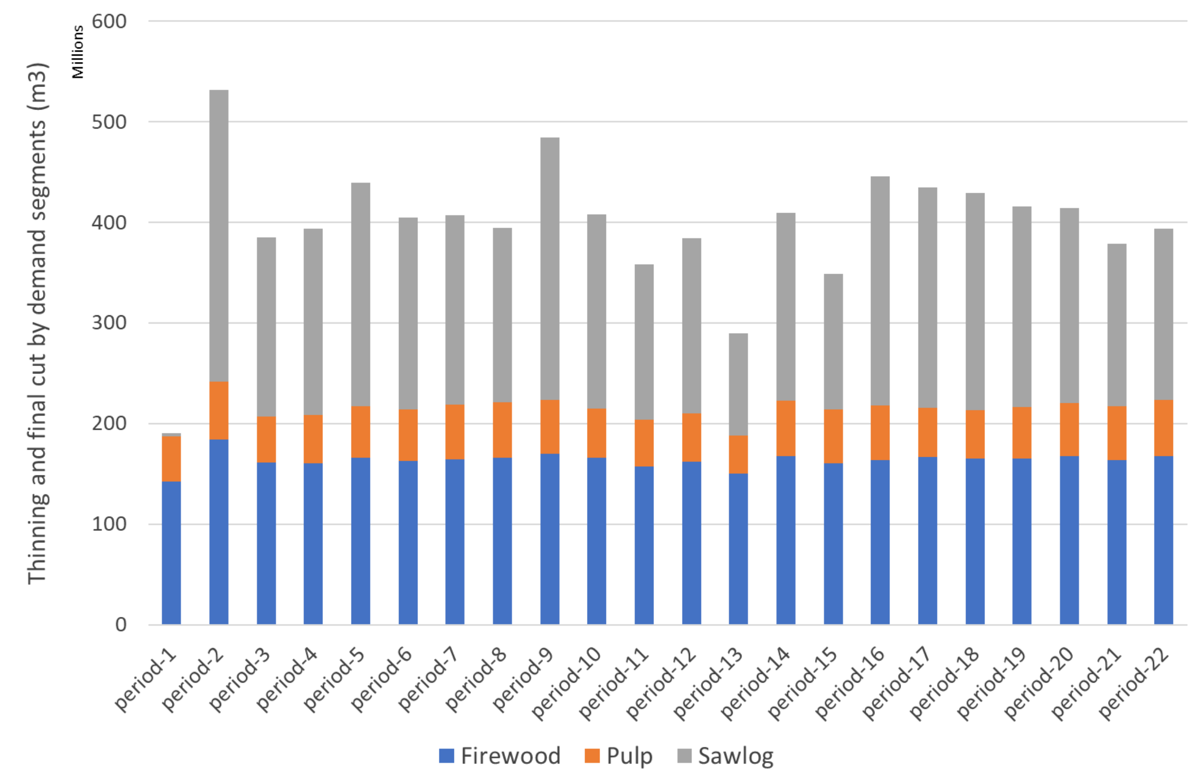
Figure 32 provides an overview of the total harvest for the final cut (primary felling) and thinning (secondary cut) of each modelling period. We can observe how harvested wood breaks down into the three product categories in FOX-RO. The volume in period 1 is lower than the rest of the periods because the final harvest is only optimized from period 2, which eventually does account for the absence of harvesting in period 1 as forests reach harvesting age in the meantime.

Thinning occurs automatically as a function of forest composition and age. Therefore, the volume of thinning changes across periods, but is relatively stable as a component of the overall timber harvest. Its value ranges between 155 and 190 million m^3 per period, 74-80% of which is firewood, and the rest is pulpwood. Period 1 provides the best representation for thinning volumes. In all the other periods the additional harvested volume is resulting from the final cut, and all the sawlog originates from final cut.[64]

Note that total harvest is indicated decade by decade, so the quantities are the sum of 10 years' harvest figures. The quantities can be divided by 10 to reach an estimated average of annual harvest for any decade. For the whole modelling horizon, the annual average harvest is 39.7 million m^3, 60% from final cut, and the annual share of final cut ranging between 42% and 68% (starting in period 2).

[64] It is only beech among the species that produces sawlogs before its median cutting age, i.e. it is the only source of sawlogs in thinning. So the rate of sawlogs within total thinning remains low because all the other species produce their sawlogs as part of final felling.

Figure 32. Total harvest (thinning plus final cut) by demand segments in Romania (million m^3)



Scenarios with carbon price

Carbon prices are introduced into the optimization objective function of FOX-RO in 10-euro increments. A linear carbon tax-and-subsidy scheme has the potential to substantially change the flow of costs and benefits over the model horizon. It rewards every additional ton of carbon sequestered after the previous period by a flat rate subsidy payment (e. g. 20 EUR/t of CO_2) and penalizes each ton of carbon that gets released with harvesting by a flat rate tax payable after total released carbon.

Carbon payments are the inverse of timber payments since the carbon subsidy is payable only if timber production (i.e. harvest) is delayed with another period. Similarly, if timber is produced and sold to generate income the carbon tax is payable at the same time after the release of carbon.

In Figure 33, the reference scenario is denoted with p-0 meaning no carbon payments. The rest of the scenarios represent total carbon stock in CO_2 equivalent with carbon prices between 10 EUR/t and 100 EUR/t in 10-euro increments. 10-50 EUR/t result in identical carbon sink pathways, with p=50 eclipsing the uniformly running paths corresponding to lower carbon prices.

In the reference scenario there is a small decline in sequestered CO_2 stock as a result of the reduced forest stock (Figure 33). A carbon price of 60 EUR/t is needed to counterbalance the baseline trend of a gradually falling standing stock and the corresponding loss of sequestered carbon. Above this price level there is remarkable growth in additional carbon sinking as forests grow standing stock and sequester significant additional amounts of carbon compared to the baseline trend. A carbon price of 70 EUR/t makes a dramatic difference: forests are encouraged to grow their standing stock and sequester significant additional amounts of carbon on top of the baseline trend. Prices higher than that add only marginally to the gains.

Figure 33. CO_2 stock at different carbon prices in Romania (million tons CO_2)

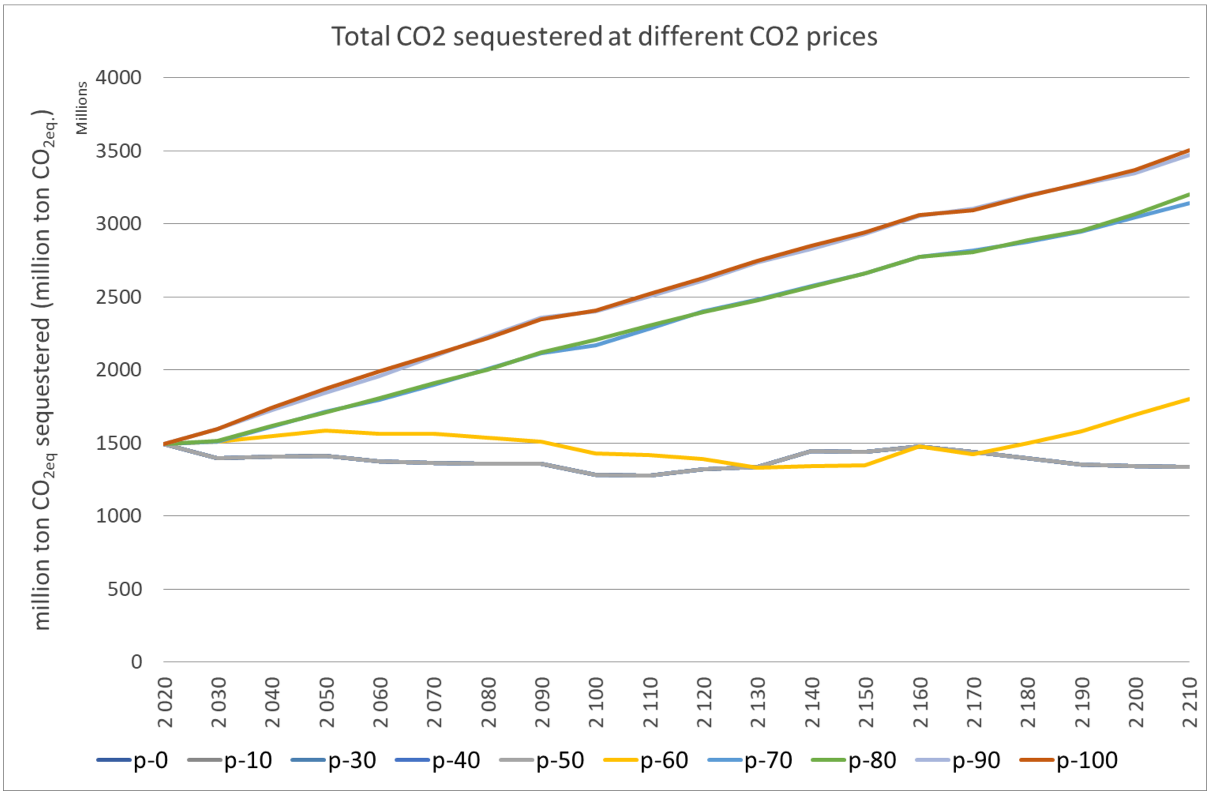
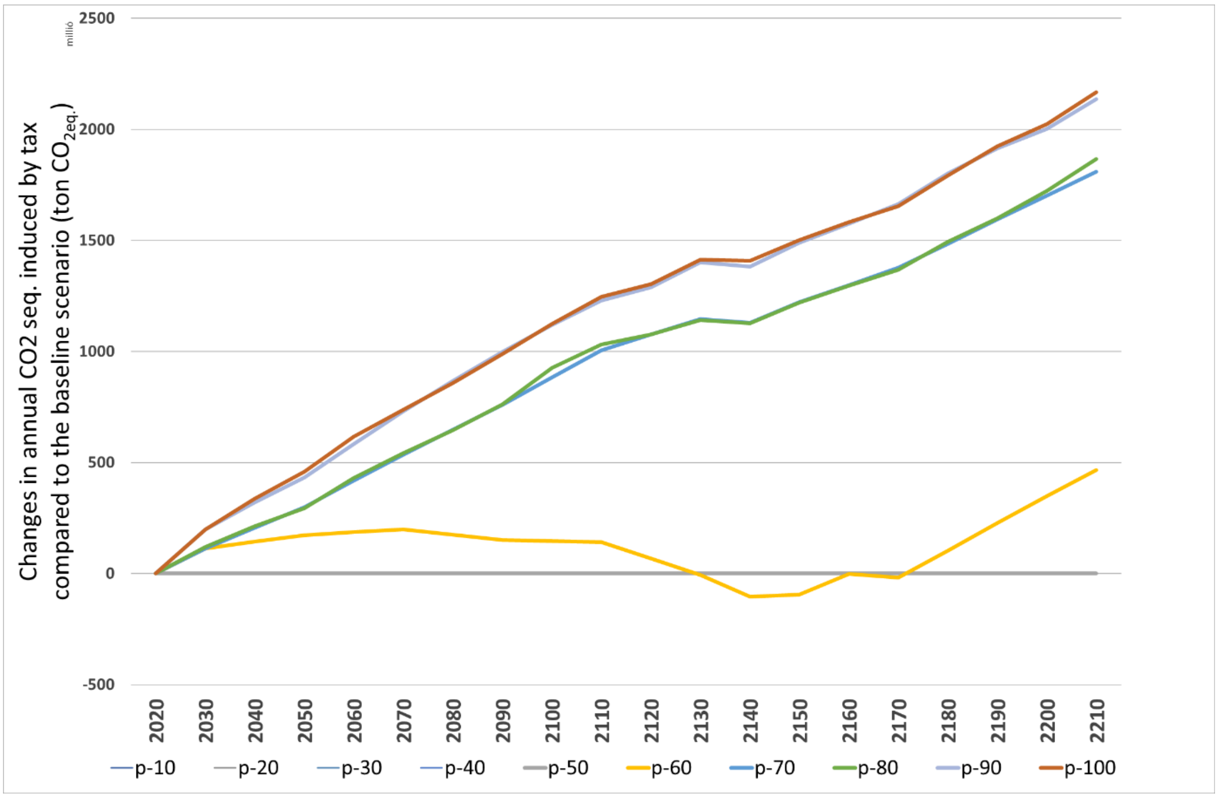


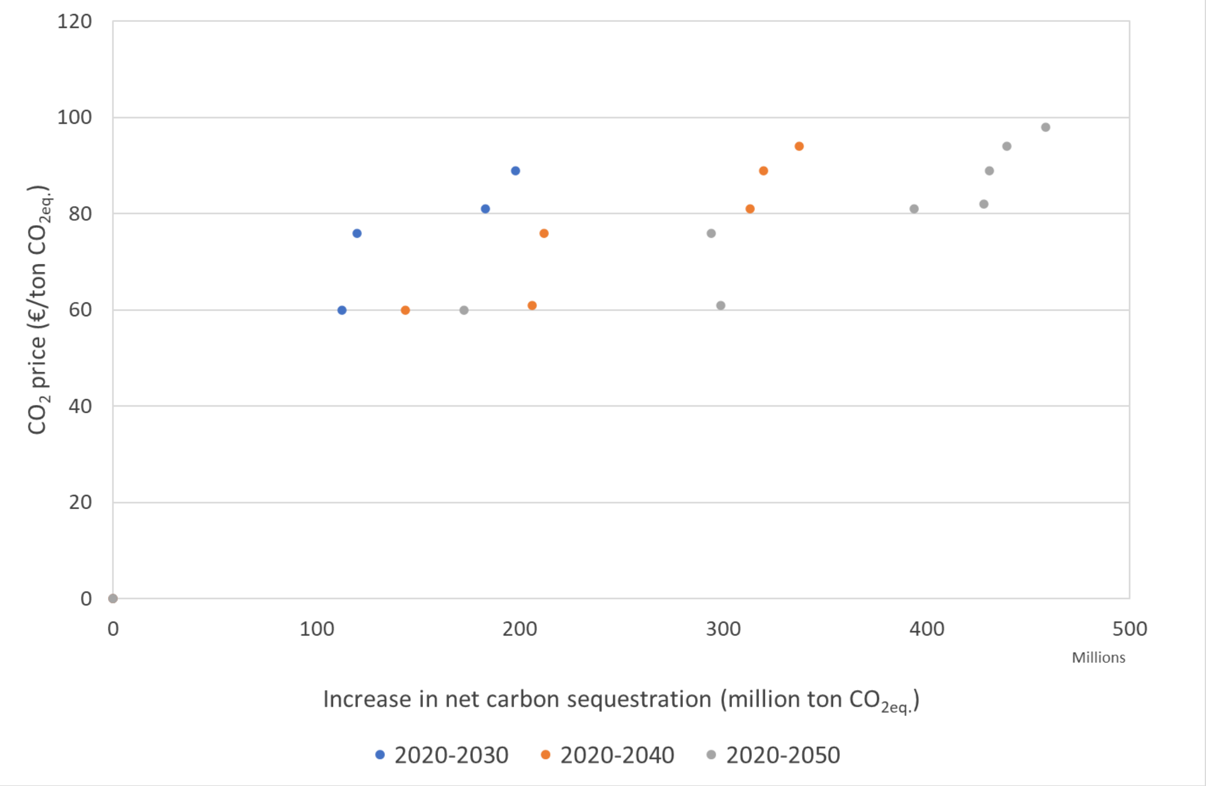
Figure 34 shows the ability of carbon prices to induce additional carbon sequestration relative to the reference scenario. Prices 50 and lower make no difference within the modelling horizon, but a 60 EUR/t carbon pricing becomes a game changer, resulting in an additional 173 million ton of cumulative CO_2 sequestration by 2050. At 70 EUR/t this reaches 299 million tons, and 100 EUR/t generates 458 million tons of surplus sequestration. Above 70-80 EUR/t the rate of growth slows and additional carbon sinking potential of the forest fund territory is fully exploited at 90-100 EUR/t.

Figure 34. Changes in sequestered CO_2 stock at different carbon prices, compared to the baseline (Reference) scenario in Romania (million tons CO_2)



The chart in Figure 35 translates modelling results into economic values using three carbon sequestration supply curves of forests in Romania for the first half of the century. These are inverse supply curves, depicting prices in terms of quantities. They can be interpreted as the amount of CO_2 sequestered at a certain CO_2 price or the price of an additional ton of sequestration to achieve a certain sink level. The X axis represents cumulative results of a one, two and three decade-long carbon pricing at fixed prices from 2020 through 2030, 2040 and 2050 respectively.

Figure 35. Increase in net aggregated carbon sequestration at different CO_2 prices in Romania, 2020 - 2050



The chart focuses on the first half of the century and provides point observations by FOX-RO of three distinct 'short-run' supply curves. These observations deliver very straightforward messages. Provided the regulatory instruments setting a carbon price level for a decade an increase in net carbon sequestration is induced. For example, at 60 EUR/t, additional carbon sinking is 112 million tons from 2020 to 2030. Keeping the carbon price at 60 EURs for another decade increases the cumulative sum of carbon capture to 144 million tons. If the same carbon price is maintained to 2050, the total carbon sinking increases to 173 million tons.

As observed earlier, there is a swaying pattern of net harvesting in the first 5-6 periods of the model. There is a loss of standing stock in periods 2 and 4, with constant or slightly increasing stock in periods 3, 5 and 6, meaning total additional sequestration would not be evenly distributed across the decades. Carbon prices alter the slope of baseline sinking, mostly in periods with declining stock relative to the Reference Scenario. In the first decade, 11.2 mt/yr of additional annual sequestration is gained on average over the 10 year period at a carbon price of 60 EUR/t. The impact is lower over the next two decades (7.2 mt/yr average) but lowest from 2020 through 2050 (5.8 mt/yr average).

Figure 36 shows cumulative supply curves for the second half of the century. These 'long-run' supply curves make clear that higher carbon prices are needed for carbon capture to grow during this period. At 80 EUR/t, 524 million tons are sequestered by 2060 and 925 million tons by 2100, which are 13.1 million t/yr and 11.6 million t/yr annual averages respectively.

Figure 36. Increase in net aggregated carbon sequestration at different CO_2 prices in Romania, 2050-2100

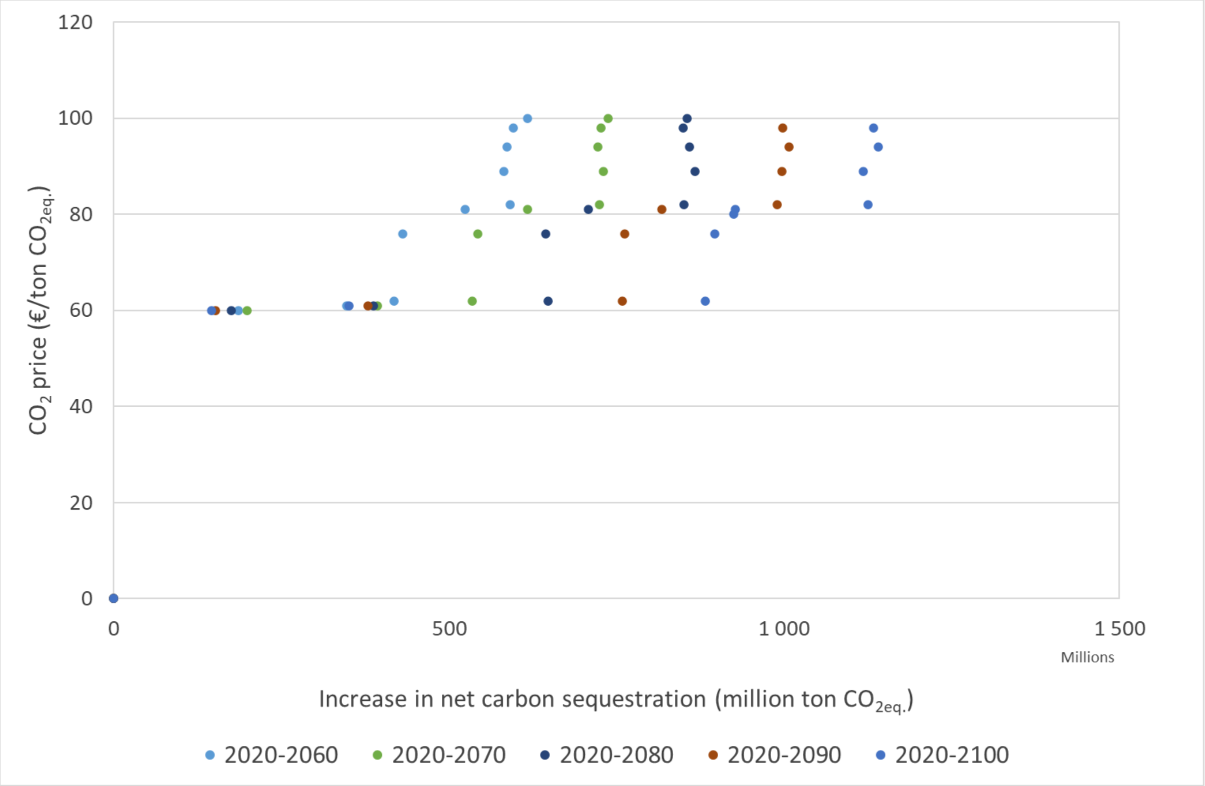
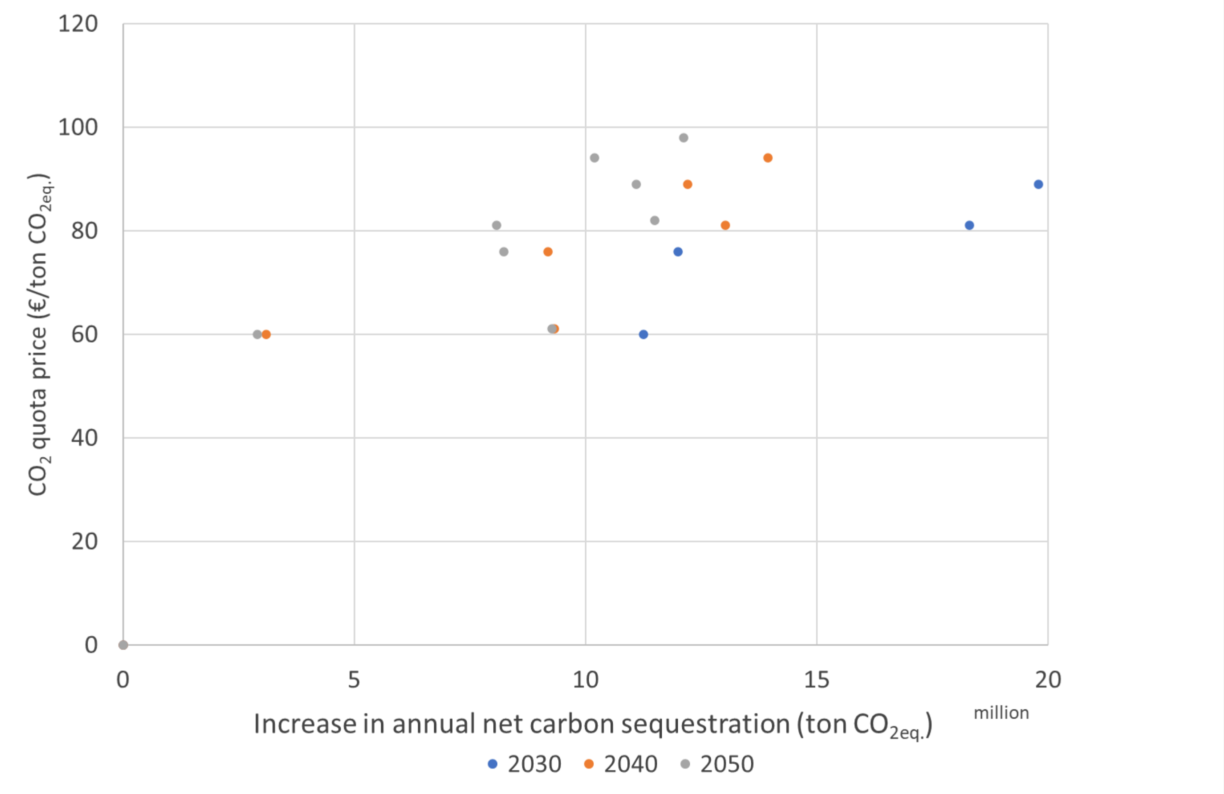


Figure 37 converts FOX-RO outputs into economic terms using Marginal Abatement Cost (MAC) curves described earlier. MAC curves show how much it costs to avoid one more unit of emission at any emission level. This concept provides a useful tool for developing the least-cost national emission mitigation strategy through aggregating all available abatement options by their marginal cost curves.

The growth in annual forest sequestration at different CO_2 prices fits the national abatement cost curve, but again forest-based carbon sequestration cannot be switched on and off in reality and the cumulative growth of the live stands is a prerequisite to any given year's carbon abatement option. So, the annual forest carbon MAC curves must be carefully interpreted, preferably together with the more nuanced cumulative supply curves.

Figure 37. Increase in annual net carbon sequestration at different CO_2 prices (i.e. marginal abatement costs) in different milestone years in Romania



Milestone years 2030 and 2050 allow the marginal cost of forest carbon sequestration to be compared with other climate policy abatement options. The MAC curves show diverse carbon capture at different carbon prices, but gains are greatest through 2030 before falling in decrease by 2040 and 2050. This means that surplus sequestration targets can be achieved at lower marginal cost in 2030 than in 2050. For example, 10 million tons of extra sequestration in the milestone years would require a carbon price gradually increasing from below 60 EUR/t to over 90 EUR/t by 2050.

Romania needs a price of at least 60 EUR/tCO_2 to improve its carbon sinking, equivalent to lower expectations for industrial carbon prices.

A CO_2 price of 60 EUR/t is lower than the market price of emission allowances (EUA) within the European Emissions Trading Scheme (ETS) at the time of closing this study. EUA price has been constantly at or above 60 EUR/t for over 3 consecutive months from early September to mid-December 2021. This means that among the 11 thousand industrial installations under the ETS many find it cheaper to buy allowances at high prices rather than reduce their own emissions by technology improvements.

Meeting industrial CO_2 prices of 70 - 80 EUR/t, Romanian forests could sink about 12 million tons of additional CO_2 annually, or half of the 24 – 26 million tons of CO_2 net annual forest sink during recent years. As a result, the forest sector could sink a total of 36-38 million tons of CO_2 annually. This is 32-34% of Romania's total GHG emissions in 2019 (111.8 million tCO_2eq without LULUCF and Memo Items according NIR-RO 2021).

Conclusion

This study presents a bio-economic model of Forest Carbon Sink Optimization (FOX) developed by REKK for the 2021 BIO_SCREEN-CEE project applied to Hungary and Romania, with the Bulgarian model suspended pending data acquisition.

The most important finding is that forest management, assumed to reflect economic optimisation by forest managers before carbon payments are introduced, can easily be adapted to optimize with positive and/or negative carbon payments involved. Furthermore, carbon payments substantially influence forest management decisions and, consequently, the annual volume of carbon sequestration and the total carbon stock. Forests will keep producing all the three basic product segments - sawlogs, pulpwood and firewood - even with elevated, positive carbon prices.

Romania and Hungary exhibit remarkable differences in their response to carbon prices:

- Hungary's forest stock is rapidly approaching maturity for felling, so relatively low carbon prices are sufficient to reduce intensive harvesting. The forest sector can contribute significantly to the national abatement of 60 million tons of CO_2 emissions over the next 3 decades at a relatively low cost.
- Hungarian forests can sink 5 – 8 million tons of additional CO_2 on top of the Reference Scenario, more than doubling net annual sinking over the past decade to reach 9 – 13 million tons of CO_2. This represents 14% - 20% of the 64.4 million tons of total GHG emissions in 2019 (without Memo Items and LULUCF).
- The vast Romanian forest sector is more diverse, robust in annual increments, and less intensively harvested, making forestry carbon sinking robust even without carbon pricing. Thus, strong carbon prices (min. 60 EUR/tCO_2) would be needed to increase carbon sinking further, though this is equivalent to current industrial ETS prices.
- A CO_2 price of 60 EUR/t or higher triggers a dramatic boom in Romanian carbon sequestration. With one of largest forest sectors in the EU, Romania can use forest carbon pricing to keep its natural resource from declining. It also represents a comparative advantage for Romania, meaning it could sell the surplus carbon sinking to other European countries where carbon abatement is more costly.

FOX modelling results are open to interpretation especially keeping in mind the inherent limitations:

- FOX currently only accounts for stem-wood, just one of the carbon pools in forestry - for the sake of simplification
- All harvested wood is taken to be fully oxidized within the harvesting period (instantaneous release to the atmosphere), meaning the total carbon of harvest is assumed to be lost to the atmosphere and the forest manager must make a carbon release payment for the whole amount. This will be addressed in an upcoming more sophisticated approach.
- FOX assumes that all the three distinct demand segments have perfectly inelastic demand, meaning that markets absorb any amount of production at the set prices. This is a theoretical approach used by other bioeconomic forest management models that may or may not be verified by empirical observations. This will affect longer term outcomes than the short run.

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Aside from Bulgaria, data limitations were omnipresent throughout the research phase:

- The biological yield tables from the Hungarian forest authority (Sopp, 1974) contain data for up to 110 years, meaning a decision had to be made on how to extend the theoretical lifetime of tree species to enable FOX to optimize over a longer time horizon. As described above, yield functions had to be estimated with projections using the EFISCEN methodology in order for yield assumptions above the age group of 110 years to be replaced by yield observations.
- Product segment data was limited: species composition of product categories, relative share of product categories in age groups, marketed volumes, scattered and inconsistent price statistics.
- Absent widely used yield tables (Giurgiu & Draghiciu) in Romania, the net increment of the standing and the thinning stock was estimated from National Forest Inventory aggregate standing volume data for every 20-year age class in the NFAP-RO. However, some of the derived increments resulted in improper (negative) values. Therefore, the net increment of the main standing and thinning stock was modelled using FOX-HU estimates. Romanian results could be further improved with more specific yield tables.

FOX results are policy oriented. They can be used to assess the range of carbon payments necessary to trigger sufficient carbon sinking to meet more ambitious EU 2030 climate targets under the Fit-for-55 package (COM/2021/554). For now the Commission has tabled its strategic views on carbon sequestration pricing.

- All three countries have got carbon sequestration targets that are mostly ambitious compared to current levels of carbon removals and forest reference levels (FRL) projected by NFAPs. The national targets proposed by the Commission: Bulgaria: -9.7 mtCO_2eq, Hungary: -5.7 mtCO_2eq, Romania: -25.7 mtCO_2eq.
- FOX can estimate the marginal cost of meeting these national targets based on the potential of existing forests in each country.
- If demand elasticity is introduced later in the development of the FOX model, it can analyse the effects of induced carbon sinking by means of forest carbon pricing on product markets.

We strongly believe that the results presented in this study should convince stakeholders to use FOX as a new policy analytical tool. It will continue to be developed with the acquisition of more reliable input data including FOX can be developed further conceptually - including but not exclusively by addition of more carbon pools, differentiation of carbon release timelines, flexibility of demand, and inclusion of new afforestation.

Appendix A

Table 9. Estimated and applied main standing volume by age class and species (measured in m^3/ha) in Hungary

Age / Specie	Oaks	Turkey oak	Beech	Horn-beam	Black locust	Other hardwood	Hybrid poplar	Poplars	Other softwood	Conifers
10	30	19	33	24	40	41	60	53	55	56
20	87	63	82	60	89	111	202	179	123	129
30	151	124	143	100	127	179	342	301	181	197
40	213	183	209	137	155	233	433	379	225	252
50	264	228	275	167	177	273	506	440	257	293
60	307	261	338	190	194	303	566	489	284	325
70	340	284	398	207	208	325	615	528	304	349
80	367	299	456	218	218	342	656	560	319	368
90	389	310	509	225	227	356	691	586	331	382
100	407	317	558	229	234	367	720	607	340	394
110	423	322	607	232	240	376	745	624	346	403
120	437	325	656	234	244	382	766	638	351	410
130	450	327	704	235	247	386	783	648	354	415
140	462	327	752	235	250	389	798	656	355	419
150	473	327	801	235	251	390	811	662	356	422
160	483	327	849	235	252	390	821	665	356	423
170	492	327	897	235	252	390	829	667	356	423
180	500	327	945	235	252	390	836	667	356	423
190	508	327	992	235	252	390	841	667	356	423
200	515	327	1040	235	252	390	844	667	356	423
210	521	327	1088	235	252	390	847	667	356	423
220	527	327	1135	235	252	390	848	667	356	423
230	532	327	1183	235	252	390	848	667	356	423
240	538	327	1230	235	252	390	848	667	356	423
250	542	327	1278	235	252	390	848	667	356	423
260	547	327	1325	235	252	390	848	667	356	423
270	551	327	1372	235	252	390	848	667	356	423
280	554	327	1420	235	252	390	848	667	356	423
290	558	327	1467	235	252	390	848	667	356	423
300	561	327	1514	235	252	390	848	667	356	423
310	564	327	1561	235	252	390	848	667	356	423
320	566	327	1608	235	252	390	848	667	356	423
330	569	327	1655	235	252	390	848	667	356	423
340	571	327	1702	235	252	390	848	667	356	423
350	573	327	1749	235	252	390	848	667	356	423
360	575	327	1796	235	252	390	848	667	356	423
370	576	327	1843	235	252	390	848	667	356	423
380	578	327	1890	235	252	390	848	667	356	423
390	579	327	1937	235	252	390	848	667	356	423
400	580	327	1984	235	252	390	848	667	356	423
410	581	327	2031	235	252	390	848	667	356	423

Table 10. Estimated and applied thinning increment by age class and species (measured in m^3/ha) in Hungary

Age / Specie	Oaks	Turkey oak	Beech	Horn-beam	Black locust	Other hardwood	Hybrid poplar	Poplars	Other softwood	Conifers
10	10	1	8	0	32	9	14	11	13	3
20	31	18	23	17	34	38	78	56	27	28
30	53	39	32	28	23	55	92	88	29	46
40	61	61	39	27	17	56	54	51	28	46
50	60	68	43	23	12	49	46	49	26	42
60	57	58	46	20	8	40	40	46	24	35
70	52	47	47	17	6	33	35	45	22	29
80	45	37	47	15	4	26	31	43	19	22
90	38	27	47	13	2	20	27	42	16	17
100	32	19	47	12	1	15	25	41	14	13
110	32	19	47	11	0	14	22	40	14	12
120	31	19	47	11	0	13	21	39	13	11
130	31	19	47	10	0	12	19	39	13	10
140	31	19	47	10	0	11	18	38	12	10
150	31	19	47	10	0	10	16	38	12	9
160	31	18	47	9	0	10	15	37	12	9
170	30	18	47	9	0	9	14	37	11	8
180	30	18	47	9	0	9	13	37	11	8
190	30	18	48	9	0	8	13	36	11	7
200	30	18	48	9	0	8	12	36	11	7
210	30	18	48	8	0	7	11	36	11	7
220	30	18	48	8	0	7	11	36	10	7
230	30	18	48	8	0	7	10	35	10	6
240	30	18	48	8	0	6	10	35	10	6
250	30	18	48	8	0	6	9	35	10	6
260	30	18	49	8	0	6	9	35	10	6
270	30	18	49	8	0	6	8	35	10	6
280	29	18	49	8	0	5	8	35	10	5
290	29	18	49	7	0	5	8	34	10	5
300	29	17	49	7	0	5	7	34	10	5
310	29	17	49	7	0	5	7	34	10	5
320	29	17	49	7	0	5	7	34	9	5
330	29	17	49	7	0	4	6	34	9	5
340	29	17	49	7	0	4	6	34	9	5
350	29	17	49	7	0	4	6	34	9	4
360	29	17	49	7	0	4	6	34	9	4
370	29	17	49	7	0	4	5	34	9	4
380	29	17	49	7	0	4	5	33	9	4
390	29	17	50	7	0	4	5	33	9	4
400	29	17	50	7	0	4	5	33	9	4
410	29	17	50	7	0	3	5	33	9	4

Appendix B

Table 11. Estimated and applied main standing volume by age class and species (measured in m^3/ha) in Romania

Age / Specie	Coniferous	Beech	Oak	Mixed Hard	Mixed Soft
10	56	33	30	31	56
20	129	82	87	81	168
30	197	143	151	133	275
40	252	209	213	177	346
50	293	275	264	211	401
60	325	338	307	237	446
70	349	398	340	256	482
80	368	456	367	270	512
90	382	509	389	280	536
100	394	558	407	287	556
110	403	607	423	292	572
120	410	656	437	296	585
130	415	704	450	299	595
140	419	752	462	300	603
150	422	801	473	301	609
160	423	849	483	301	614
170	423	897	492	301	617
180	423	945	500	301	619
190	423	992	508	301	621
200	423	1040	515	301	622
210	423	1088	521	301	623
220	423	1135	527	301	623
230	423	1183	532	301	623
240	423	1230	538	301	623
250	423	1278	542	301	623
260	423	1325	547	301	623
270	423	1372	551	301	623
280	423	1420	554	301	623
290	423	1467	558	301	623
300	423	1514	561	301	623
310	423	1561	564	301	623
320	423	1608	566	301	623
330	423	1655	569	301	623
340	423	1702	571	301	623
350	423	1749	573	301	623
360	423	1796	575	301	623
370	423	1843	576	301	623
380	423	1890	578	301	623
390	423	1937	579	301	623
400	423	1984	580	301	623
410	423	2031	581	301	623
420	423	2078	582	301	623
430	423	2125	583	301	623
440	423	2172	584	301	623
450	423	2218	584	301	623

460	423	2265	584	301	623
470	423	2312	585	301	623
480	423	2359	585	301	623
490	423	2406	585	301	623
500	423	2452	585	301	623
510	423	2499	585	301	623
520	423	2546	585	301	623
530	423	2592	585	301	623
540	423	2639	585	301	623
550	423	2686	585	301	623
560	423	2732	585	301	623
570	423	2779	585	301	623
580	423	2826	585	301	623
590	423	2872	585	301	623
600	423	2919	585	301	623

Table 12. Estimated and applied thinning increment by age class and species (measured in m^3/ha) in Romania

Age / Specie	Coniferous	Beech	Oak	Mixed Hard	Mixed Soft
10	3	8	10	10	13
20	28	23	31	27	54
30	46	32	53	36	70
40	46	39	61	40	45
50	42	43	60	38	40
60	35	46	57	32	37
70	29	47	52	25	34
80	22	47	45	20	31
90	17	47	38	15	28
100	13	47	32	12	27
110	12	47	32	11	25
120	11	47	31	11	24
130	10	47	31	10	23
140	10	47	31	10	23
150	9	47	31	10	22
160	9	47	31	9	21
170	8	47	30	9	21
180	8	47	30	9	20
190	7	48	30	9	20
200	7	48	30	9	20
210	7	48	30	8	19
220	7	48	30	8	19
230	6	48	30	8	19
240	6	48	30	8	18
250	6	48	30	8	18
260	6	49	30	8	18
270	6	49	30	8	18
280	5	49	29	8	17
290	5	49	29	8	17

300	5	49	29	7	17
310	5	49	29	7	17
320	5	49	29	7	17
330	5	49	29	7	17
340	5	49	29	7	16
350	4	49	29	7	16
360	4	49	29	7	16
370	4	49	29	7	16
380	4	49	29	7	16
390	4	50	29	7	16
400	4	50	29	7	16
410	4	50	29	7	16
420	4	50	29	7	16
430	4	50	29	7	15
440	4	50	29	7	15
450	4	50	29	7	15
460	4	50	29	7	15
470	3	50	29	7	15
480	3	50	29	7	15
490	3	50	29	7	15
500	3	50	29	7	15
510	3	50	29	7	15
520	3	50	29	7	15
530	3	50	29	6	15
540	3	50	29	6	15
550	3	50	29	6	15
560	3	50	29	6	15
570	3	50	29	6	15
580	3	50	29	6	14
590	3	50	29	6	14
600	3	50	29	6	14

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