SECURE-BIO-SUPPLY

Lagerhantering–hur inventeras lagren och hur kan man uppskatta lagringsförlusterna?

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NOVIA UNIVERSITY OF APPLIED SCIENCES

Åbo Akademi University

Metsäkeskus Forest Centre

Solid biomass storage

- Fossil fuels are replaced → may require longer term storage of solid biofuels
- Biomass has low (energy) density
  - More transportation and handling equipment required
  - More storage space
  - Cost of collection, handling, transportation and storage is higher
- Due to degradation leading to dry matter and energy losses, biofuels have higher storage losses than traditional fossil fuels such as coal and peat
- In the project, a simple calculator for estimating the costs of storing different types of solid biomass fuels was developed, including stem wood, logging residues, whole trees, wood chips, bark, stumps
- Different common tree species e.g.: pine, spruce, birch
- **Dry matter losses** and the **moisture content** are central to the energy content in biomass.
- $q_{p,net,d}$ is the net calorific value on a dry basis (MJ/kg), M_{ar} the moisture content on a wet basis (%), $q_{p,net,ar}$ the net calorific value as received (MJ/kg), BD_{ar} the basic density (kg/m^3), E_{ar} the energy content as received (MWh/m^3)

$$q_{p,net,ar} = q_{p,net,d} * \left(\frac{100 - M_{ar}}{100}\right) - 0.02443 * M_{ar}$$

$$E_{ar} = \frac{1}{3600} * q_{p,net,ar} * BD_{ar}$$

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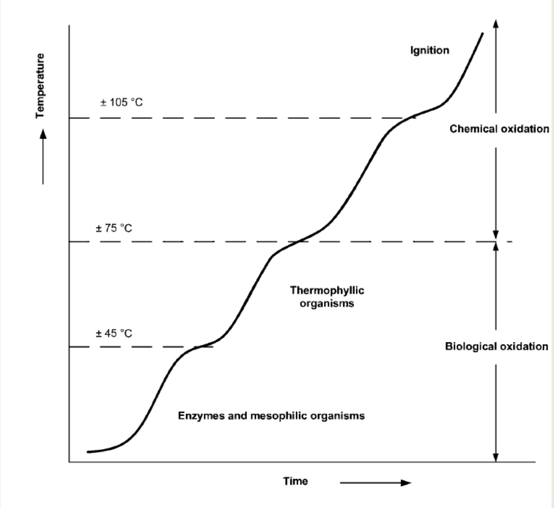
Dry matter losses in stored biomass

- Dry matter losses are usually very high during the beginning of the storage period
- In the calculator, dry matter losses are calculated using an exponential decay function (Routa et al., 2018):

$M_t = M_0 \times e^{-kt}$, where: M_0 is the initial dry mass, k the decay constant (monthly), t the time in months, M_t is the dry biomass remaining in the pile at time t.

- Degradation processes include biological and chemical processes. Dry matter losses can be a few % per month
- Modeling of dry matter losses and moisture content is challenging
- Biomass is a heterogenous material, there can be large variation between piles
- Differences in weather, storage conditions and microclimate
- Estimating dry matter losses as a function of time is difficult, so average monthly dry matter loss rates are used



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Estimation of moisture content using drying models

- Moisture content (MC) models for drying of stemwood and logging residues in roadside storages and in-stand from Erber et al. (2014) were used
- Moisture content is estimated based on evaporation (evapotranspiration) and precipitation
- Evapotranspiration is calculated using the FAO Penman-Monteith equation (Allen et al., 1998)

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

- The weather data needed was obtained from the Finnish Meteorological Institute and Copernicus (2023)
  - FMI weather data for the whole country interpolated to a 10 x 10 km using the Kriging interpolation method (Venäläinen & Heikinheimo, 2002)
  - ERA5 hourly wind data with a resolution of 0.25° × 0.25° was obtained from Copernicus
- The use of gridded weather data allows for calculating the drying rates for local Ostrobothnian conditions
- Daily moisture change = coefficient × (evaporation – precipitation) + constant
- The model does not estimate the daily MC change during winter, estimation stops when snow cover arrives
- Resumes when snow melts and the soil moisture, W_{vol}, m^3/m^3 drops below 0.5, calculated according to Heikinheimo et al., (1996).
- +5% higher MC at the start of spring for uncovered piles when snow melts

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Initial moisture content

- Moisture content of freshly harvested logging residues and stemwood in Finland by month, based on Routa et al. (2015) and Erber et al. (2014)

Logging residues	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Pine	57	57	57	56	56	55	55	57	57	57	57	57
Spruce	57	57	57	56	56	55	55	57	57	57	57	57
Birch	44	44	43	46	51	46	43	42	42	47	48	47

Stemwood	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Pine	57	57	57	56	56	55	55	57	57	57	57	57
Spruce	57	57	57	56	56	55	55	57	57	57	57	57
Birch	45	45	45	46	48	42	42	42	42	44	45	45

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Storage at medium-sized terminal 5 ha

- Pine stemwood stored at a medium-sized paved terminal for a total of 3 years
- Monthly dry matter loss estimated at 0.5% for covered, 1.2% for uncovered stemwood
- Initial energy content of pine stemwood at 57% MC 1.74 MWh/m^3
- Stemwood cost 27.95 €/m^3
- Cost of 80 km transportation to terminal: 6.72 €/m^3
- Total fuel cost 34.67 €/m^3
- Storage height 6 m
- Solid volume factor 45% for conversion between solid m^3 and bulk m^3
- Storage area used 50%
- Interest rate 5%
- Annual land cost 2.01 €/m^2
- Labor cost of covering per m^2 fuel 0.2 €/m^2 → 0.074 €/m^3
- Material cost of cover 2.73 €/m^2 → 1.01 €/m^3
- Volume stored 67500 m^3

Uncovered pine stemwood energy and economic loss	
Energy initial	117.5 GWh
Energy final	89.9 GWh
Energy lost	27.5 GWh
Cost of energy loss	548 578 €

Covered pine stemwood energy and economic loss	
Energy initial	117.5 GWh
Energy final	112.9 GWh
Energy lost	4.6 GWh
Cost of energy loss, covered pine stemwood	91 118 €

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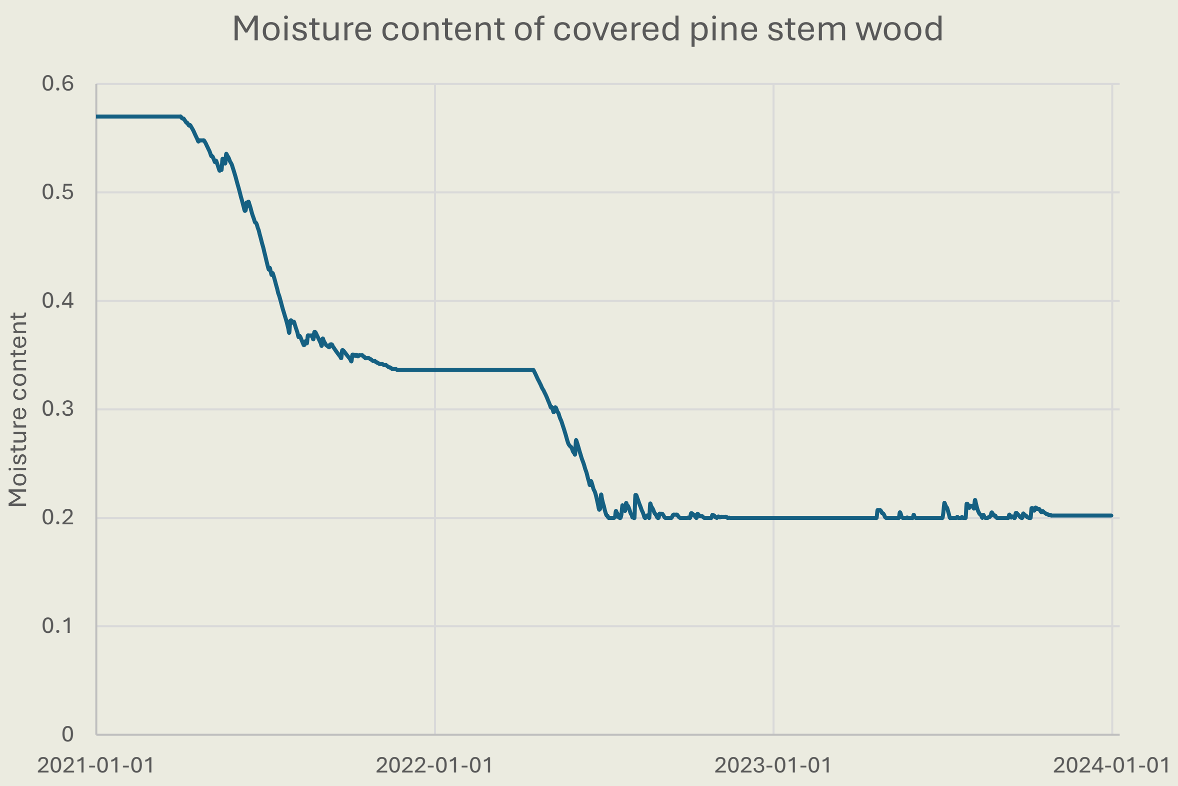
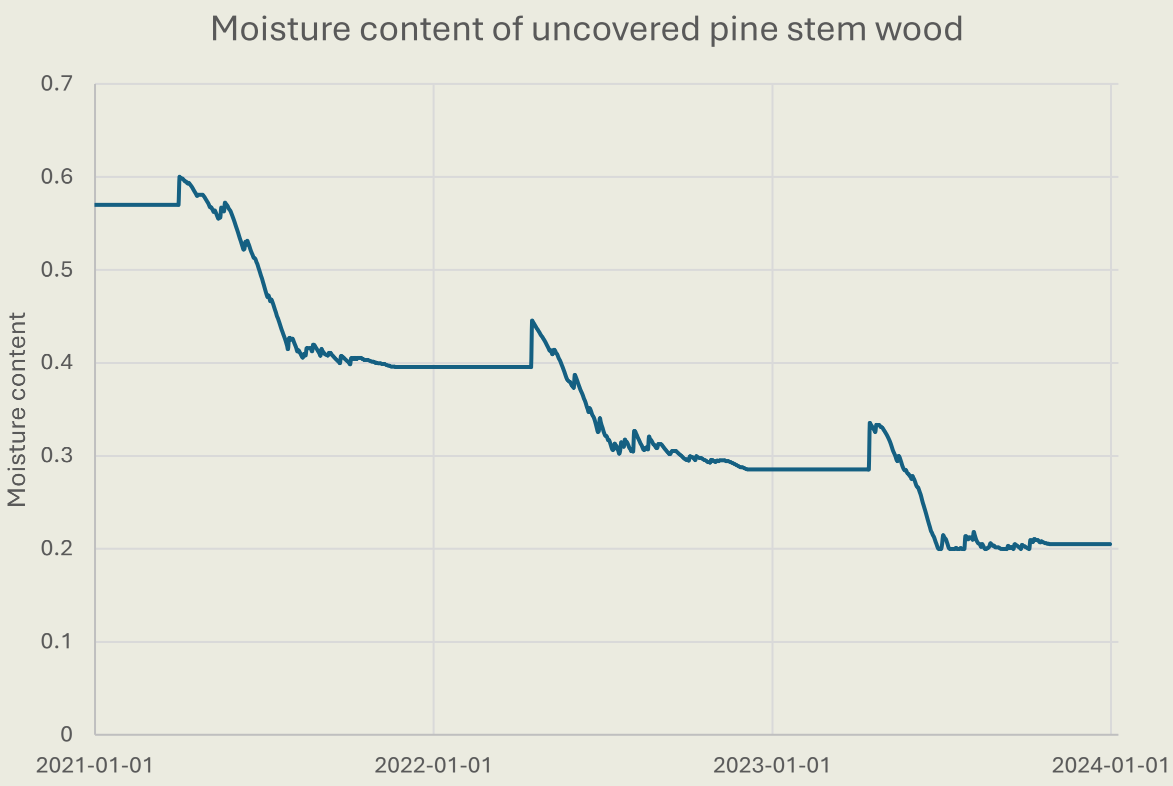
Drying curves of pine stemwood harvested in December 2020





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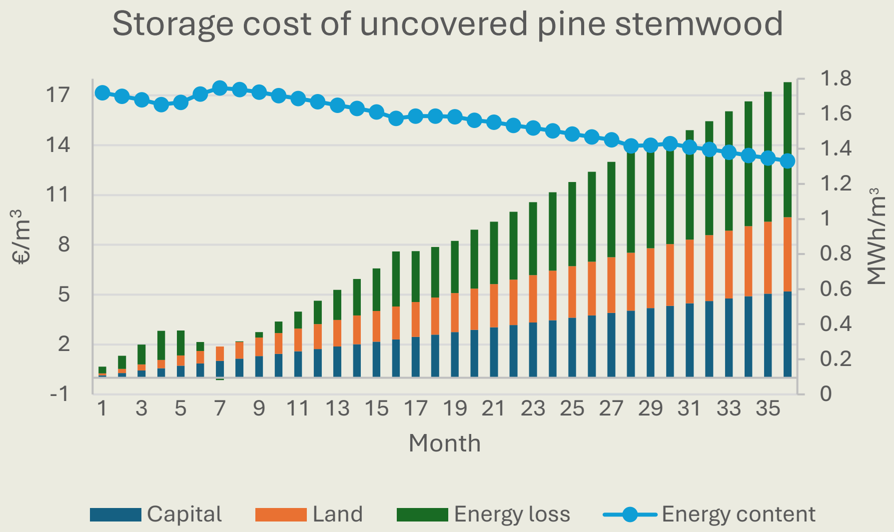
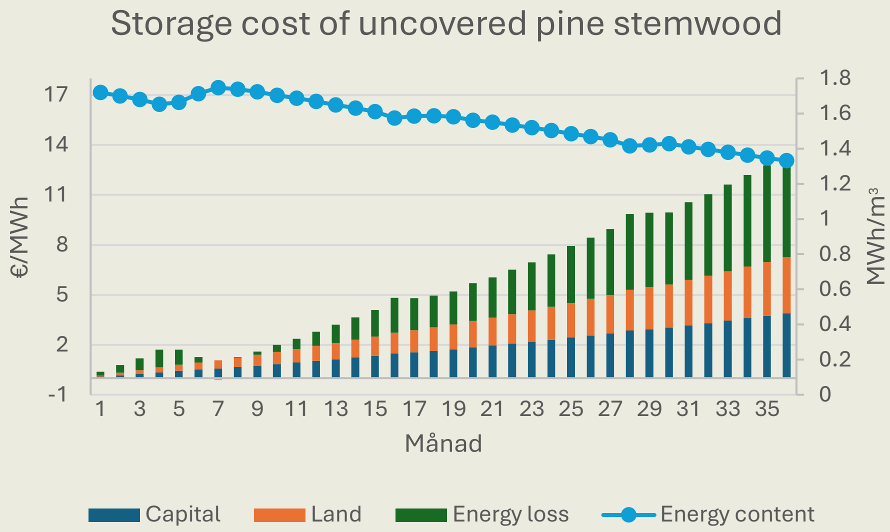
Storage cost of uncovered pine stemwood





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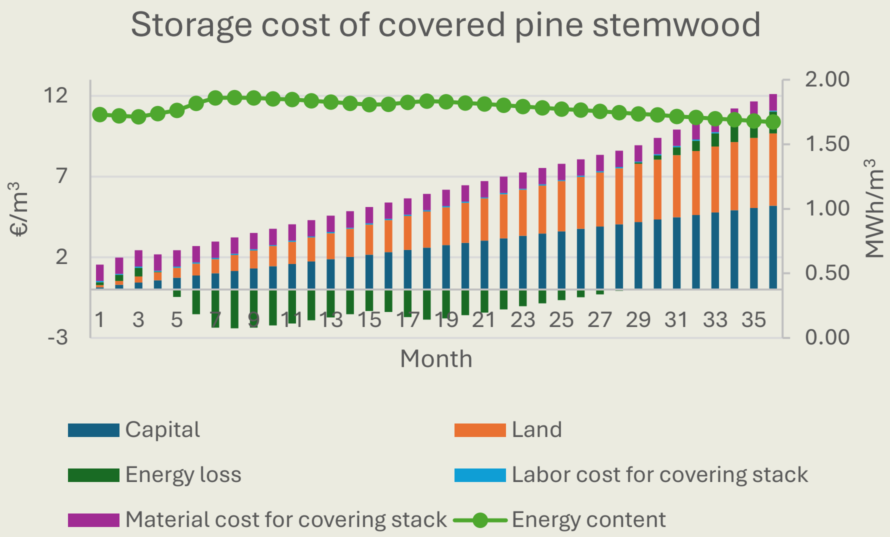
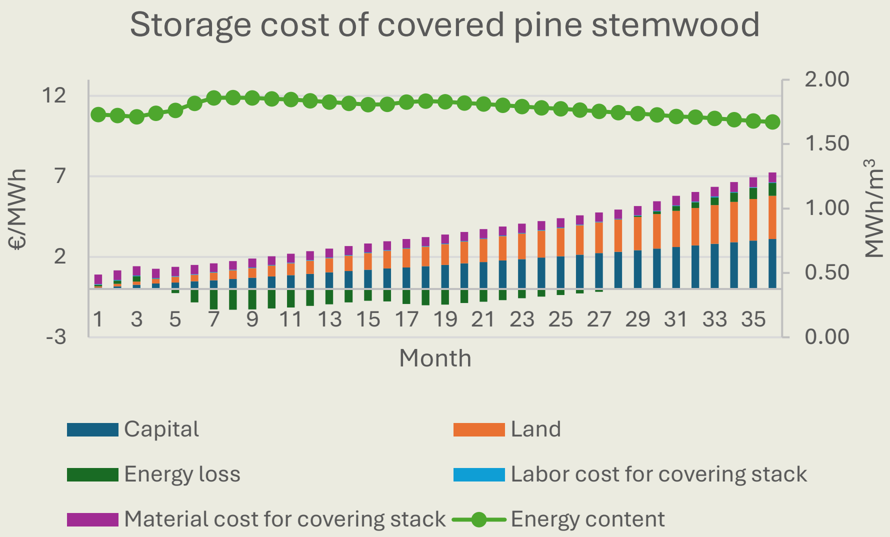
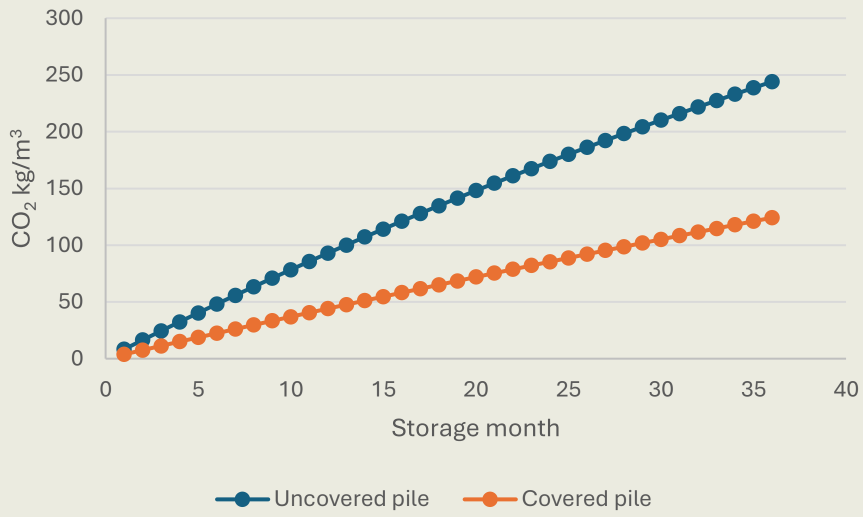
Storage cost of covered pine stemwood





CO_2 emissions from storage

- As the biomass degrades, the dry matter loss leads to greenhouse gas emissions
- The carbon in the biomass being broken down leads to CO_2 emissions
- Also CH_4 and NO_x emissions occur but in small and uncertain quantities (Sahoo et al., 2018)
- The carbon content is about 50% in woody biomass. An estimate of CO_2 emissions is made based on the basic density of spruce pine stemwood of 390 kg/m^3



Storage at medium-sized terminal 5 ha

- Norway Spruce logging residues stored at a medium-sized paved terminal for a total of 3 years
- Monthly dry matter loss estimated at 1.4% for uncovered, 1% for covered logging residues
- Initial energy content of Norway spruce logging residues at 57% MC: 1.90 MWh/m^3
- Logging residue cost 16.70 €/m^3
- Cost of 80 km transportation to terminal: 6.72 €/m^3
- Total fuel cost 23.42 €/m^3
- Storage height 6 m
- Solid volume factor 20% for conversion between solid m^3 and bulk m^3
- Storage area used 50%
- Interest rate 5%
- Annual land cost 2.01 €/m^2
- Labor cost of covering per m^2 fuel 0.2 €/m^2 → 0.167 €/m^3
- Material cost of cover 2.73 €/m^2 → 2.275 €/m^3
- Volume stored 30000 m^3

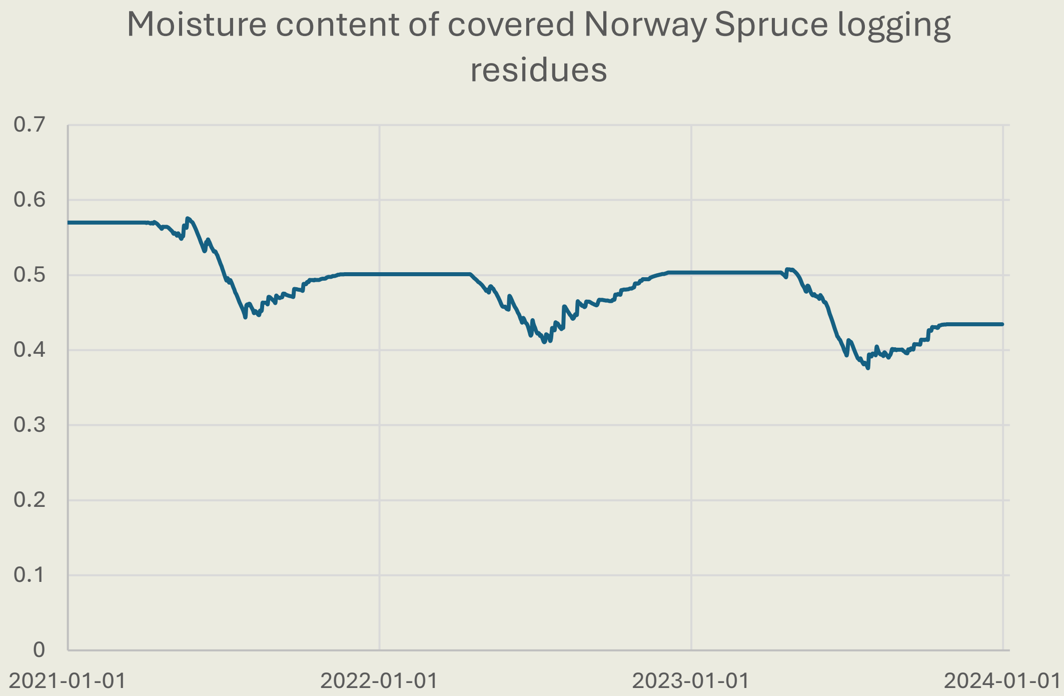
Uncovered Norway Spruce logging residues energy and economic loss

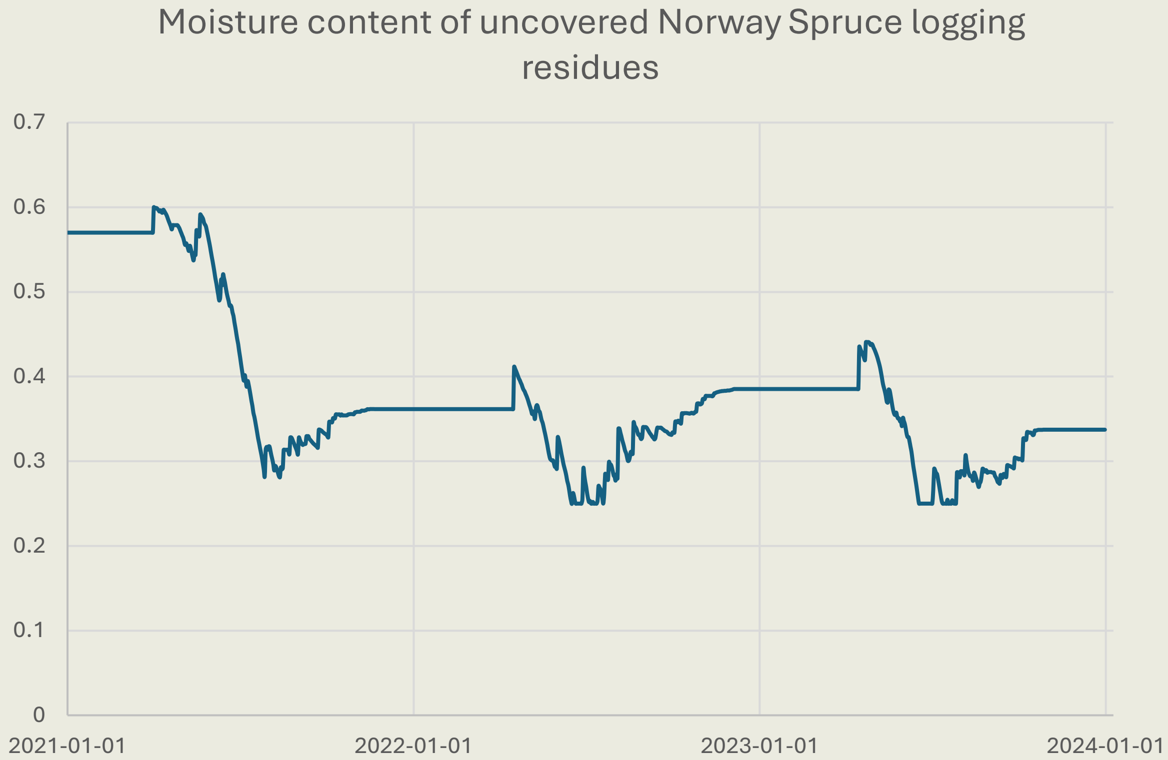
Energy initial	57.1 GWh
Energy final	39.5 GWh
Energy lost	17.7 GWh
Cost of energy loss, uncovered Norway Spruce logging residues	217 545 €

Covered Norway Spruce logging residues energy and economic loss

Energy initial	57.1 GWh
Energy final	43.9 GWh
Energy lost	13.2 GWh
Cost of energy loss, uncovered Norway Spruce logging residues	162 481 €

Drying curves of Norway Spruce logging residues harvested in December 2020





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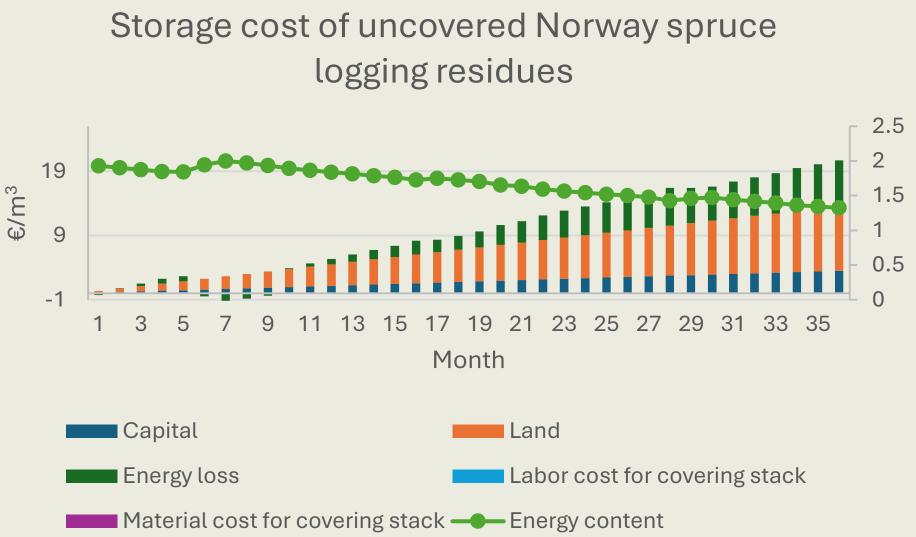
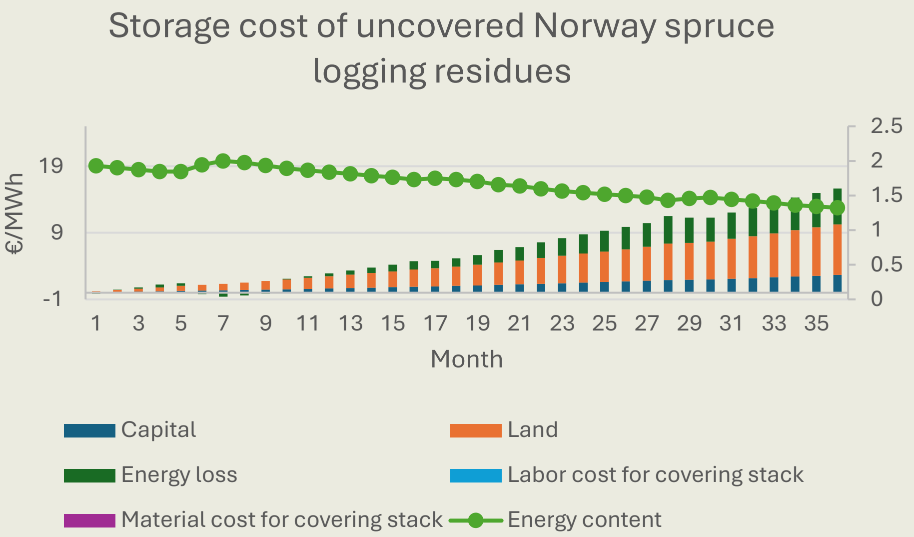
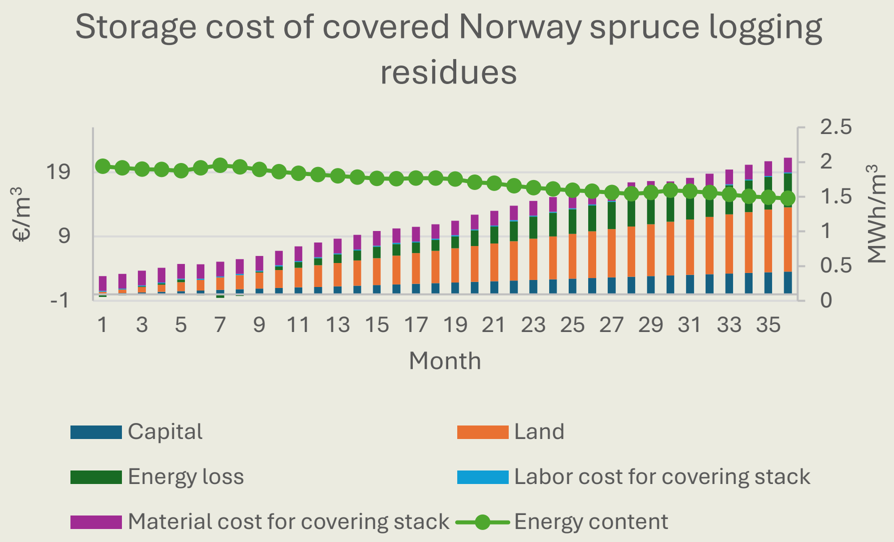
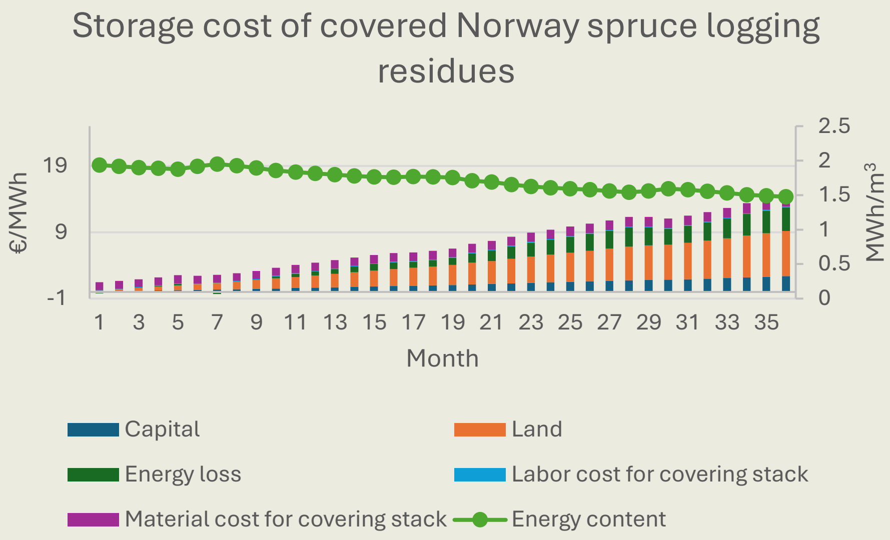
Storage costs of uncovered Norway Spruce logging residues





Storage cost of covered Norway Spruce logging residues



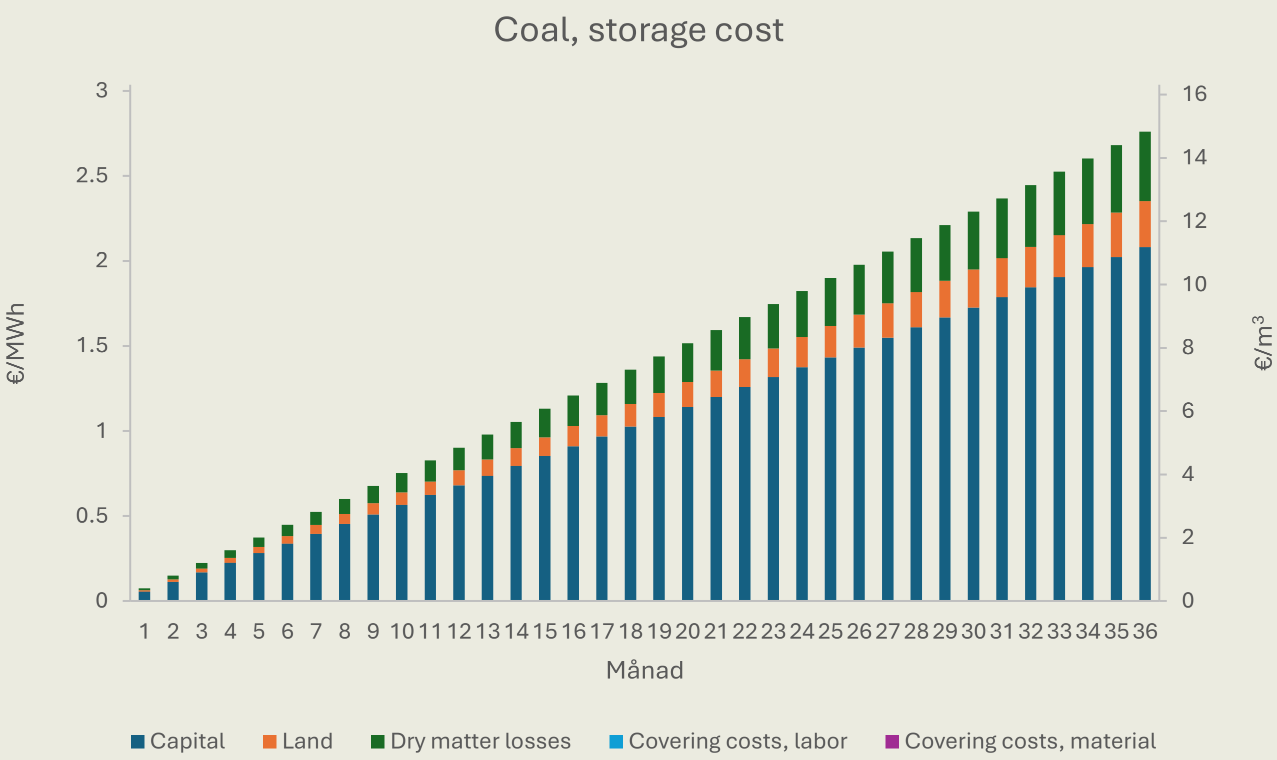


Storage costs of coal and peat

- Storage height 20 m
- Shape factor 0.5
- Stored at the user (power plant),

land cost 2.34 €/m²

- 0.083%/mon DML (1% annual)



	Sod Peat	Milled Peat	Coal
Moisture content as received (% wet basis)	38.9	48.5	10
Dry matter density (kg/m³)	233	175	700
Energy content of dry matter (MJ/kg)	21.2	20.8	27.9
Energy content as received (MJ/kg)	12.00287	9.527145	24.8657
Energy content as received (kWh/kg)	3.334131	2.646429	6.907139
Bulk density as received (kg/m³)	381.3421	339.8058	777.7778
Energy content (MWh/m3)	1.271445	0.899272	5.372219
Fuel cost (€/m³)	18.28	15.13	72.38

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Storage costs of coal and peat

- Storage height 15 m
- Shape factor 0.5
- Stored at the user (power plant),

land cost 2.34 €/m²

- 0.5%/mon DML

	Sod Peat	Milled Peat	Coal
Moisture content as received (% wet basis)	38.9	48.5	10
Dry matter density (kg/m³)	233	175	700
Energy content of dry matter (MJ/kg)	21.2	20.8	27.9
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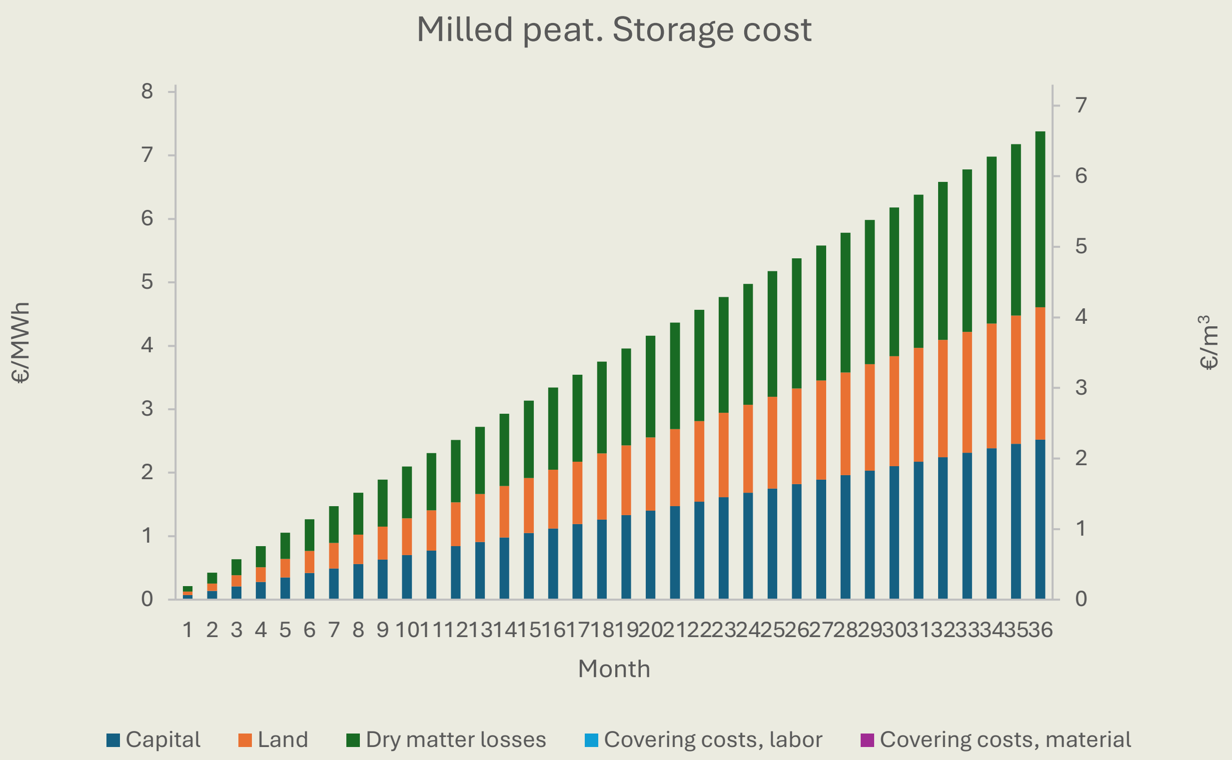

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Storage costs of coal and peat

- Storage height 15 m
- Shape factor 1
- Stored at the user (power plant),

land cost 2.34 €/m²

- 0.5%/mon DML

	Sod Peat	Milled Peat	Coal
Moisture content as received (% wet basis)	38.9	48.5	10
Dry matter density (kg/m³)	233	175	700
Energy content of dry matter (MJ/kg)	21.2	20.8	27.9
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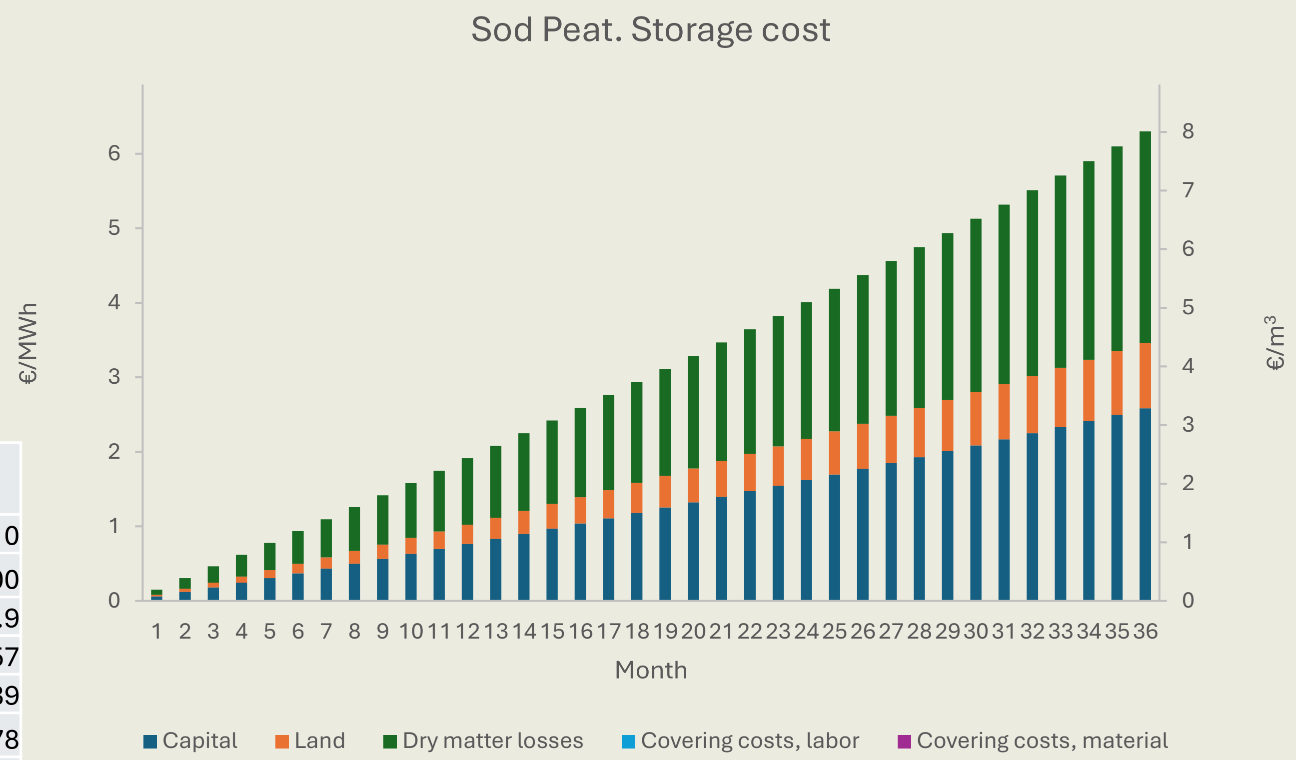

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Conclusion

- Coal is the cheapest to store ~2.8€/MWh (end-user)
- Peat 6-7 €/MWh (end-user)
- Covered pine stemwood 7.2 €/MWh, uncovered 13.4 €/MWh (terminal)
- Covered Norway Spruce logging residues 14.4 €/MWh, uncovered Norway Spruce logging residues 15.7 €/MWh (terminal)

Future research ideas

- Improved moisture/drying models, models for more fuel types like stumps, chips
- More research measuring long-term dry matter losses in biomass
- An online calculator for obtaining new fuel price information and weather data for drying calculations

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