Economic impacts of various forest management activities to enhance carbon sequestration efforts in Pennsylvania and Maryland.

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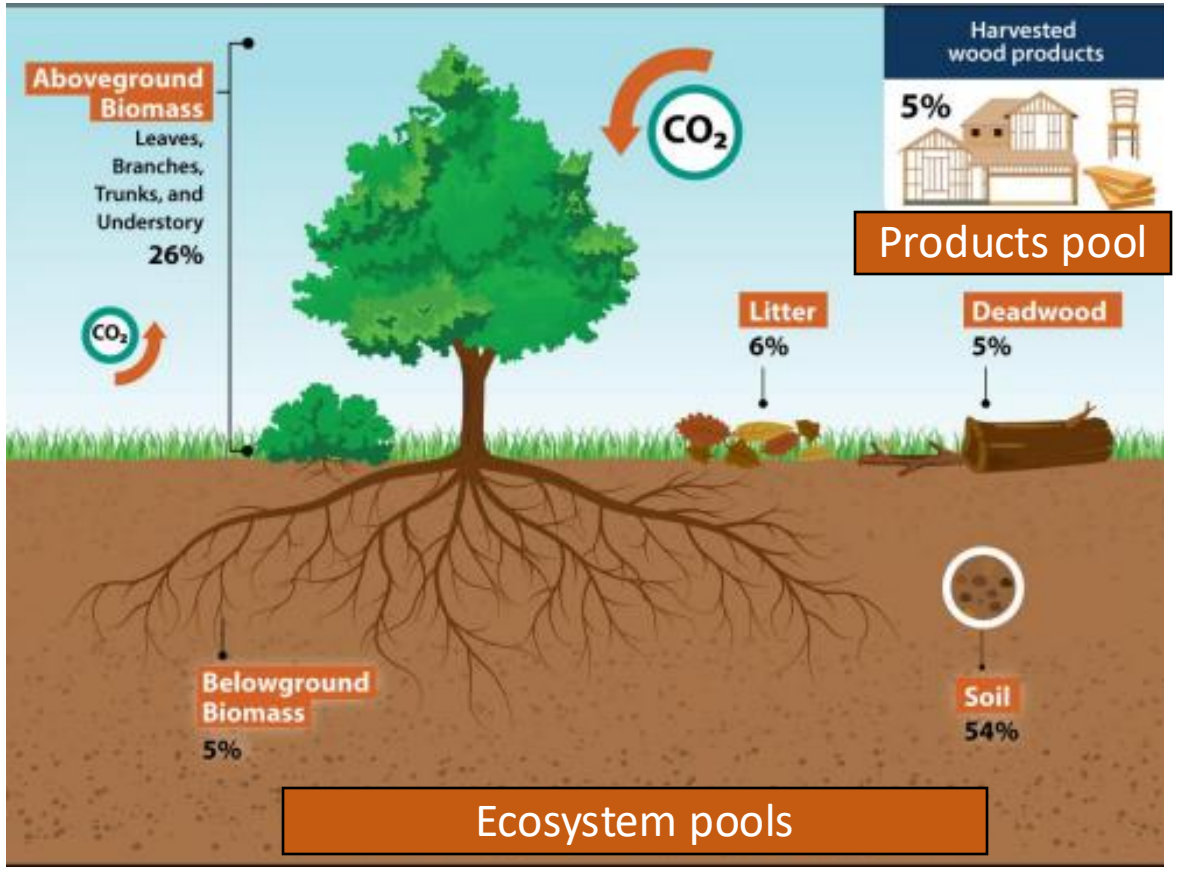
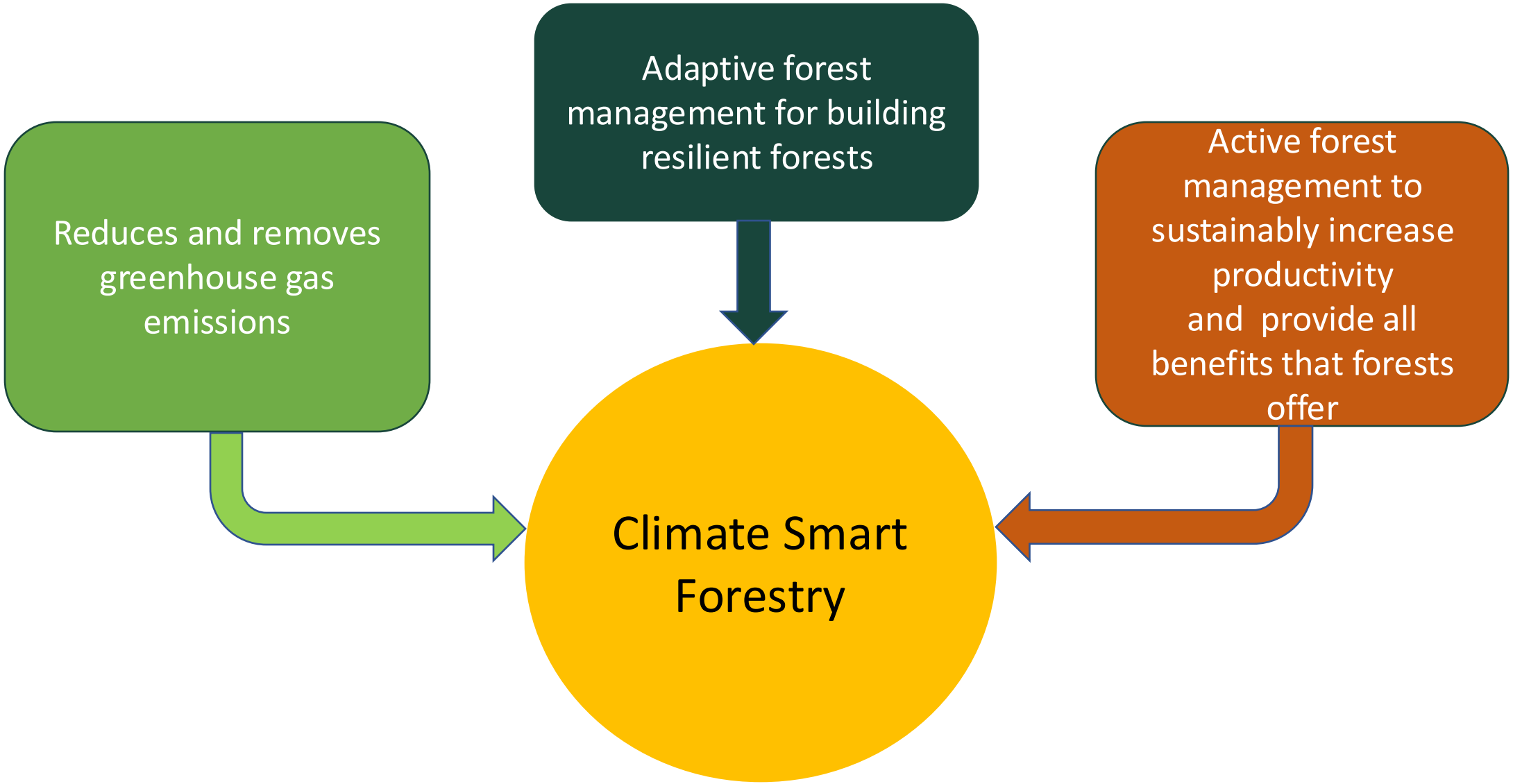
Background

- Forests play an important role in mitigating the effects of climate change
- In 2020, U.S. Forests sequestered 767 MMT CO_2 equivalent (offset of 13% gross GHG emissions) (Hoover and Riddle 2022)
- Growing recognition of forest's role in climate change has spurred interest to understand how such benefits from forests can be bolstered in the future



Source: Hoover and Riddle (2020)



A framework of climate smart forestry

Carbon Management: climate considerations

- Lots of terms!: climate-smart forestry, carbon stewardship, adaptive management, adaptive silviculture
- Carbon is just one management goals among other goals
- Optimizing carbon means balancing climate trade-offs with other traditional management goals in the context of ecosystem integrity and climate adaptation

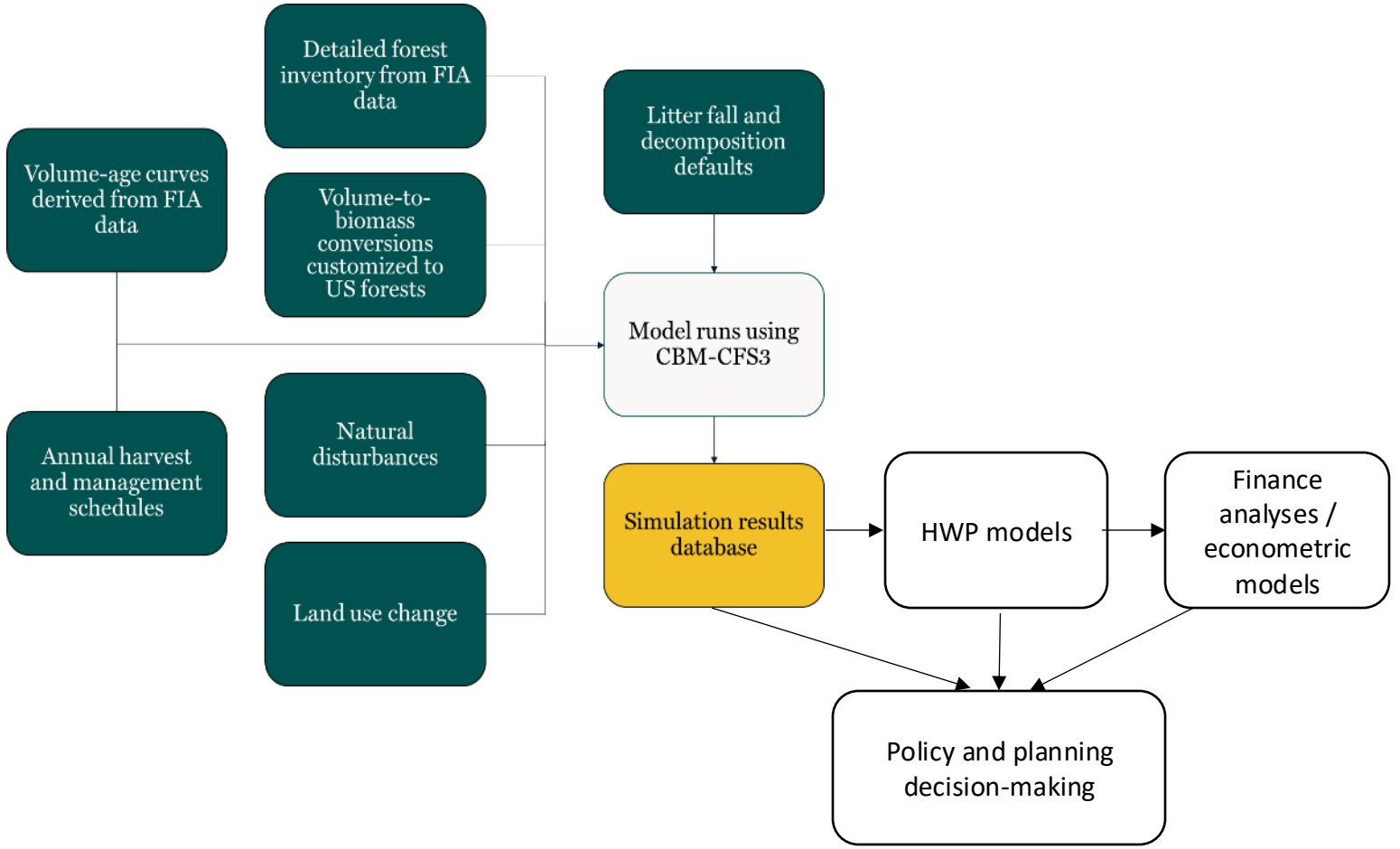
Objective

To quantify financial tradeoffs of carbon and timber products resulting from the CBM-CFS management scenarios for increasing carbon compared to the business as usual (BAU) scenario.

Forest Growth and Removal Projection

Carbon Budget Model – Canadian Forest Sector (CBM-CFS3)

- Empirically-derived processed based model
  - Forest inventory data
  - Activity Data
    - Harvest schedule
    - LUC
    - Other disturbances
  - Volume-to-biomass estimation
  - Process-based equations for turnover and decay
  - Associated framework CBM-HWP-MD & CMB-HWP-PA



Data and Methods

I. Estimation of timber products generated under business as usual (BAU) and alternative carbon management scenarios from the Harvested Wood Products (HWP) model was obtained using the following formula:

$$Volume = \frac{(Carbon * 2)}{Specific\ Gravity}$$

State-specific weighted specific gravities were used for conversion of softwood/hardwood component of forest types in each state

Maryland:

	Volume (MCF)	
softwood	9424.09737	*29.87%*
hardwood	22130.8831	*70.13%*
total	*31554.98*	

Weighted Specific Gravity	
softwood	0.5075104
hardwood	0.51647761

Pennsylvania:

	Volume (MCF)	
softwood	13573.2432	*5.38%*
hardwood	238539.78	*94.62%*
total	*252113.02*	

Weighted Specific Gravity	
softwood	0.39312572
hardwood	0.57964335

Estimation of Timber Products

Data obtained from HWPs model in different product stream categories

Variable	Product – General	Product – Specific	For Export?	Unit
ex.roundwood.MBF	Roundwood	Roundwood - for export	Y	MBF
ex_saw.MBF	Sawnwood	Sawnwood - for export	Y	MBF
D.saw.MBF	Sawnwood	Sawnwood logs, new domestic	N	MBF
R.saw.MBF	Sawnwood	Sawnwood, recycled	N	MBF
ex_veneer.MBF	Veneer	Veneer logs - for export	Y	MBF
D.veneer.MBF	Veneer	Veneer logs, new domestic	N	MBF
ex_D.pulp.tons	Pulp	Pulp - for export	Y	tons
ex_M.pulp.tons	Pulp	Pulp from mill residue - for export	Y	tons
ex_RS.pulp.tons	Pulp	Pulp, recycled - for export	Y	tons
D.pulp.tons	Pulp	Pulp	N	tons
M.pulp.tons	Pulp	Pulp from mill residue	N	tons
R.pulp.tons	Pulp	Pulp, recycled	N	tons
ex_D.CP.MCF	Composite panels	Composite panels - for export	Y	MCF
ex_M.CP.MCF	Composite panels	Composite panels from mill residue - for export	Y	MCF
D.CP.MCF	Composite panels	Composite panels	N	MCF
M.CP.MCF	Composite panels	Composite panels from mill residue	N	MCF
D.OI.MCF	Other industrial	Other industrial	N	MCF
M.bioenergy.tons	Bioenergy	Bioenergy from mill residue	N	tons
D.PPP.MBF	Poles, posts, pilings	Poles, posts, pilings	N	MBF

Revenue Estimation

Revenue from timber products estimated as:

$$Revenue\ TP = (Vol.Harvested * Stumpage\ Price)$$

Revenue from carbon credits estimated as:

$$Revenue\ CC = (CO_2\ equivalent * Price\ of\ carbon)$$

where,

CO_2 equivalent is obtained for two emission scenarios from previous work by FCCP

Stumpage Price for Revenue Estimation

Average stumpage price (2016 to 2021) in Pennsylvania

Product Type	Stumpage Price	Unit
Hardwood		
Logs	253.9	$/Mbf
Pulp	3.6	$/ton
Poles, post, pilings	253.9	$/ton
Softwood		
Logs	94.1	$/Mbf
Pulp	3.7	$/ton
Poles, post, pilings	94.1	$/ton

Starting year 2023, stumpage prices were increased by 3% every year for HWs and 2.5% per year for SWs.

Average stumpage price (2010 to 2021) in Maryland

Product Type	Stumpage Price	Unit
Hardwood		
Logs	270	$/Mbf
Pulp	3	$/ton
Poles, post, pilings	270	$/ton
Softwood		
Logs	156	$/Mbf
Pulp	4	$/ton
Poles, post, pilings	156	$/ton

Starting year 2023, stumpage prices were increased by 3% every year for HWs and 1% per year for SWs till 2032 and 2.5% starting 2033.

Percentages chosen based upon historical timber price trends in PA from 2007 to 2017 as per Jacobson (2022)

Forest Management Practices Costs Data for Cost Estimation

Data obtained from Environmental Quality Incentives Program's (EQIP) payment schedule 2022

Forest Practices Costs in Pennsylvania

Type of Forest Management Practice	EQIP Code	Per unit cost of implementing the management practice
Thinning	666	$327.2/acre
Prescribed fire	338	$75.95/acre
Site preparation cost in clearcut areas	490	$221.74/acre
Stand establishment cost in clearcut areas	612	$813.70/acre for HW species and $390.67/acre for SW species
Afforestation cost	612	$813.70/acre
Restocking cost	612	$636.20/acre
Fencing cost	382	$387/acre
Silvopasture planting cost	381	$128/acre

Forest Practices Costs in Maryland

Type of Forest Management Practice	EQIP Code	Per unit cost of implementing the management practice
Thinning	666	$317.98/acre
Prescribed fire	338	$68.18/acre
Site preparation cost in clearcut areas	490	$200.85/acre
Stand establishment cost in clearcut areas	612	$797.73/acre for HW species and $380.97/acre for SW species
Afforestation cost	612	$696.02/acre
Restocking cost	612	$380.97/acre
Fencing cost	382	$393/acre
Silvopasture planting cost	381	$128/acre

Starting year 2023, all forest practices costs were increased by 1.69% per year to account for inflation.

Economic Tradeoffs of Carbon and Timber Products Estimation

To quantify financial tradeoffs of carbon and timber products resulting from the CBM-CFS management scenarios, Net Present Value for each modeled scenario were estimated and compared to BAU scenario.

$$NPV = \sum \frac{R}{(1+i)^t} - \sum \frac{C}{(1+i)^t}$$

R is the revenue generated from the harvested wood products and/or carbon credits under each management scenario for a certain duration [Short term (2023 to 2032), Medium term (2023 to 2050), Medium-long term (2023 to 2070) and Long term (2023 to 2100)]

C is the costs associated with implementing each modeled management scenario including BAU for the same duration

i is the minimum acceptable real rate of return (RoR) and

t is the time in years during the period considered.

Management Scenarios in CBM-CFS

1. Business-as-usual (BAU) Scenario:

   -Represents continuation of current management practices (harvests, thinning, and prescribed burn). Projection starts from 2020 till 2170.

   -Basis for comparison to alternative scenarios

- 2. Alternative Management Scenarios

  -Created by changing BAU parameters beginning in 2020 representing potential changes in future management decisions or disturbance events.

  -Scenarios relate to one specific practice or objective, where only one BAU practice is changed and the rest of the BAU remains the same.

Business-as-usual simulation

Maryland

Land-use change			
Forest loss	-2,989 ha yr^{-1}	Forest Gain	+2,796 ha yr^{-1}
Natural disturbances			
Wildfire	176 ha yr^{-1}	Disease	11,368 ha yr^{-1}
Insect defoliation	3,970 ha yr^{-1}	Abiotic (wind, animal)	2,656 ha yr^{-1}
Insect mortality	151 ha yr^{-1}		
Forest management practices			
Prescribed fire (~40% understory consumption)	155 ha yr^{-1}		
State forests			
Clearcut (90% merchantable biomass removal)	13,245 tC yr^{-1} (55,195 m^3 yr^{-1})	Group selection / overstory removal (30% merchantable biomass removal)	11,187 tC yr^{-1} (43,348 m^3 yr^{-1})
Shelterwood cut (50% merchantable biomass removal)	190 tC yr^{-1} (720 m^3 yr^{-1})	Thinning (30% merchantable biomass removal)	923 tC yr^{-1} (3,846 m^3 yr^{-1})
Private forests			
Clearcut (90% merchantable biomass removal)	31,520 tC yr^{-1} (131,350 m^3 yr^{-1})	Shelterwood cut (50% merchantable biomass removal)	84,136 tC yr^{-1} (85,322 m^3 yr^{-1})
Seed tree cut (70% merchantable biomass removal)	32,390 tC yr^{-1} (212,575 m^3 yr^{-1})	Group selection / overstory removal (30% merchantable biomass removal)	10,842 tC yr^{-1} (86,890 m^3 yr^{-1})
Diameter-limit-cut (70% merchantable biomass removal)	23,839 tC yr^{-1} (214,919 m^3 yr^{-1})	Thinning (30% merchantable biomass removal)	19,384 tC yr^{-1} (64,209 m^3 yr^{-1})

Pennsylvania

Land-use change			
Forest loss	-10,453 ha yr^{-1}	Forest Gain	+3,454 ha yr^{-1}
Natural disturbances			
Wildfire	960 ha yr^{-1}	Disease	3,957 ha yr^{-1}
Insect defoliation	47,832 ha yr^{-1}	Abiotic (wind, animal)	5,053 ha yr^{-1}
Insect mortality	374 ha yr^{-1}		
Forest management practices			
Prescribed fire (~40% understory consumption)			
State forests			
Clearcut (90% merchantable biomass removal)	7,894 tC yr^{-1} (39,806 m^3 yr^{-1})	Group selection / overstory removal (30% merchantable biomass removal)	95,869 tC yr^{-1} (371,573 m^3 yr^{-1})
Shelterwood cut (50% merchantable biomass removal)	206,873 tC yr^{-1} (787,685 m^3 yr^{-1})	Thinning (30% merchantable biomass removal)	49,718 tC yr^{-1} (194,179 m^3 yr^{-1})
Private forests			
Clearcut (90% merchantable biomass removal)	49,462 tC yr^{-1} (245,280 m^3 yr^{-1})	Shelterwood cut (50% merchantable biomass removal)	173,546 tC yr^{-1} (591,618 m^3 yr^{-1})
Seed tree cut (70% merchantable biomass removal)	281,346 tC yr^{-1} (1,093,346 m^3 yr^{-1})	Group selection / overstory removal (30% merchantable biomass removal)	205,761 tC yr^{-1} (80,329 m^3 yr^{-1})
Diameter-limit-cut (70% merchantable biomass removal)	203,833 tC yr^{-1} (791,733 m^3 yr^{-1})	Thinning (30% merchantable biomass removal)	543,168 tC yr^{-1} (2,074,145 m^3 yr^{-1})
US Forest Service / other federal forests			
Shelterwood cut (50% merchantable biomass removal)	21,911 tC yr^{-1} (85,610 m^3 yr^{-1})	Thinning (30% merchantable biomass removal)	66 tC yr^{-1} (265 m^3 yr^{-1})
Group selection / overstory removal (30% merchantable biomass removal)	11,660 tC yr^{-1} (46,798 m^3 yr^{-1})		

What landowners are paid for

- Avoided emissions
  - An indirect mitigation activity
    - I don't harvest what I say I would have harvested and get paid for the carbon stocks (above some threshold) that I leave in the forest
- Removals
  - A direct mitigation activity
    - when my carbon stocks increase, I am paid for it

Carbon Price

- Price per ton of CO_2 equivalent used for financial analysis was $8.29 dollars for year 2022 (as accessed in Oct 6,2022).

- Transaction cost of carbon was deducted from the market price to get the price of carbon used for financial analysis

- Transaction cost of carbon was estimated using the formula proposed by Pearson et al. (2013).

$$TC = 1 + 0.23 * P^c$$

where TC is the transaction cost of carbon,
1 represents the fixed cost of carbon ($1 per ton) and $0.23 * P^c$ represents the variable cost of carbon which is assumed to be 23% of the market price of carbon.

Starting year 2023, carbon price was assumed to increase by 2% every year

Live Carbon Prices Today

CarbonCredits.com Live Carbon Prices	Last	Change	YTD
Compliance Markets			
European Union	€78.67	0.00 %	−1.93 %
California	$30.83		−3.72 %
Australia (AUD)	$28.00	0.00 %	−45.10 %
New Zealand (NZD)	$80.30	0.00 %	+17.31 %
South Korea	$14.24	0.00 %	−43.12 %
Voluntary Markets			
Aviation Industry Offset	$2.98	0.00 %	−62.75 %
Nature Based Offset	$7.40	0.00 %	−47.44 %
Tech Based Offset	$2.37	0.00 %	−53.35 %

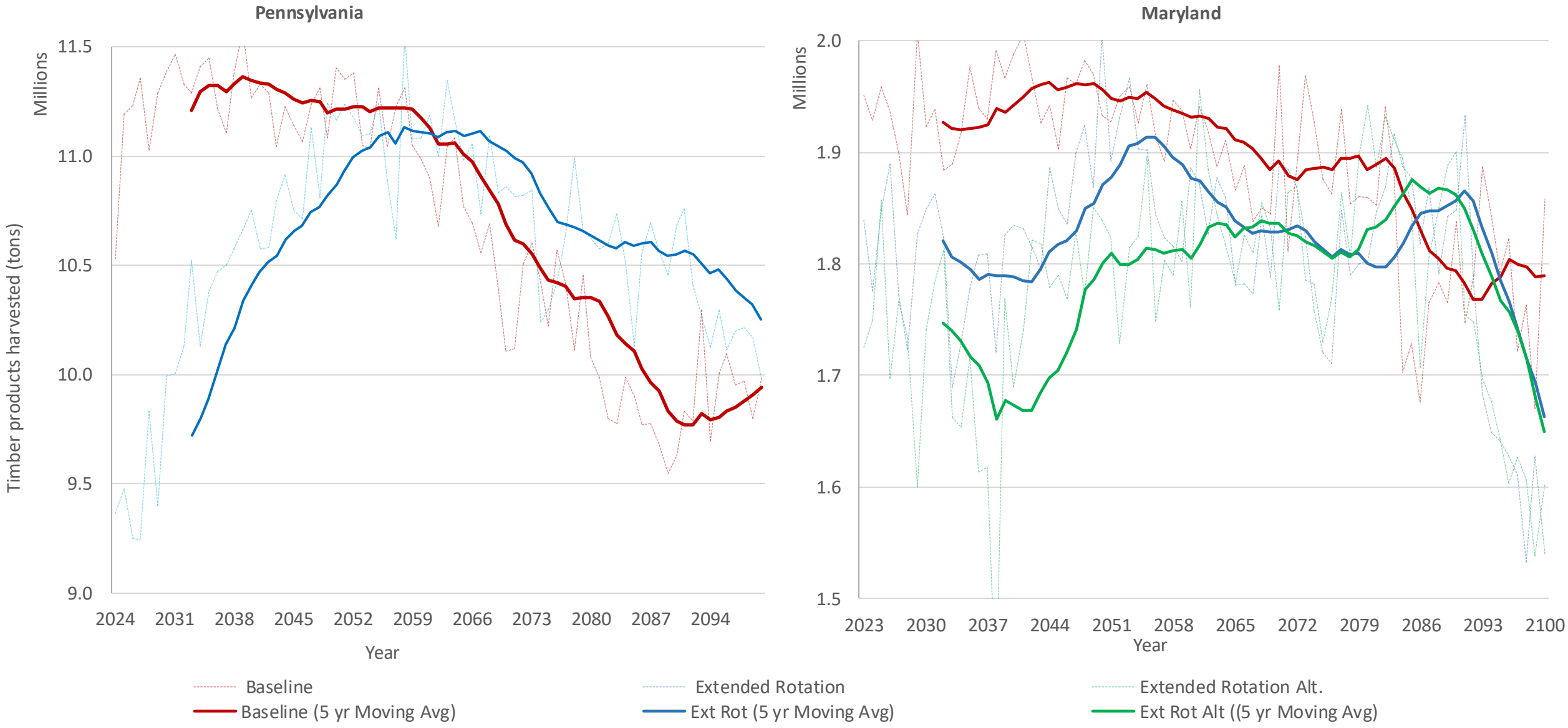
CarbonCredits.com Real-time Pricing (Updates Every 5 Mins)

Click here to learn how carbon credits are priced.

https://carboncredits.com/carbon-prices-today/?sl=cc-google-ads&gclid=Cj0KCQjw852XBhC6ARIsAJsFPN2FVsJRnxzxC42TZMKSM-Ue3wo7hVTTiOkz1eaJdi_sqLdghAJ853gaAkTdEALw_wcB

Findings

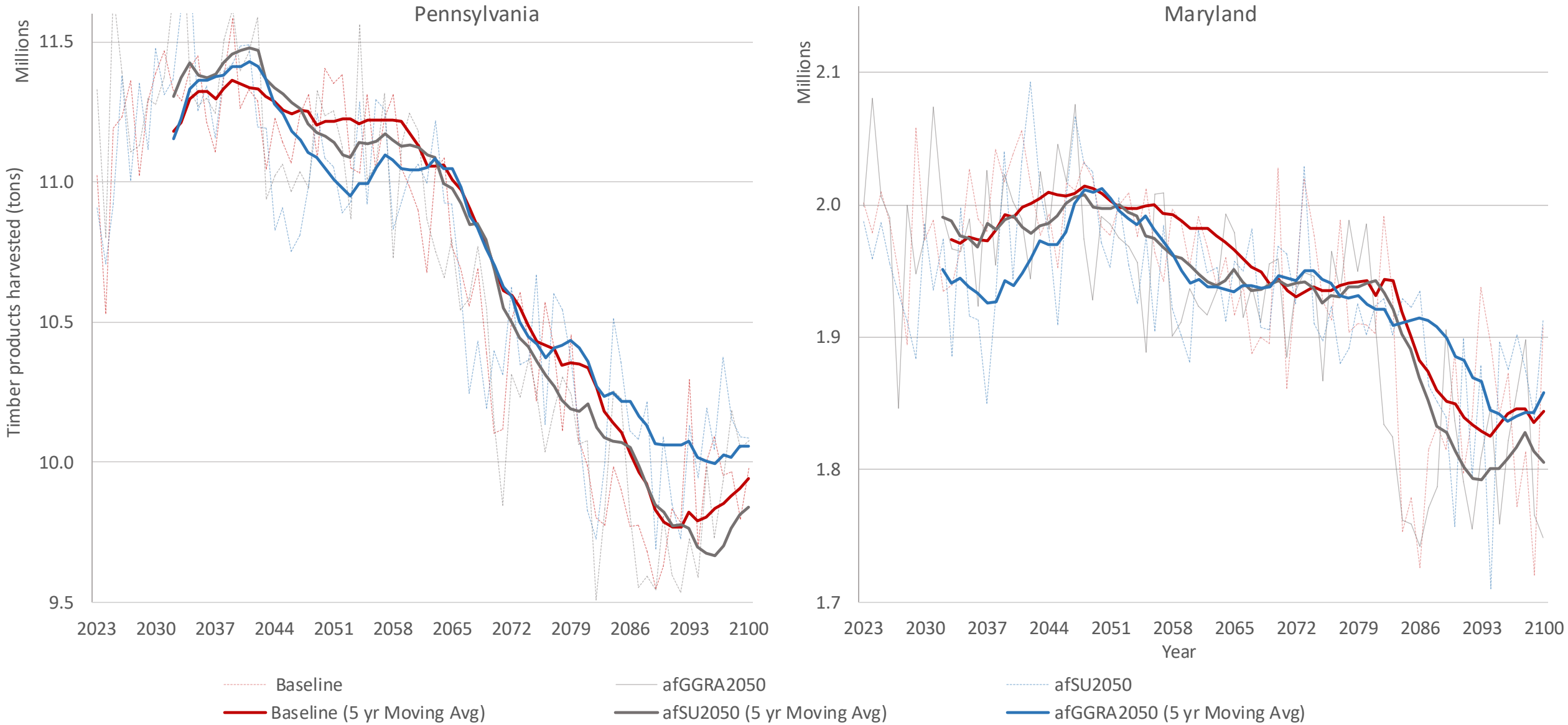
BAU Vs Extended Rotation



Extended Rotation= Increasing average harvest age of stands (+30 years on H/SWs; -10 years on Aspen in PA) (+30 years on HWs and +20 years on loblolly pine till 2170 in MD)

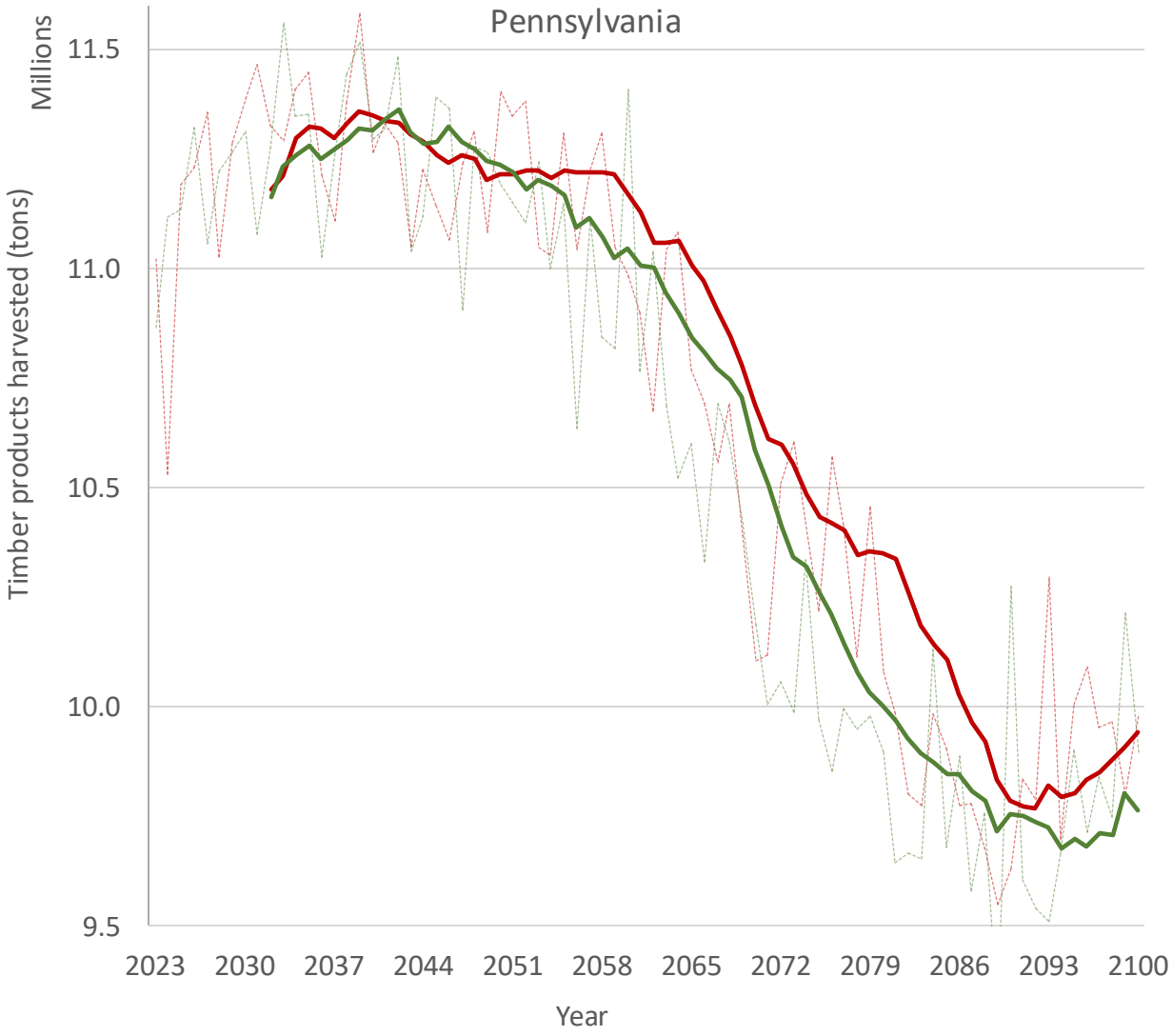
Extended Rotation Alt.= Increasing average harvest age of stands (+30 years on HWs and +40 years on loblolly pine till 2170 in MD)

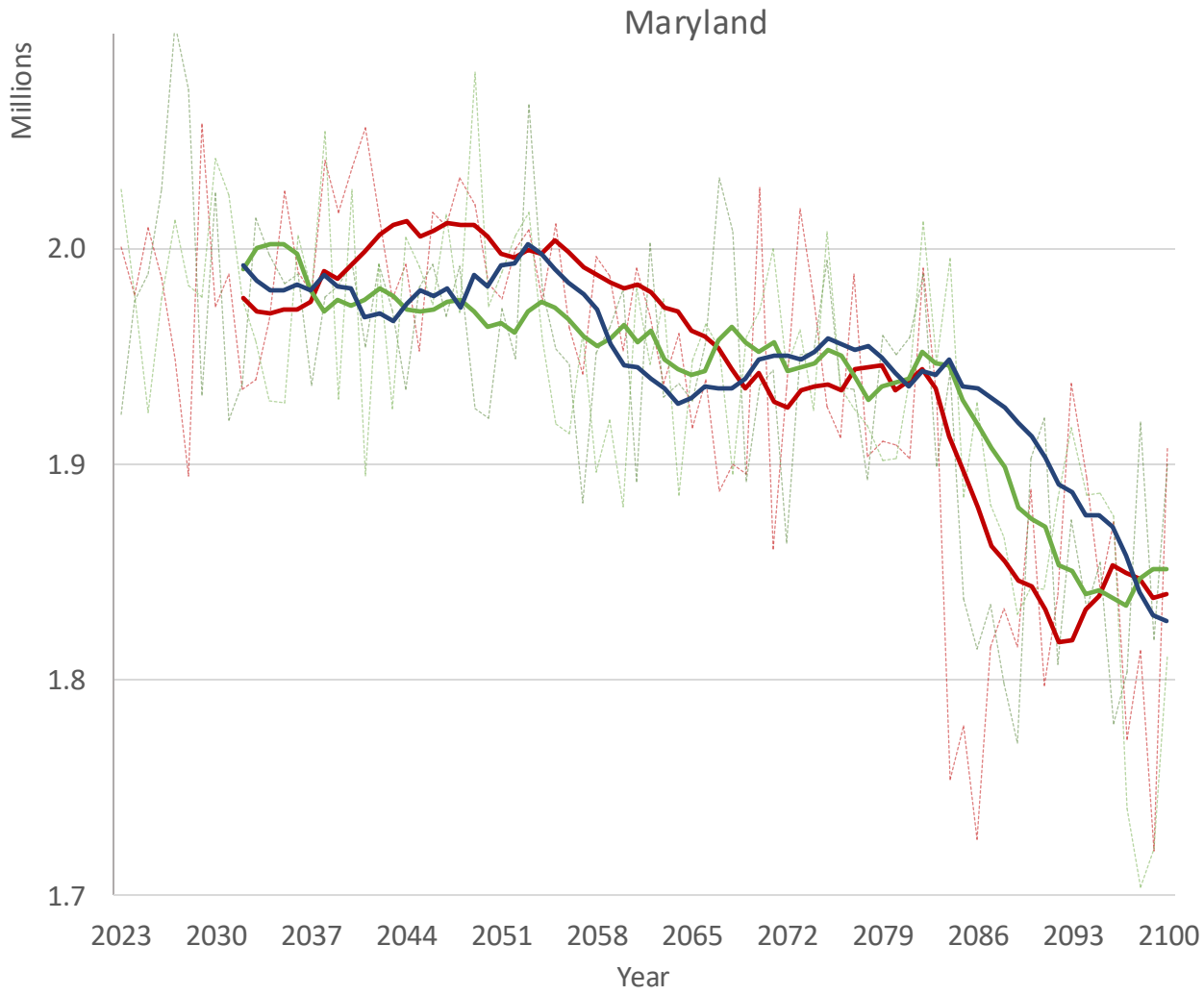
BAU Vs Afforestation



afGGRA2050 = Increasing afforestation (+2,376 acres/year till 2050 in PA; +350 acres/ year in MD)
afSU2050 = Increasing afforestation scale up (+23,760 acres/year till 2050 in PA; +3500 acres/year in MD)

BAU Vs Restocking

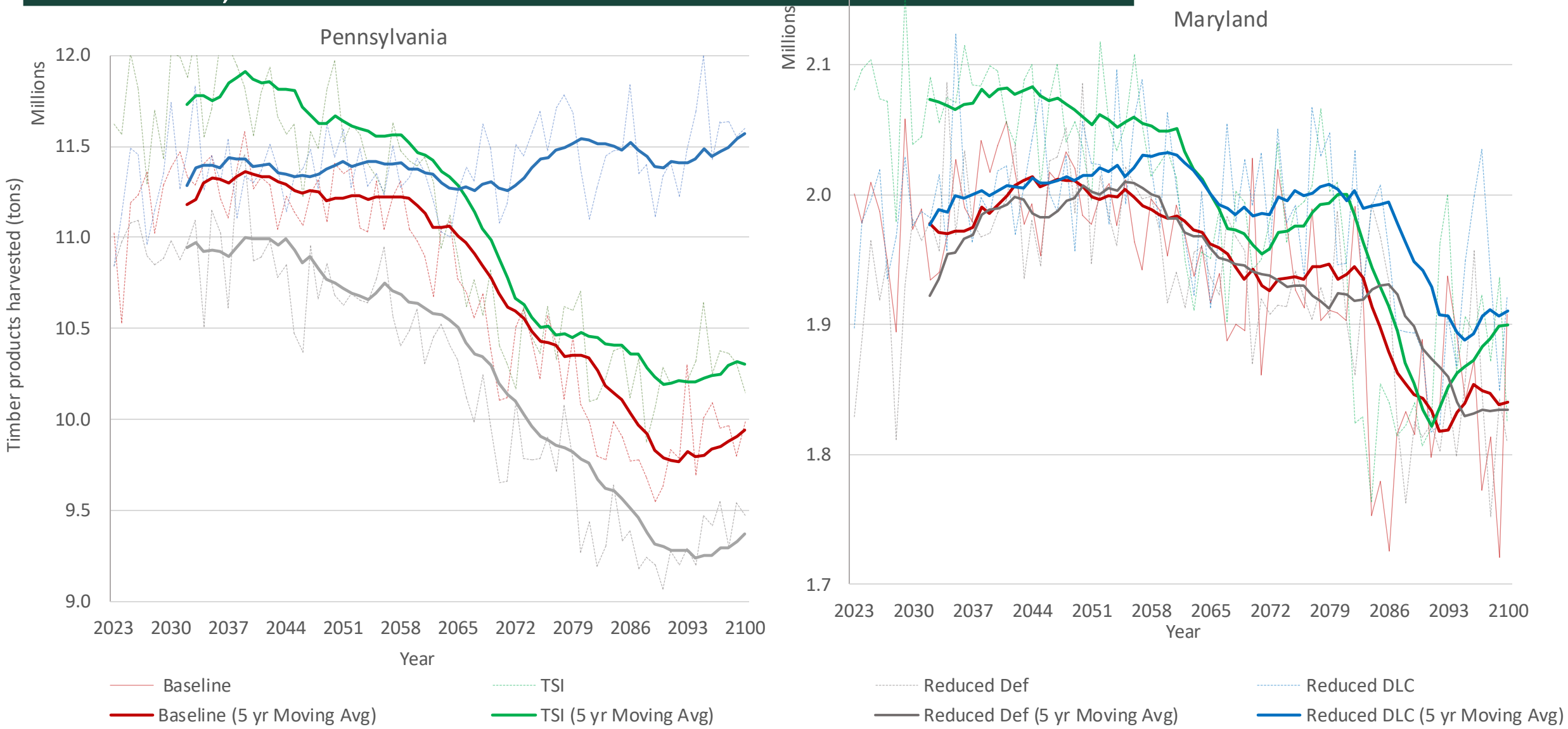




Baseline
Restock
Restock Alt
Baseline (5 yr Moving Avg)
Restock (5 yr Moving Avg)
Restock Alt (5 yr Moving Avg)

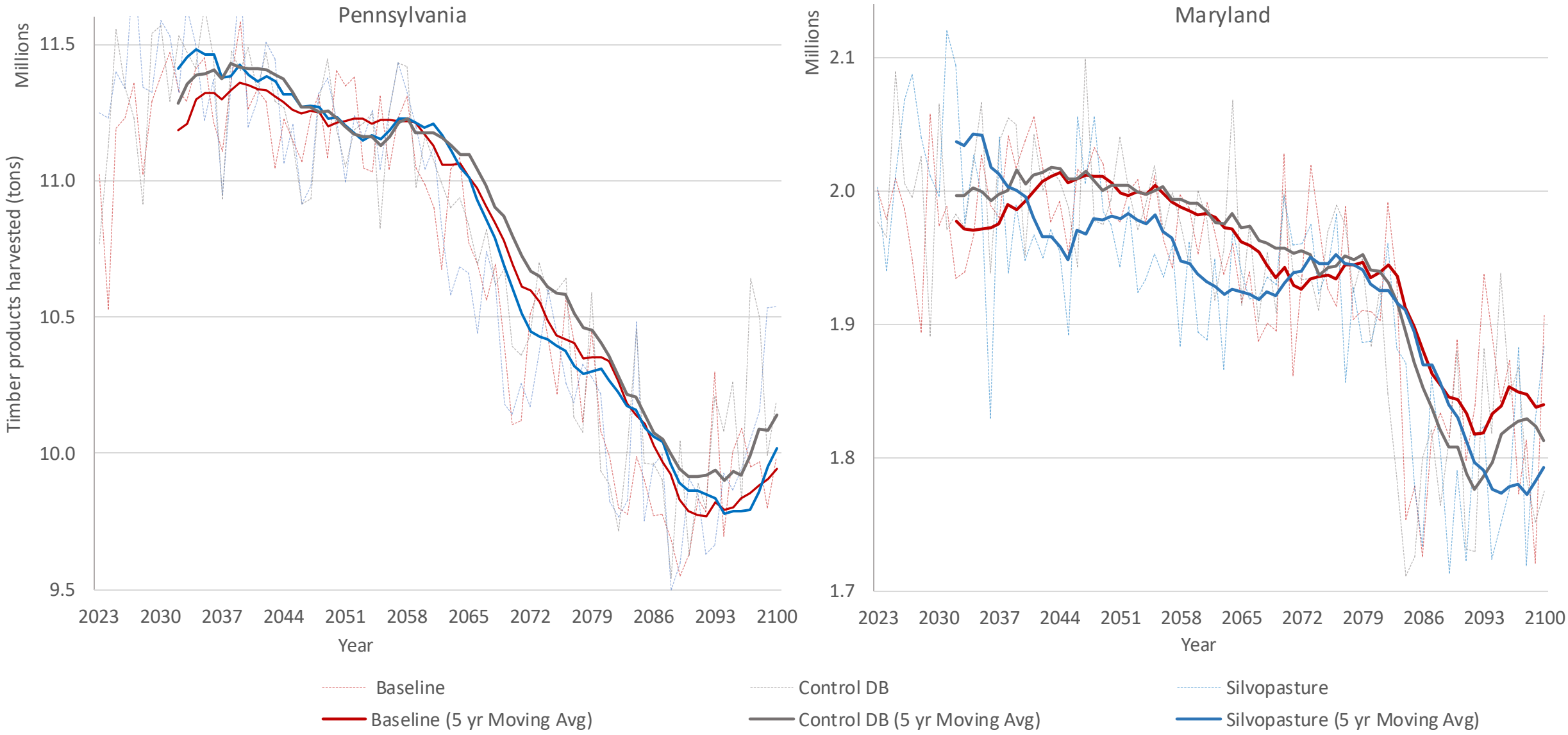
Restock = Increasing supplemental planting (+4,508 acres/year till 2170 in PA; +2500 acres/year till 2030 in MD), Restock Alt = Increasing supplemental planting (+2500 acres/year till 2050)

BAU Vs TSI, Reduced DLC and Reduced Deforestation Scenarios



TSI = Annual thinning rate (+14,892 acres/year till 2170 in PA; +5500 acres/year in MD); Annual prescribed burn rate (+25,000 acres/year till 2170 in PA; +500 acres/year in MD)
Reduced DLC = (-30,559 mt C/year until DLC = 0 in 2027; DLCs stay at 0 until 2170 in PA) (-2384 mt C/year until DLC = 0 in 2030; DLCs stay at 0 until 2170 in MD)
Reduced Deforestation = (-5,149 acres/year until 2170 in PA) (-800 acres/year until 2030; then return to baseline in MD)

BAU Vs Controlled Deer Browse and Silvopasture Scenarios



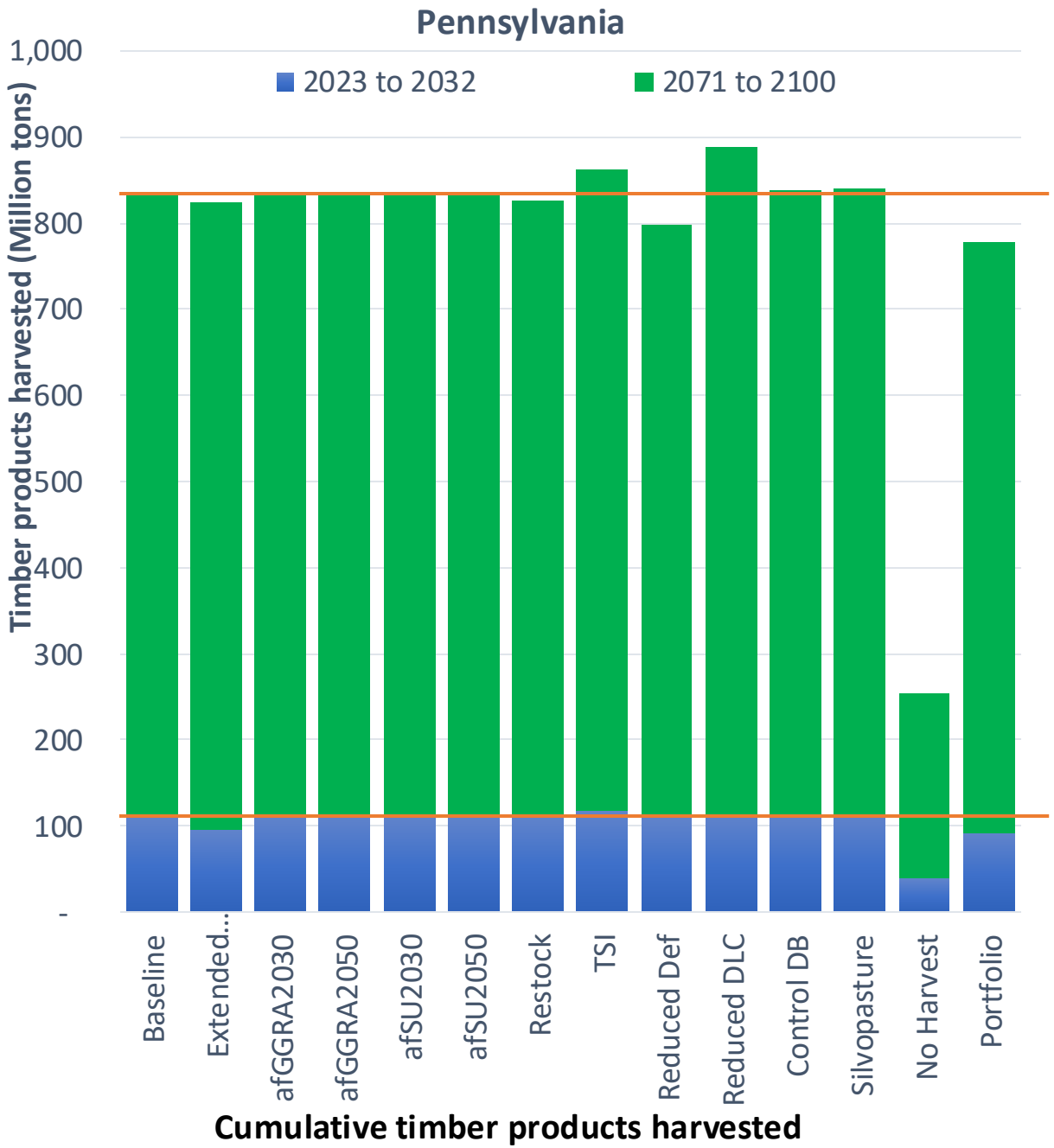
Controlled Deer browse = Annual browse control rate (+14,459 acres/year until 2170 in PA) (+2,000 acres/year until 2170 in MD)

Silvopasture = Annual Silvopasture planting rate {+15,250 acres/year (0.5% of eligible acres) until 2170 in PA} (+3,511 acres/year until 2170 in MD)

Pennsylvania: Timber Products Harvested

Scenarios	Harvested timber products (in million tons) at the specified time frame			
	Short Term			Long Term
Baseline	112			834
Extended Rotation	96			825
afGGRA2030	113			836
afGGRA2050	113			833
afSU2030	112			833
afSU2050	112			836
Restock	112			826
TSI	117			862
Reduced Def	109			798
Reduced DLC	113			889
Control DB	114			837
Silvopasture	113			841
No Harvest	39			254
Portfolio	92			777

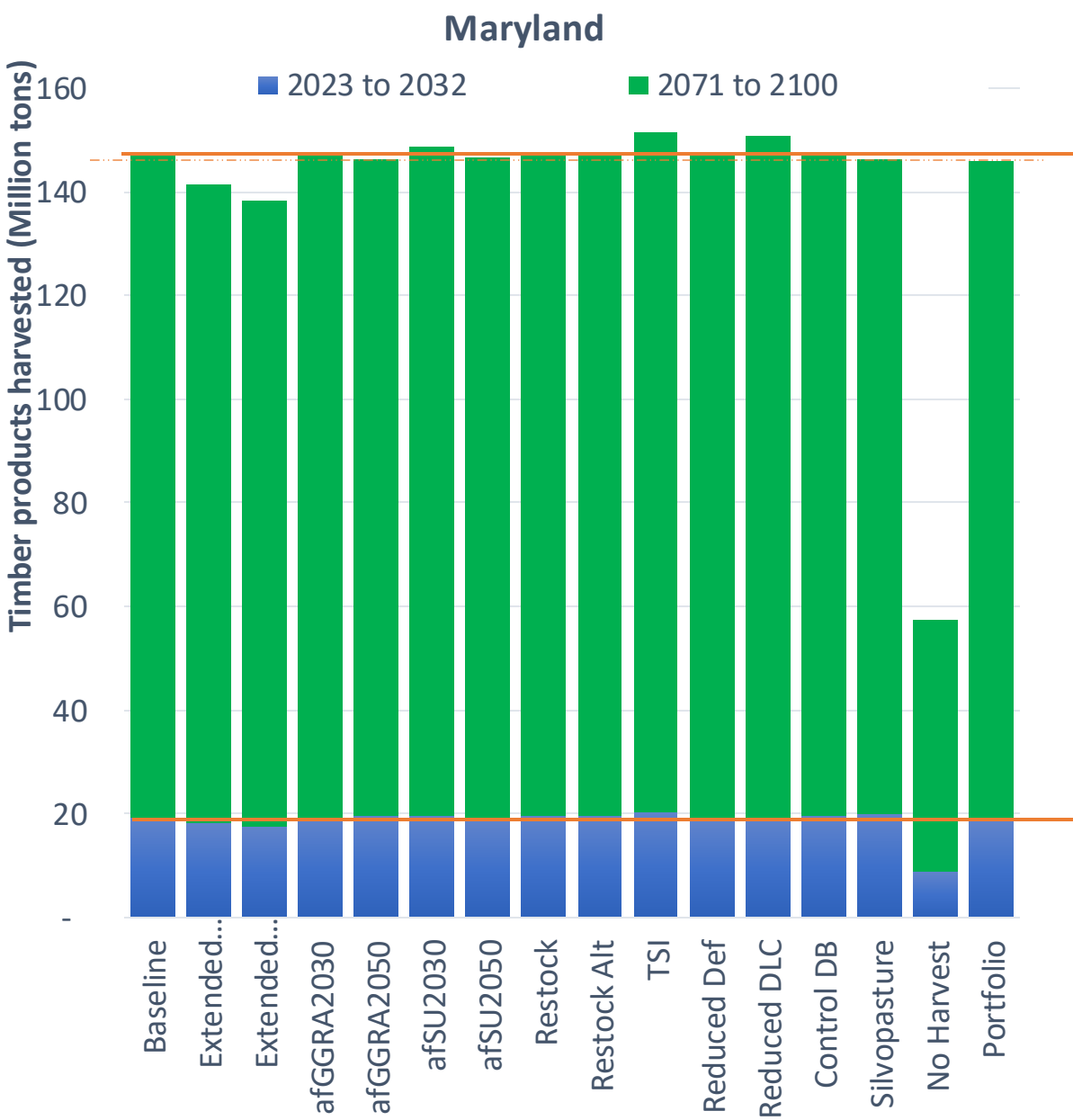
Pulp: 49%
Sawlogs: 38.5%
Composite panels: 7.5%
Bioenergy: 4.6%
Poles, posts and pilings: 0.25%



Maryland: Timber Products Harvested

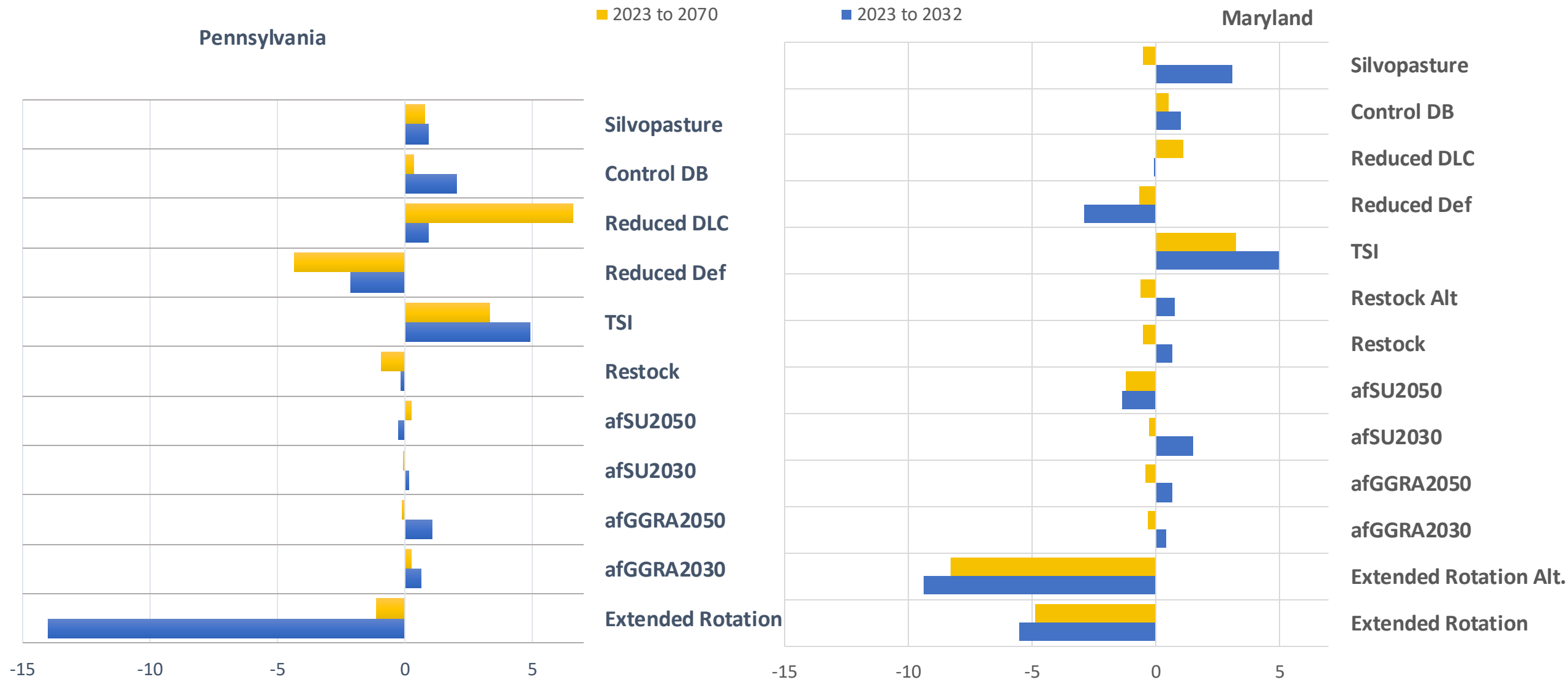
Scenarios	Harvested timber products (in million tons) at the specified time frame			
	2023 to 2032			2023 to 2100
Baseline	19			147
Extended Rotation	18			141
Extended Rotation Alt.	17			138
afGGRA2030	19			147
afGGRA2050	19			146
afSU2030	20			149
afSU2050	19			147
Restock	19			147
Restock Alt	19			147
TSI	20			152
Reduced Def	19			147
Reduced DLC	19			151
Control DB	19			147
Silvopasture	20			146
No Harvest	9			57
Portfolio	18			146

Pulp: 68%
Sawlogs: 25%
Composite panels: 4%
Bioenergy: 2%
Poles, posts and pilings: 1%

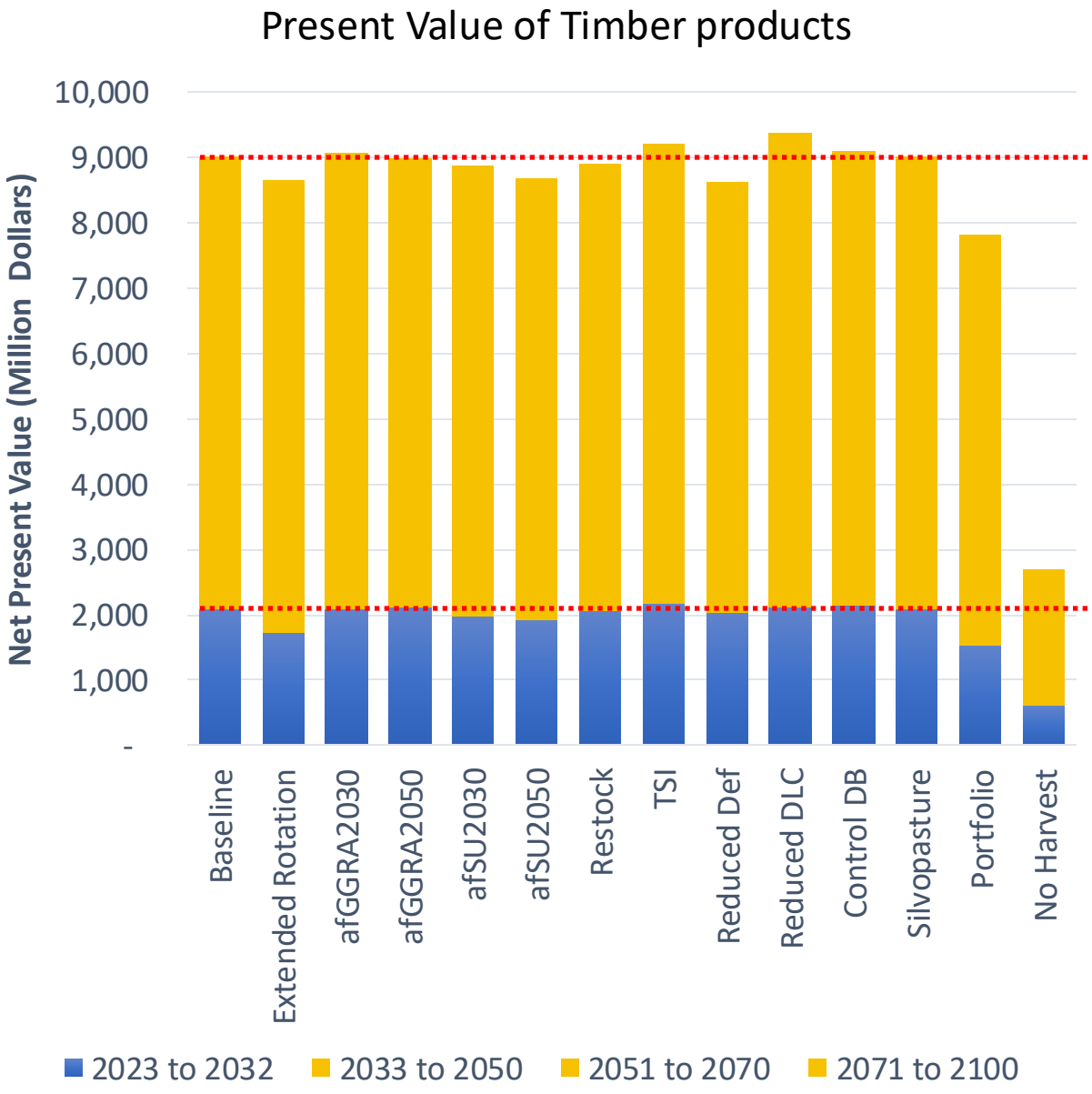


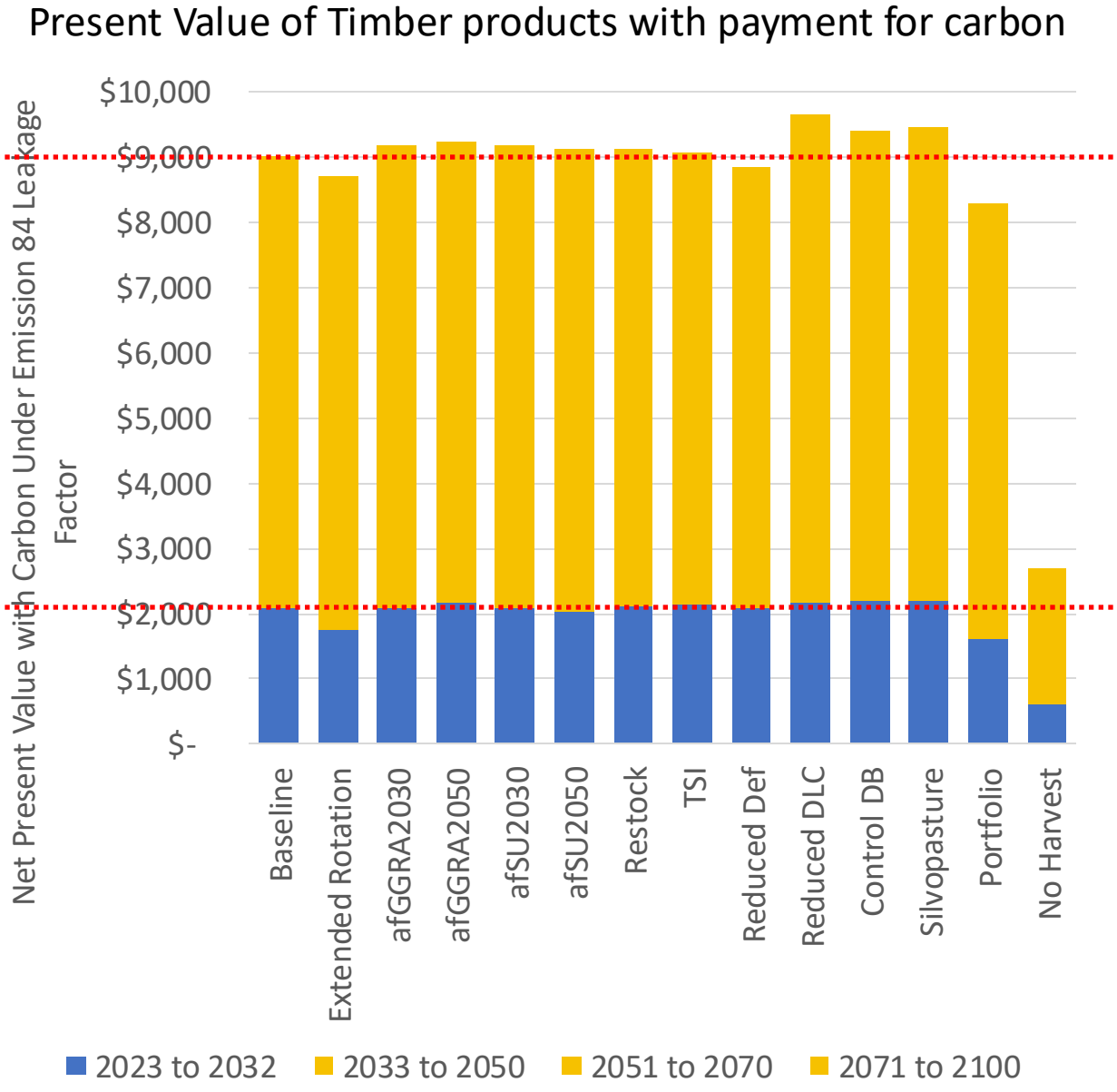
Cumulative timber products harvested

Change in timber products harvested compared to BAU (%)

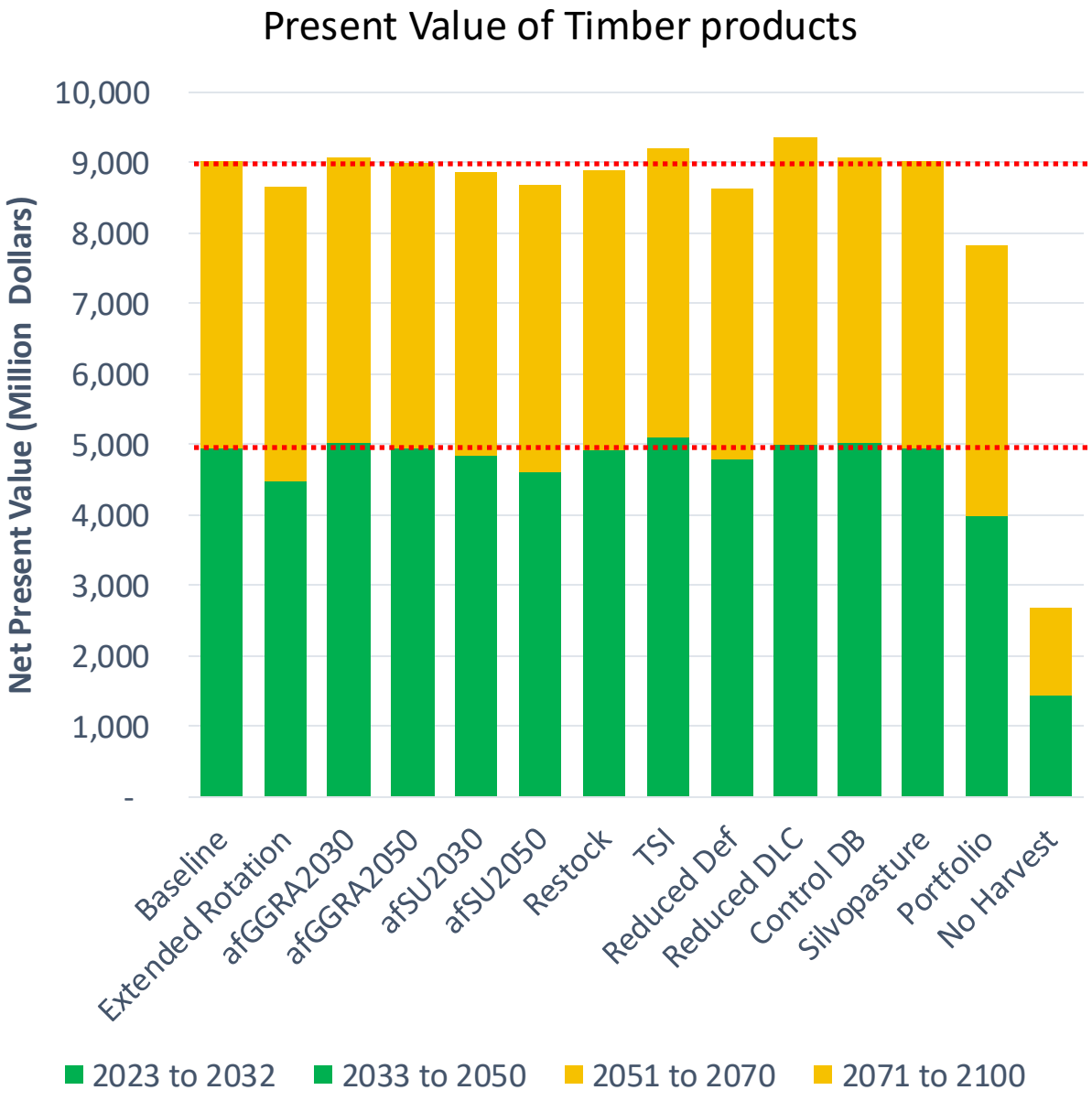


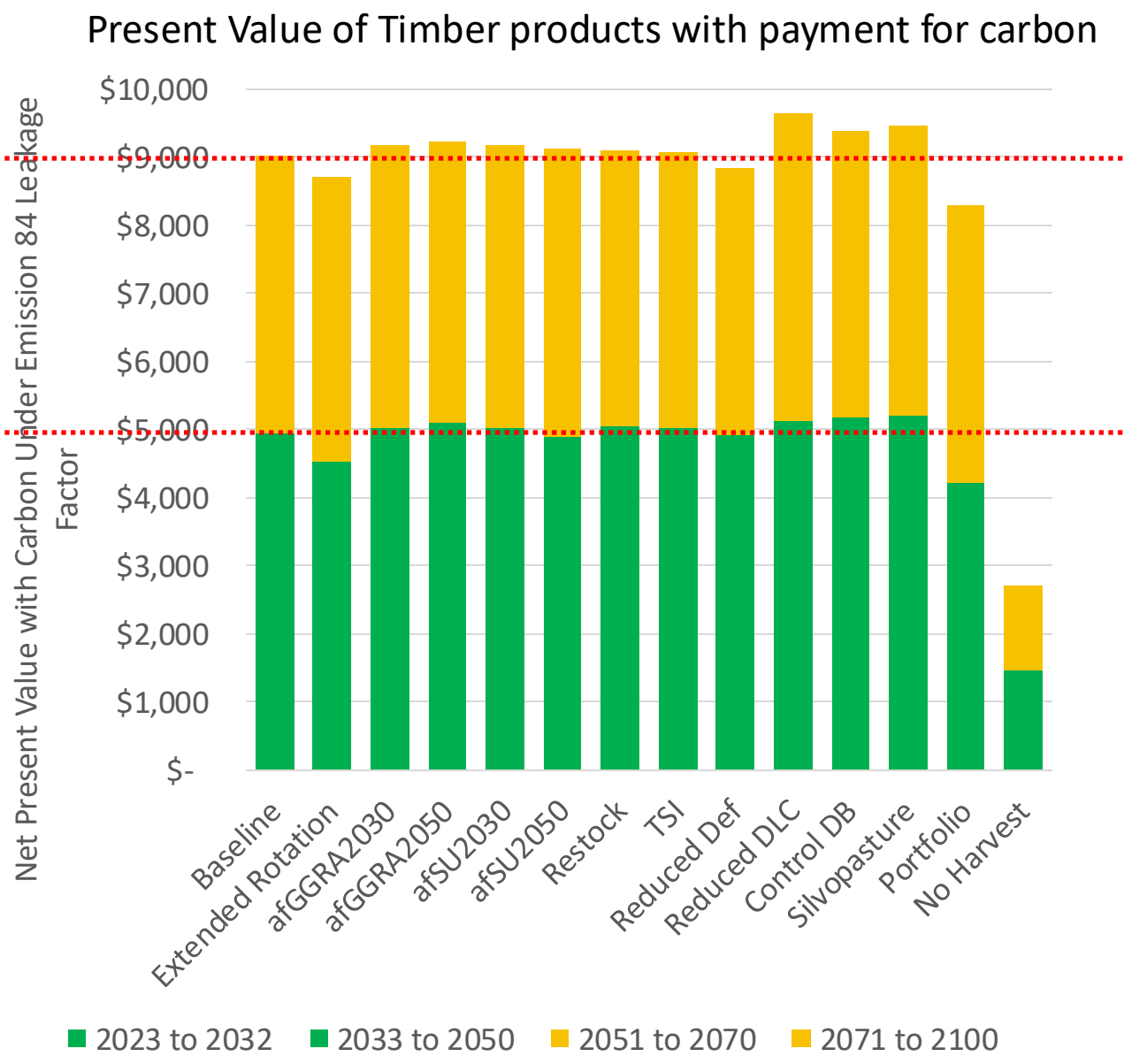
Pennsylvania: NPV





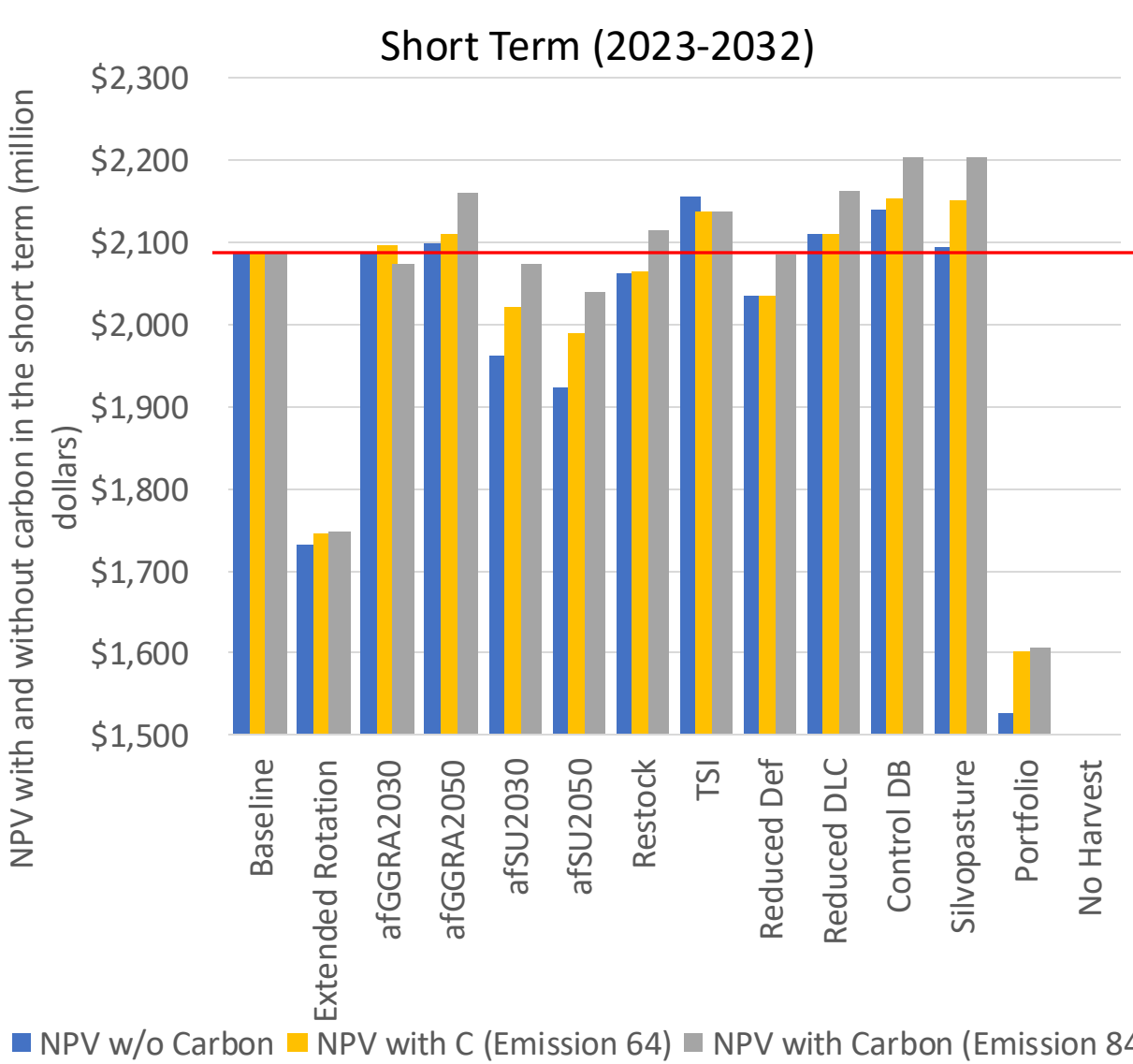
Pennsylvania: NPV

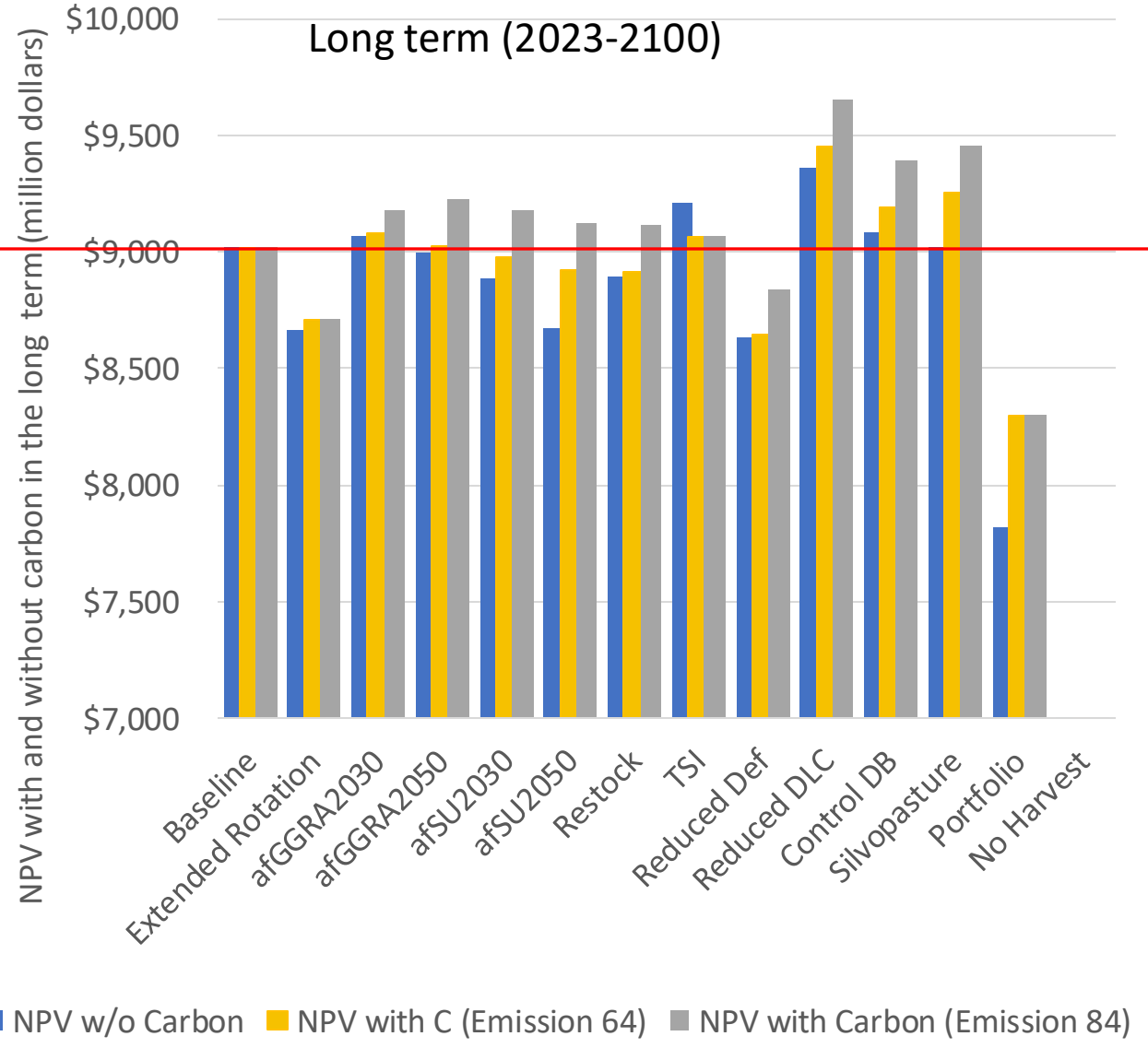




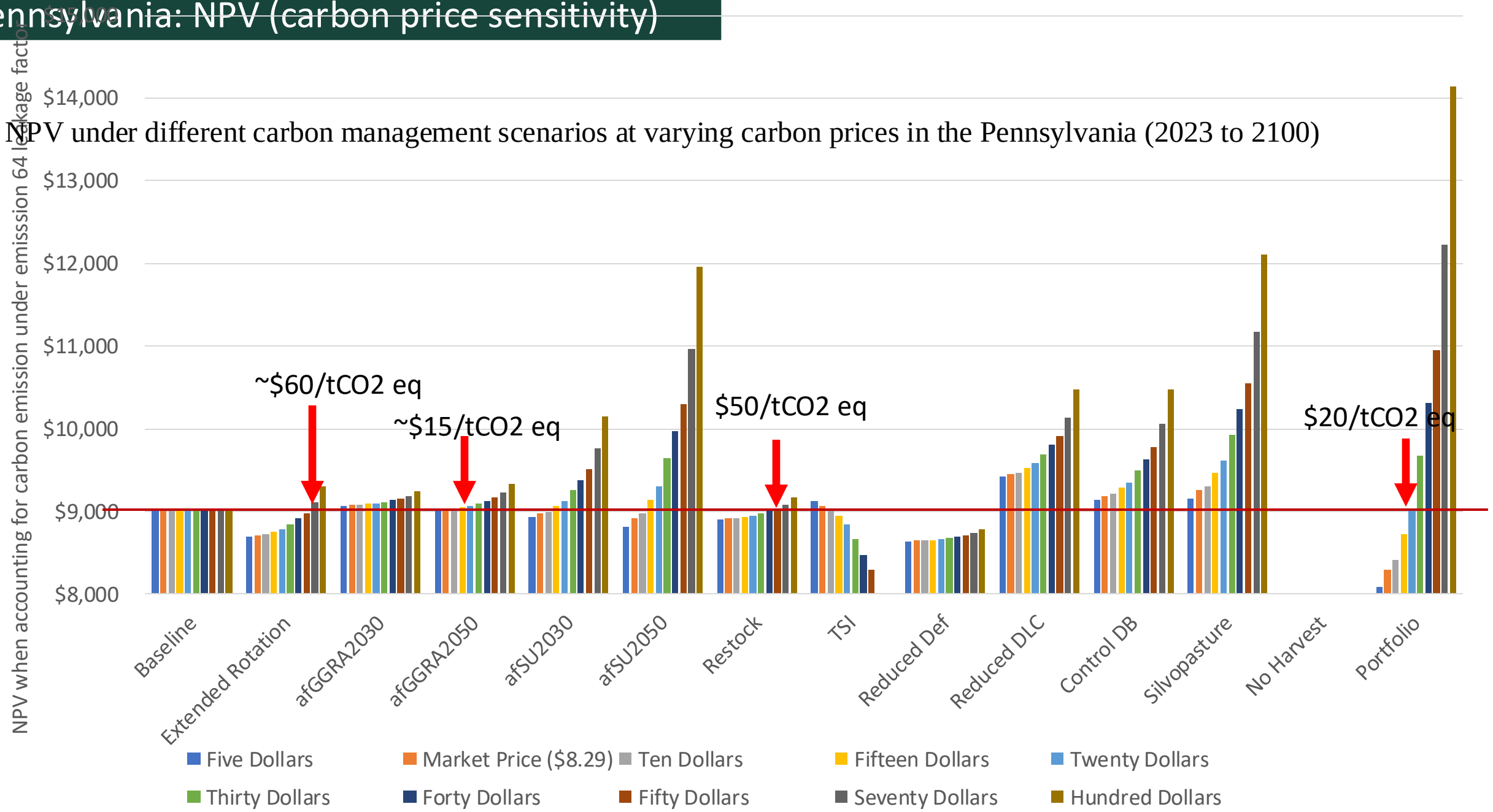
Pennsylvania: NPV

NPV under different carbon management scenarios **with and without carbon payments**

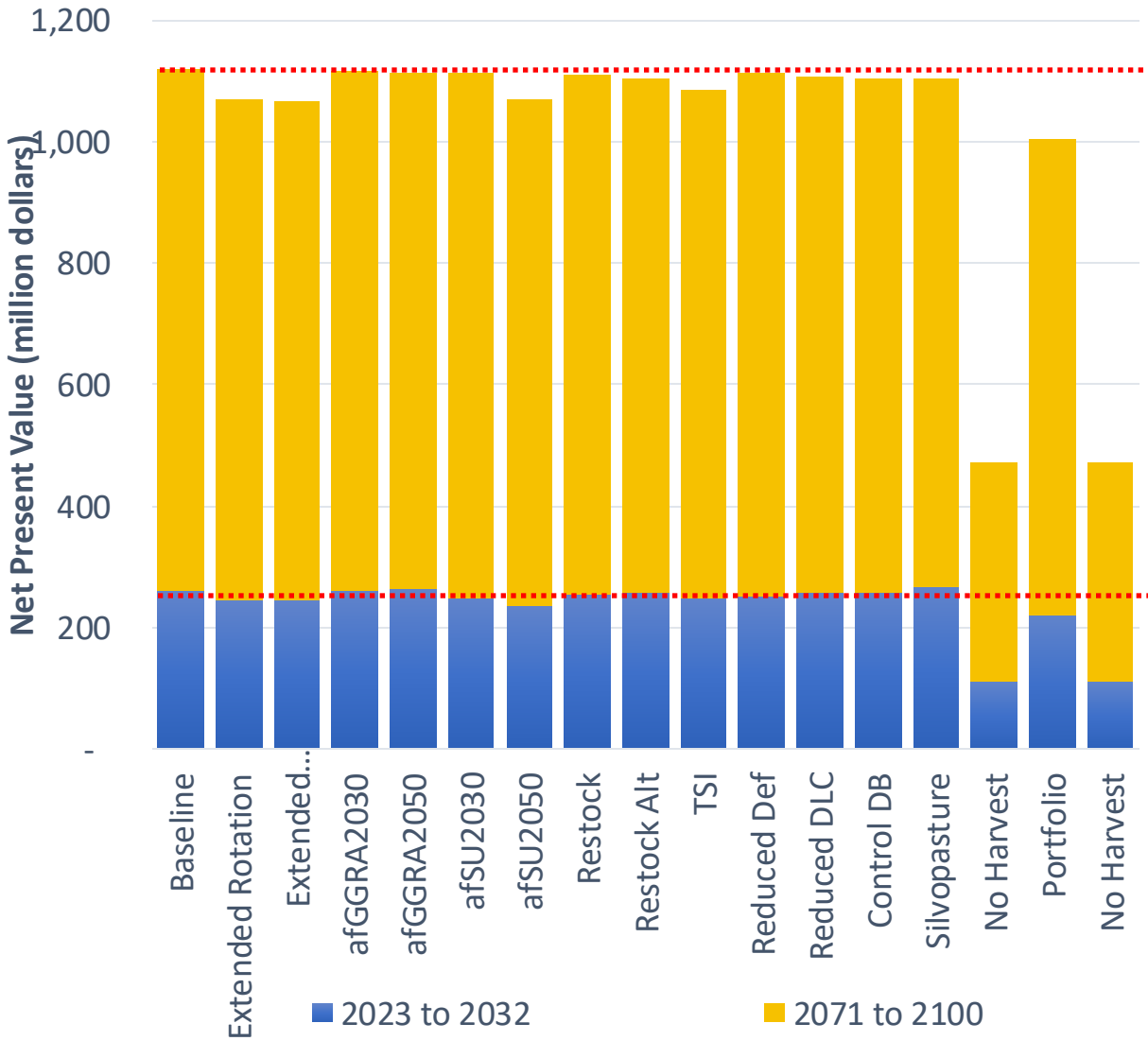


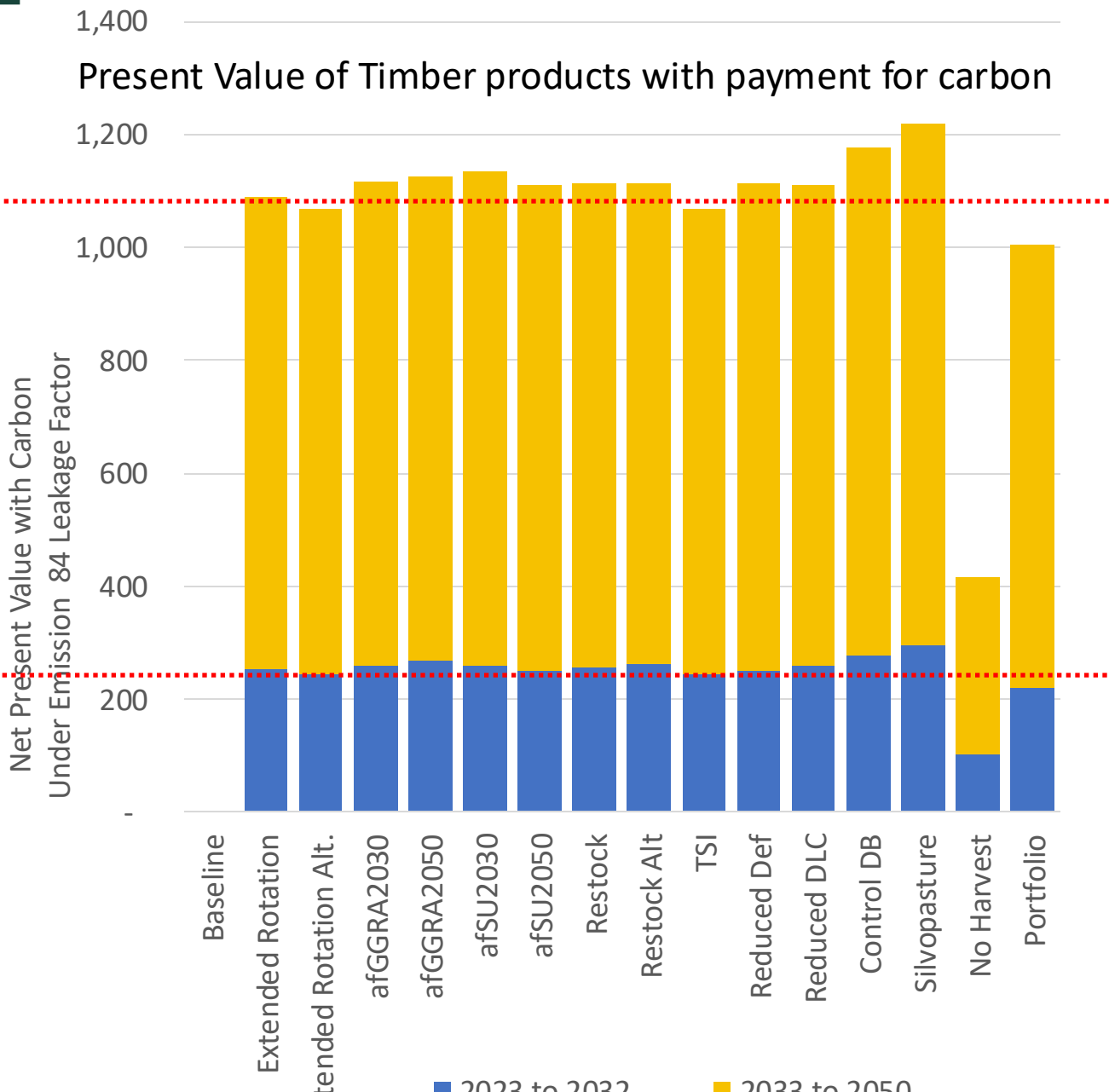


Pennsylvania: NPV (carbon price sensitivity)



Maryland : NPV

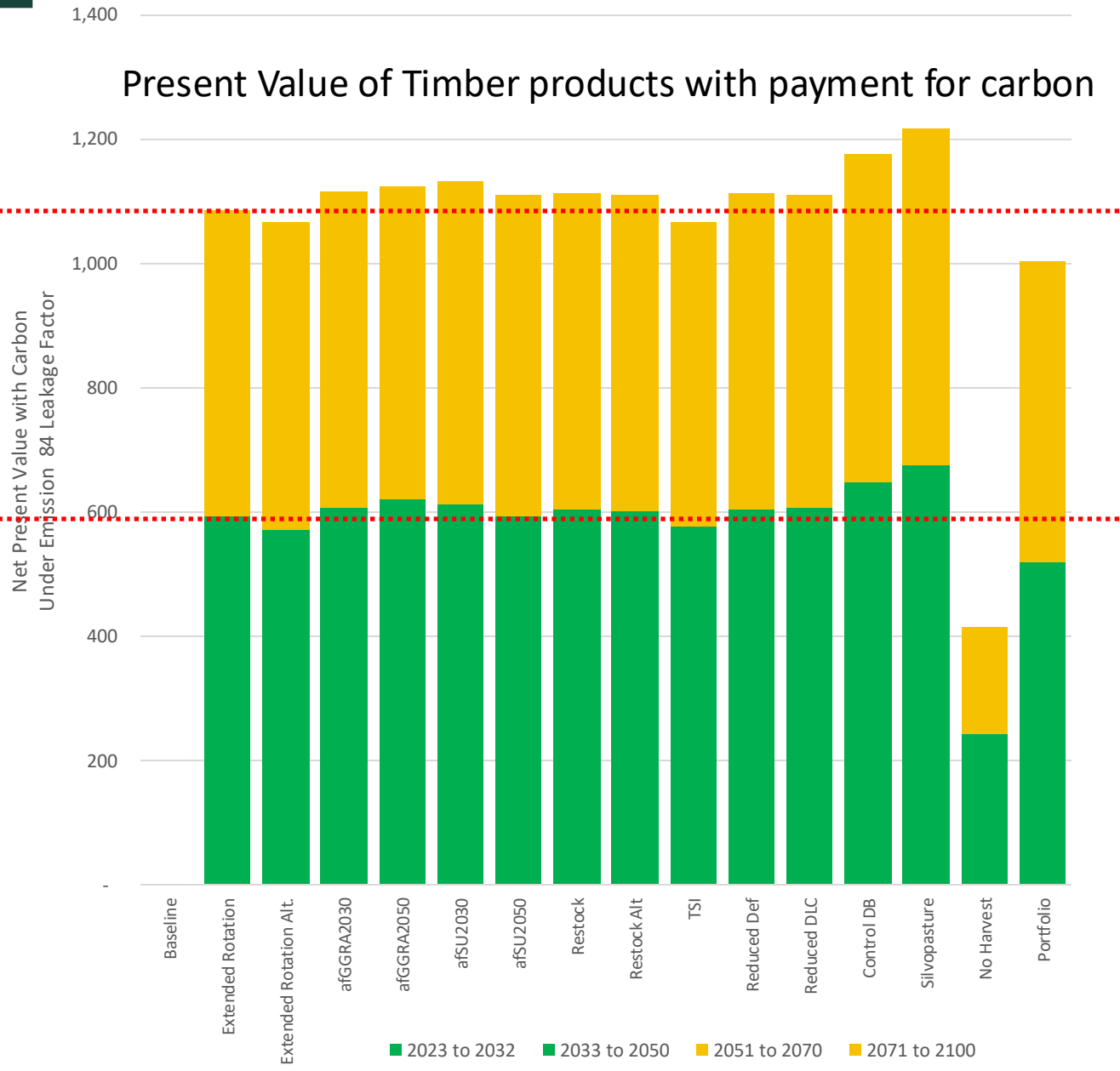




Maryland : NPV

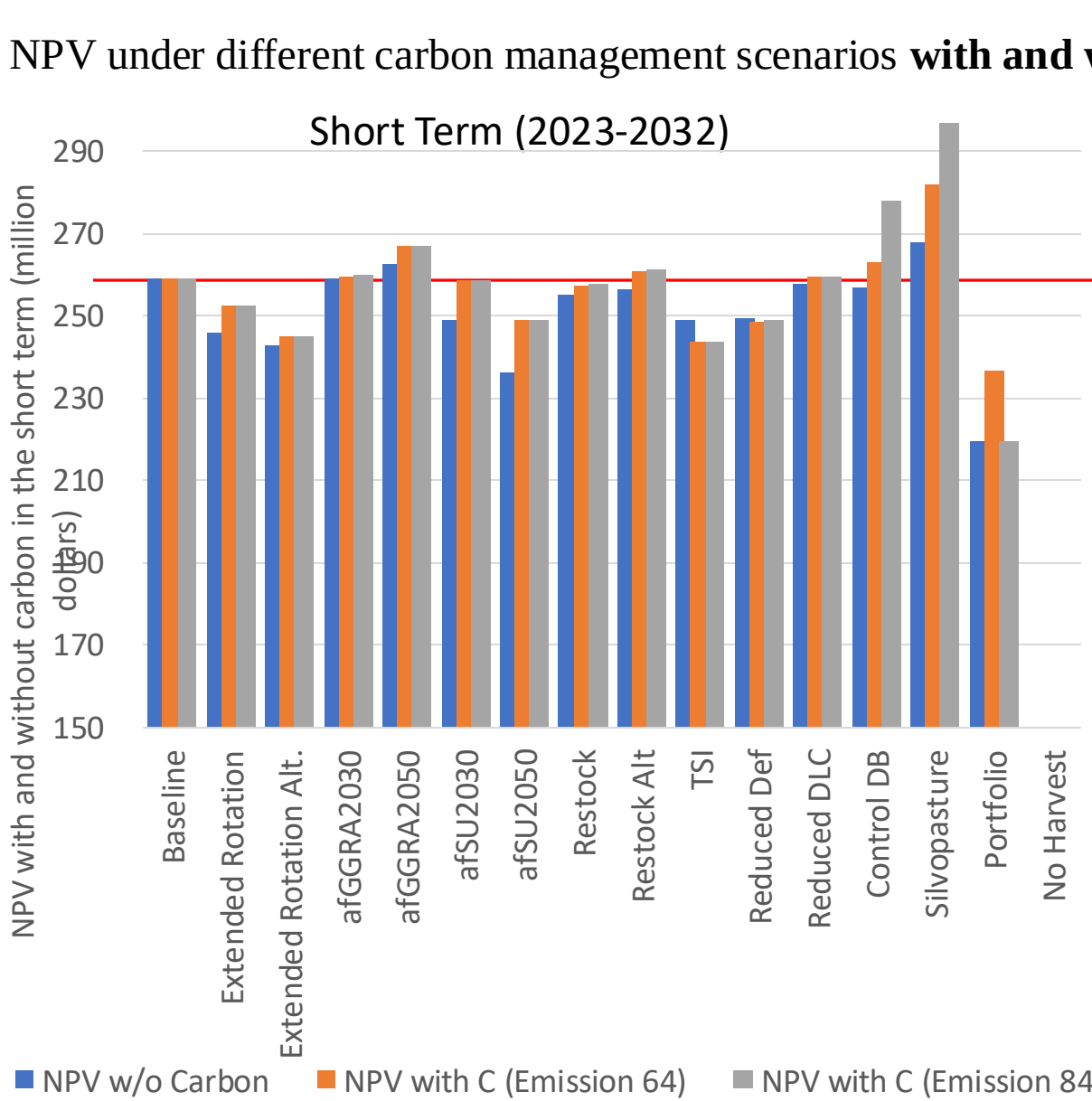
Present Value of Timber products

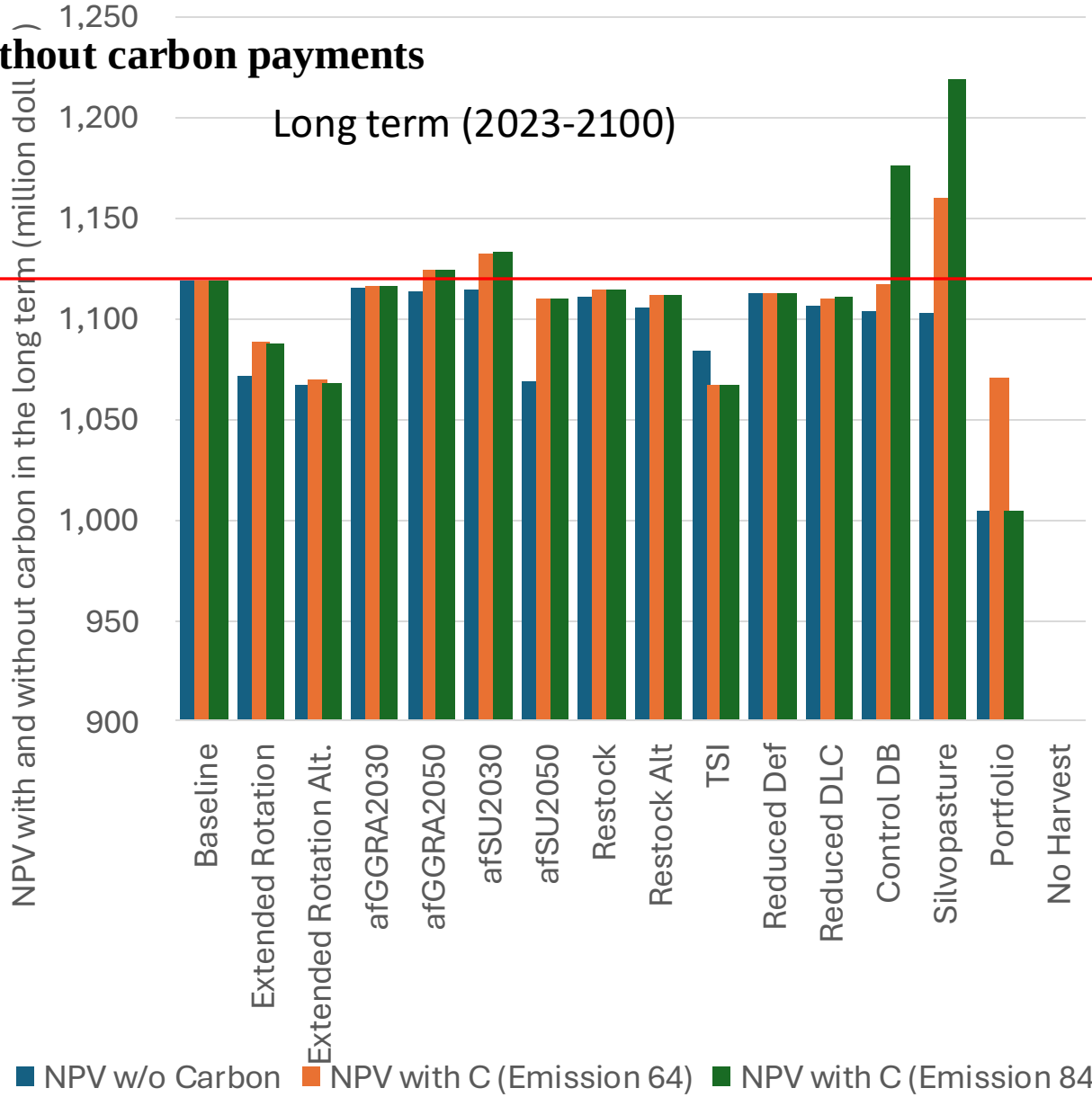
Present Value of Timber products with payment for carbon



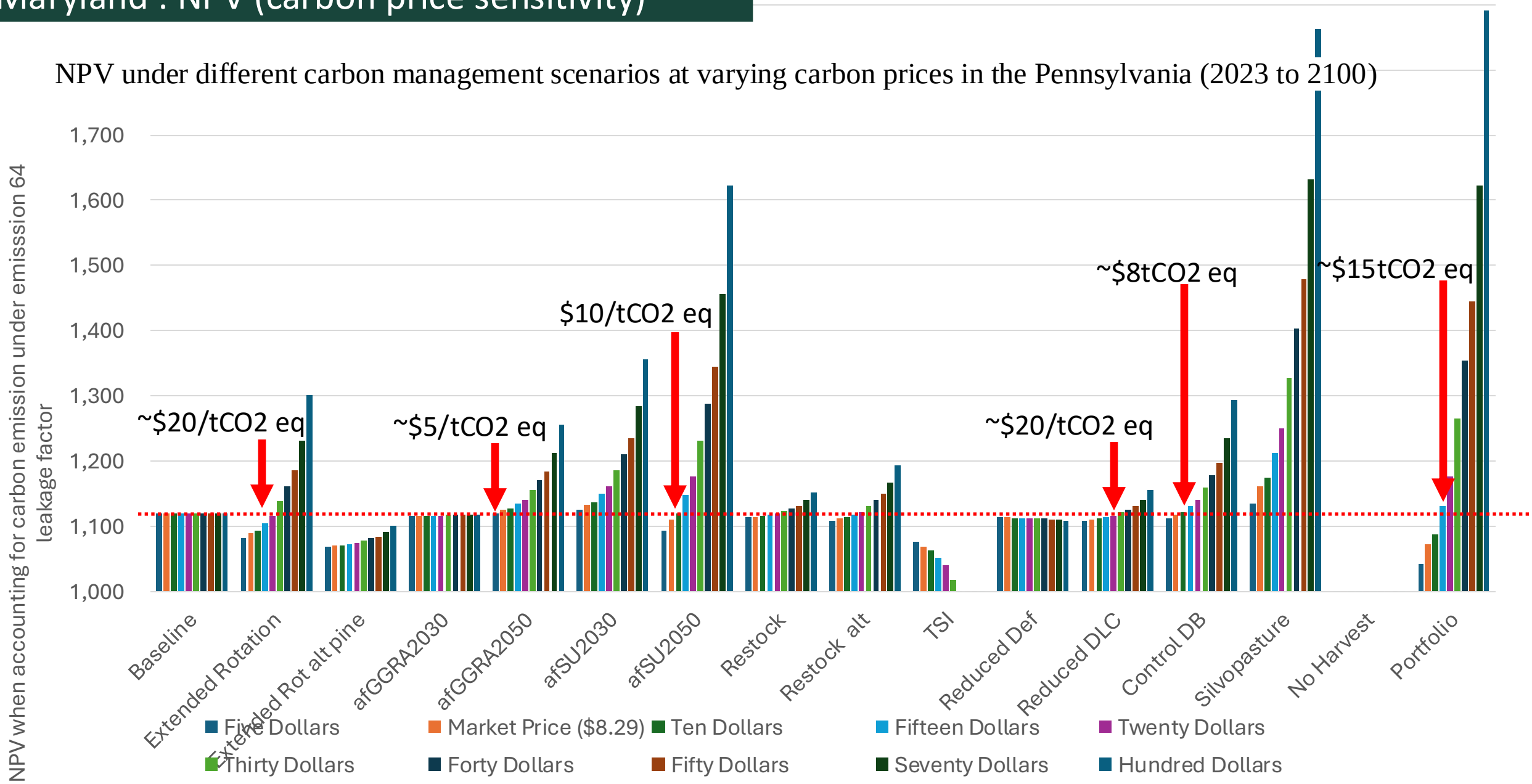
Maryland: NPV

NPV under different carbon management scenarios **with and without carbon payments**





Maryland : NPV (carbon price sensitivity)



Thank you !

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