Economic Tradeoffs in Timber Products Under Various Carbon Management Strategies for Maryland

Submitted to
Penn Soil Resource Conservation and Development Council,
Pennsylvania, USA

Prepared for
Maryland Department of Natural Resources
Annapolis, Maryland

Prepared by
Raju Pokharel, Shivan Gc, Chad Papa, and Kylie Clay
Michigan State University

Department of Forestry
MICHIGAN STATE UNIVERSITY

August 2024

Acknowledgement:

Penn Soil Resource Conservation and Development Council, Pennsylvania, USA
USDA Forest Service
Northern Institute of Applied Climate Science (NIACS), USDA Forest Service
Maryland Department of Natural Resources, Annapolis, Maryland
Forest Carbon and Climate Program, Department of Forestry, Michigan State University

Table of Contents

List of Tables

List of Figures

Background

Forests play an important role in climate change as they sequester carbon from the atmosphere and store it in different repositories, also known as carbon pools. These include forest ecosystem pools such as the above and below ground biomass, deadwood, litter, and soils. Forests also release sequestered carbon back into the atmosphere through processes such as respiration, combustion, and decomposition. Carbon sequestered in the forests can leave the forest ecosystem through timber harvests and enter the products pool. So long as the harvested wood product is in use, the carbon accrued in such products remains stored. It eventually returns to the atmosphere upon products disposal and decomposition, which could take a significant amount of time (several decades or more) depending upon the type of product generated.

Forests can act as a sink or source of carbon depending upon the relationship between carbon accumulation and loss. In the Unites States, the forests have been a net carbon sink since 1990s (Hoover and Riddle 2022). The U.S. Forest inventory data of 2020 shows that America's forests sequestered 767 million metric tons of CO_2 equivalent which represents an offset of approximately 13% of the gross greenhouse gas emissions in the country the same year (Hoover and Riddle 2022).

Growing recognition of the role that forests play in mitigating the effects of climate change has spurred interest among policy makers, federal and state government agencies, and academia alike in exploring and understanding how carbon benefits from forests can be bolstered in the future. Though carbon capture in forests is a natural phenomenon, forest management practices can alter the ways that forests sequester carbon. Also, changing climatic conditions can compound forests' vulnerability to natural disturbances imposed by invasive insects and diseases, droughts and wildfires and affect the area of forests and forest's capacity to sequester and store carbon in the future. Given this, timely and appropriate forest carbon management interventions could be crucial for building forests' resilience and enhance forests capacity to adapt to novel conditions and promote long-term carbon storage. Federal and state government agencies are in a unique position to promote climate benefits from forests as they can influence management practices in forests under their jurisdiction and those owned by other ownerships through technical and financial assistance. Many states provide incentives in the form of tax breaks, cost share programs and technical assistance to private forest landowners for promoting sustainable management of their forests. With increasing recognition of the role that forests play in combating climate change, the states are further looking for ways of promoting forest management practices to sequester more carbon in the future. Federal government agencies are also exploring avenues to support climate benefits from agriculture and forestry sectors through initiatives such as the United States Department of Agriculture's climate smart agriculture and forestry strategy. For government agencies to be proactive in supporting, advocating for, and implementing climate smart forest management strategies, they need accurate and updated information about the role that different carbon management strategies have on emissions level at present and in the future. Additionally, information about the impacts that forest carbon management strategies can have on forests health and other ecosystem services that forests provide in the long run is equally important.

The management interventions focused on promoting carbon benefits from the forests can have varying effects on other ecosystem services that forests generate. For instance, a potential approach to increase carbon stock in a forest could be to increase the average rotation age of a forest stand. By doing so, the trees are allowed to stand in the forest for a longer duration thus resulting in larger sized trees which store more carbon. In addition to storing more carbon in the form of mature trees, other positive effects of this management approach could be that larger trees generate high value products which has a longer life or are more likely to be used for products that stays intact for longer duration. Mature forest stands can also offer better habitat conditions for plants and animals that favor such an environment. However, it is equally important to understand the long-term effect of such management practice on forests' health and its ability to sequester carbon in the long run. Other approaches to increase carbon storage in a forest could be to reforest abandoned lands, restock poorly stoked forests, and carry out timber stand improvement practices to promote forest growth to name a few. Irrespective of the management strategy adopted, it is important to understand the long-term effect of such strategies on forests health, its vitality, the capacity to sequester carbon along with the impact that such strategies have on myriad ecosystem services that forests provide. An effective forest carbon management must balance the different objectives of landowners and managers and account for the complex ecological processes that drive forest dynamics to optimize carbon stores over the long term. Additionally, for any management strategy to come to fruition, there are likely to be costs associated with designing and implementing it. Therefore, to make a meaningful carbon management decision, an assessment of benefits versus costs of different management strategies is also needed. Forest carbon is beginning to have an economic value in the marketplace alongside traditional timber products. However, several economic hurdles lie in the way of the implementation of forest carbon management. Forest carbon management practices often require landowner investment while providing limited economic returns, especially in relation to alternative practices aimed at generating timber revenues. An analysis of the financial implications of the scenarios involving land managers' goals and the complex ecological process is needed to understand the economic feasibility of forest carbon programs.

State government agencies in Pennsylvania and Maryland recently contracted with the researchers at Michigan State University Forest Carbon and Climate Program (MSU FCCP) to understand the impact that existing forests and forest management practices in each state have on emissions level at present and the impact of such practices on forests health and climate benefits in the future. Additionally, the project modeled a broad range of forward-looking forest carbon management scenarios using the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS) parameterized for conditions in Pennsylvania and Maryland to assess how such scenarios would perform in terms of carbon sequestration in the forests. Besides, the project also used customized lifecycle harvested wood products model (HWP) built using Abstract Network Simulation Engine (ANSE) framework and utilized displacement factors to evaluate substitution benefits from using wood products and bioenergy in place of more emission-intensive materials. The purpose of that project was to guide Pennsylvania and Maryland in making informed decisions for optimizing forest management for both carbon sequestration and economic benefits and to encourage the inclusion of forests and forest products sector in state level climate action planning. Following the findings obtained from this project, Penn Soil RC&D contracted with the researchers at MSU to further look at the economic tradeoffs of the modeled forest management actions resulting from the earlier project and inform what it means for the forestry sector in each state. The specific objectives of the current project are to:

1. To convert carbon outputs (metric tonnes) resulting from the CBM-CFS models into timber product outputs (bd.ft. and cu.ft.) and

2. To quantify the 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.

Proposed management scenarios for financial tradeoffs assessment include:

- Business-as-usual (BAU)
- Extending rotations
- Increasing afforestation (four scenarios)
- Increasing restocking of understocked stands
- Increasing timber stand improvement (TSI)
- Maintaining forest land base (no forest loss)
- Reduced diameter limit harvesting
- Controlling deer browse
- Silvopasture from land other than forests.
- No harvesting activities
- Portfolio

In general, this study conducts a comparative analysis of various modeled scenarios (change in management activities and land use) with BAU scenario using the net present value (NPV) approach. To achieve the outlined objectives, following activities were conducted in order:

1. A remote meeting was held with Penn Soil and state representatives to discuss the project, expectations from the project, and procedures to be adopted for accomplishing the project.
2. Following this, a remote meeting was conducted with project partners to discuss CBM-CFS3 modeling to understand modeled scenarios and results that would be relevant for use in financial tradeoff analysis.
3. Multiple meetings (remote and in-person) were held with MSU FCCP team members to discuss steps for linking timber products to carbon outputs.
4. Multiple remote meetings were held with project partners in both states and a thorough review of relevant literature was conducted to discuss costs, revenues, and carbon prices to be used for economic analysis.

5. Once the financial tradeoff analysis was conducted in excel spreadsheet, a remote meeting was held with project partners to review the initial findings and to provide feedback on the outcomes obtained.
6. Draft reports were then prepared for each state and shared with the project partners for further review and feedback.

The next section of this report outlines the scenarios used for economic tradeoff analysis in detail, discusses the data and methods employed for economic analysis, and presents the findings obtained.

This report focuses on the scenarios used and economic tradeoff analysis conducted for Maryland. A comparable report has been prepared for Pennsylvania.

Description of scenarios modeled in Maryland

Table 1. shows baseline parameters for business as usual (BAU) scenario and Table 2 lists parameters for alternative management scenarios considered for the economic analysis in Maryland.

Table 1. Maryland BAU baseline parameters. All carbon measurements are in metric tons (tC)

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})

Table 2. Alternative management scenario parameters for Maryland. All carbon measurements are in metric tons (tC).

Scenario	Description	Parameter value	Parameter value change
Altered rotations	Increased / decrease in the average harvest age of stands	Minimum age of allowable harvest	+ 30 years on all hardwoods until 2100 +20 years on loblolly pines until 2100
Altered rotations alt.	Increase/decrease in the average harvest age of stands	Minimum age of allowable harvest	+ 30 years on all hardwoods until 2100 +40 years on loblolly pines until 2100
afGGRA2030	Increase in the annual rate of afforestation until 2030	Annual afforestation rate (area)	+ 142 ha yr^{-1} until 2030
afGGRA2050	Increase in the annual rate of afforestation until 2050	Annual afforestation rate (area)	+142 ha yr^{-1} until 2050
afSU2030	Increase in the annual rate of afforestation until 2030	Annual afforestation rate (area)	+ 1416 ha yr^{-1} until 2030
afSU2050	Increase in the annual rate of afforestation until 2050	Annual afforestation rate (area)	+ 1416 ha yr^{-1} until 2050
Restocking	Increase annual rate of stands being restocked through active planting until 2030	Annual supplemental or under planting rate (area)	+ 410 ha yr^{-1} until 2030
Restocking alt.	Increased annual rate of stands being restocked through active planting until 2050	Annual supplemental or under planting rate (area)	+ 410 ha yr^{-1} until 2050
Timber stand improvement	Increase in the annual rate of commercial thinning and prescribed burns	Annual thinning rate (area) Annual prescribed burning rate (area)	+ 2226 ha yr^{-1} until 2100 + 202 ha yr^{-1} until 2100
Reduced deforestation	Decrease in the annual rate of deforestation	Annual deforestation rate (area)	- 324 ha yr^{-1} until 2030
Reduced diameter-limit-cuts (DLCs)	Decrease in the annual rate of diameter limit cuts (DLCs) until zero acres (i.e., high-grading)	Annual rate of diameter-limit-cuts (area)	- 10 % of DLCs yr^{-1} until area equals zero

Control DB	Increase in the annual rate of fencing to control deer browse	Annual rate of deer browse control (area)	+ 809 ha yr^{-1} until 2100
Silvopasture	Increase in the rate of silvopasture adoption on pastureland	Annual rate of adoption (area)	+ 1261 ha yr^{-1} until 2100
No harvest activities†	Complete reduction in all harvesting activities	Annual harvest rate of volumetric removals	- 100 % harvests until 2100
Portfolio	Ensemble of multiple scenarios	Rotation age of allowable harvest Annual afforestation rate Annual deforestation rate Annual restocking rate Annual rate of timber stand improvement treatments Annual DLC rate Annual silvopasture rate Annual deer browse control rate	+ 30 years on all hardwoods until 2100 +20 years on loblolly pines until 2100 +142 ha yr^{-1} until 2050 - 324 ha yr^{-1} until 2030 + 410 ha yr^{-1} until 2050 + 2226 ha yr^{-1} thinned until 2100 + 202 ha yr^{-1} prescribed burn until 2100 - 10 % of DLCs yr^{-1} until area equals zero + 1261 ha yr^{-1} until 2100 + 809 ha yr^{-1} until 2100

*Alternative pine rotation length and restocking 2050 were not run for Pennsylvania
†This scenario results in some level of carbon being transferred to the HWP sector from land-use change

Data and Methods Employed

Estimation of timber products generated under BAU and alternative scenarios modeled

The first objective of this project was to convert carbon outputs (metric tonnes) from the CBM-CFS models into timber product outputs (bd.ft. and cu.ft). For this, we worked with MSU FCCP team to obtain the results from the HWP model in volume format. Carbon outputs from HWP model were converted into volume estimates by MSU FCCP team using the following equation:

$$Volume = \frac{(Carbon*2)}{Specific\ Gravity} \tag{1}$$

State-specific weighted specific gravities were used for conversion of softwood/hardwood component of forest types in each state. For Maryland, the weighted specific gravity estimated was 0.5075104 for softwoods and 0.51647761 for hardwoods. Fraction of the product that is wood fiber was obtained using the relationship provided by Smith et. al. (2006). The total resulting volume harvested was obtained from MSU FCCP team in excel spreadsheet under nineteen different product categories (as shown in Table 3) broken down by hardwood and softwood species group. Harvested volumes were reported for each year starting 2008 to 2100. Out of the nineteen product categories in which the volume harvested were reported in, six categories representing roundwood, sawnwood, and veneer were combined to form a logs category with volumes presented in Mbf (Thousand board feet) for financial analysis. Likewise, six categories representing pulp products were combined into a single pulpwood category with volume presented in tons for financial analysis. Four categories representing composite panels were combined with other industrial to form a composite panel category with volume presented in MCF (Thousand cubic feet) which was then converted into tons using a conversion factor of 0.0329193 MCF per ton as per Winn et al. (2020). Bioenergy data was used as obtained for financial analysis and the volume is presented in tons. Poles, posts, and piling data was also included as obtained for financial analysis and the volume is presented in Mbf (thousand board feet). The resulting timber product outputs for each CBM-CFS management scenarios are reported for four different time periods: short-term (calendar year 2023 to 2032), medium term (2023 to 2050), medium-long term (2023 to 2070) and long term (2023 to 2100).

Table 3. Conversion factors employed for converting carbon obtained from HWP model in different product stream categories into volume estimates in Maryland.

		Carbon Conversion Factor Calculations					Conversion Factors[4]	
Product	Unit	Cubic ft/unit	lbs/cubic foot[1]	lbs/unit[2]	% fiber[3]	lbs to tonne	C	V
Softwood								
Sawlogs	MBF	83.33333	31.66865	2639.054	1	0.000454	0.599065	1.669267
Veneer logs	MBF	--	--	--	--	--	--	--
Pulpwood	tons	--	--	2000	1	0.000454	0.454	2.202643
Composite Panels	MCF	1000	31.66865	31668.65	0.95	0.000454	6.829344	0.146427
Fuelwood	tons	--	--	2000	1	0.000454	0.454	2.202643
Posts, Poles, pilings	MBF	83.33333	31.66865	2639.054	1	0.000454	0.599065	1.669267
Other Industrial	MCF	1000	31.66865	31668.65	1	0.000454	7.188783	0.139106
Hardwood								
Sawlogs	MBF	83.33333	32.2282	2685.684	1	0.000454	0.60965	1.640285
Veneer logs	MBF	83.33333	32.2282	2685.684	0.96	0.000454	0.585264	1.70863
Pulpwood	tons	--	--	2000	1	0.000454	0.454	2.202643
Composite Panels	MCF	1000	32.2282	32228.2	0.96	0.000454	7.02317	0.142386
Fuelwood	tons	--	--	2000	1	0.000454	0.454	2.202643
Posts, Poles, pilings	MBF	--	--	--	--	--	--	--
Other Industrial	MCF	--	--	--	--	--	--	--

1. Pounds per cubic feet = specific gravity*62.4
2. For MBF and MCF units, this is the multiplication of the previous two columns (i.e., cubic ft/unit*lbs/cubic feet); for tons, this is simply 2000.
3. % from GTR 343 table D1; % for softwood and hardwood plywood used for 'composite panels'; assuming fuelwood and pulpwood are 100% fiber (not in GTR 343)
4. Conversion factor product units are product-specific (defined in column 2); carbon is in metric tons (tonnes)

Method employed for estimating economic tradeoffs of carbon and timber products

The next objective was to quantify the financial tradeoffs of carbon and timber products resulting from the alternative management scenarios compared to the BAU scenario modeled using CBM-CFS and HWPs model. For this, we first estimated the net present value of each forest carbon management scenario at four different time periods (short term (2023 to 2032), medium term (2023 to 2050), medium-long term (2023 to 2070), and long term (2023 to 2100) including the BAU. Then the NPV of each alternative forest carbon management scenario was compared with that of BAU to assess the economic tradeoffs.

The Net Present Value (NPV) is the difference between the present value of all revenues and costs associated with a particular forest management scenario (Bullard and Straka, 1998). It is also referred to as net benefit. In our case, revenues include income generated through the sale of timber products harvested as well as carbon credits generated under each forest carbon management scenario and costs include all costs associated with the implementation of that scenario including land rent. Land rent is the opportunity costs of using the land in forestry rather than for other alternative uses.

NPV is a useful financial tool to measure the economic feasibility of carbon management and can assist in informed decision making on policy interventions. Equations 2 presents the basic formulation of NPV.

$$NPV = \sum \frac{R}{(1+i)^t} - \sum \frac{C}{(1+i)^t} \quad (2)$$

where, *R* is the revenue generated from the harvested wood products and/or carbon credits under each forest management scenario for the specified duration (short, medium, medium-long and long term). *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.

Land rent can be estimated by multiplying the land expectation value (LEV) with the discount rate. LEV is the present value of all future net revenues from the land under perpetual forestry and can be estimated using the following formula:

$$LEV = \frac{NR}{(1+r)^{T}-1} \tag{3}$$

where, *NR* is the net revenue at the end of a specified period, r is the discount rate and T is the rotation period or time until harvest. For estimating LEV, the rotation period of hardwood stands in Maryland was chosen to be 80 years and that of softwoods stands was chosen to be 60 years after consultation with the project team.

Revenue estimation

For BAU scenario, revenues were estimated for harvested wood products (logs, pulp products, composite panels, bioenergy, and poles/posts/pilings) by multiplying per unit stumpage price of the harvested wood product by the volume of that product harvested during a given year. For alternative management scenarios, revenues were estimated with and without taking into consideration the carbon emissions associated with these scenarios.

Carbon emissions associated with each management scenario were estimated using emission 64 and emission 84 leakage factors. Carbon emissions were converted into carbon credits by multiplying emissions by per unit carbon price. For a given year, if more carbon was sequestered under an alternative management scenario compared to BAU, then the revenue generated from harvested wood products including carbon for that year would be higher than that estimated without taking into account carbon emissions.

Stumpage price information for different wood products harvested in Maryland was obtained from Maryland Department of Natural Resources (DNR). Average stumpage price of logs and pulpwood from 2010 to 2021 by species groups was obtained from Maryland DNR and used as a baseline price for calendar year 2022. Table 4. lists the stumpage price information for different wood products by hardwood and softwood species group used for financial analysis in Maryland. For 2022, the stumpage price of hardwood logs in Maryland was estimated to be $270/Mbf. For hardwood pulpwood, composite panels, and bioenergy, the stumpage price was estimated to be $3/ton and $270/Mbf for hardwood poles, posts, pilings. Stumpage price of softwood logs was estimated to be $156/Mbf. Price of softwood pulpwood, composite panels, and bioenergy was estimated to be $4/ton and the stumpage price of softwood poles, posts and pilings was estimated to be $156/Mbf for 2022.

Though the stumpage price of poles, posts, and pilings are usually higher than that of logs in different parts of the country (Dickmann et al. 1997, Dickens et al. 2021), we chose to use the same stumpage price for logs and poles, posts, and pilings as it better represents the existing market practice in Maryland according to the project partners. For financial analysis, starting year 2023, stumpage prices were increased by 3% every year for hardwood species and 1% per year for softwood species till 2032 and 2.5% starting 2033. Increase in the price of hardwood follows the trend noted in the neighboring state of PA from year 2007 to 2017 as per Jacobson (2022). However, modifications were made to the price trend of softwood species in Maryland to better reflect market situation in Maryland for softwood species after discussion with the project partners.

Table 4. Average stumpage price of different wood products in Maryland from 2010 to 2021 by hardwood and softwood species group (Source: Maryland DNR).

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

To estimate revenue from carbon credits, market price of carbon for year 2022 was obtained from live carbon prices today, accessed online from a digital platform of nature-based carbon offset price maintained by carboncredits.com. For 2022, price per ton of CO_2 equivalent was $8.29 dollars (as accessed in Oct 6,2022). We deducted the transaction cost of carbon from its market price to get the price of carbon that was used for financial analysis. Transaction cost of carbon was estimated using the formula proposed by Pearson et al. (2013). According to the authors, transaction cost of carbon can be estimated using the following equation:

$TC = 1 + 0.23 * P^c$

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. For our analysis, the carbon price was assumed to increase by 2% every year starting 2023.

Additionally, sensitivity analysis was done with varying carbon prices ranging from $5/ton of CO_2 equivalent to $100/ton of CO_2 equivalent.

Cost estimation

Costs include expenses associated with implementing different forest management prescriptions outlined in the business-as-usual scenario and those associated with the modeled scenarios (Tables 1 and 2). Details of forest management practices carried out every year starting year 2008 to 2100 under each scenario were obtained from MSU FCCP team. This included information about the type of forest management practice undertaken each year and the acres the management practice was undertaken in. Per unit cost of each management practice was multiplied with the area of forest acres that underwent such practice to get the costs associated with implementing different management practices under various scenarios for financial analysis. Forest management practices included in case of BAU scenario are clearcut, group cut, high grade, seed tree, and shelterwood harvest along with thinning and prescribed burn treatments. For our analysis, we used the costs associated with carrying out thinning operations, prescribed fire treatment and site preparation as well as regeneration cost in clearcut areas under baseline BAU scenario. Costs associated with timber harvesting operations were not included in the analysis as these are assumed to be accounted for in the stumpage price of products harvested. Similar costs as those used in BAU scenario were incorporated in extended rotation scenario. For afforestation scenario, in addition to the costs used in business-as-usual scenario, afforestation costs were included. Likewise, for restocking scenario, costs associated with restocking the forest were added to the business-as-usual costs. For timber stand improvement, reduced deforestation and reduced diameter limit cut scenarios, again, similar costs as baseline scenario were included. In case of controlled deer browse scenario, additional cost of fencing to control for deer browse was included and for silvopasture scenario, silvopasture planting cost was included in addition to other costs as in business-as-usual scenario. In no harvest scenario, only the costs associated with prescribed burning was included.

Cost information about forest management practices in Maryland needed for financial analysis was obtained from the Environmental Quality Incentives Program's (EQIP) payment schedule for Maryland 2022 and is listed in Table 5. For clearcut area, we included site preparation cost of $200.85/acre and forest establishment cost of $797.73/acre for hardwood species group and $380.97/acre for softwood species group. Site preparation cost comes from-tree/shrub site preparation cost (EQIP Code 490) under Maryland EQIP payment schedule 2022. We estimated an average of hand site prep and mechanical heavy. Forest establishment cost comes from tree/shrub establishment (Code 612) under MD EQIP 2022. For hardwoods, we used tree/shrub regeneration area with protection cost ($797.73/acre) and for softwoods, we used costs for medium density conifer planting ($380.97/acre). Thinning costs come from forest stand improvement (Code 666) under MD EQIP 2022. The cost included was for thinning hand tools with a consultant ($317.98/acre). Cost for prescribed burning comes from prescribed burning (Code 338) under MD EQIP 2022. The cost included was for understory burn ($68.18/acre).

For afforestation cost in Maryland, we estimated the weighted average price of forest establishment cost for hardwood species group ($696.02/acre) and used that as a proxy for afforestation cost since 87.25% of the area afforested in the state is in hardwood forest type group. Medium density conifer planting ($380.97/acre) was used for estimating the restocking cost in MD since 89% of the restocking area in Maryland is in softwood species group. Fencing cost for control deer browse for year 2022 was estimated to be $393/acre. This is the cost required for fencing with woven wire at a cost of $3.33/linear feet (Obtained from MD EQIP Code 382) assuming 5,903 linear feet of fence is required for fencing 50 acres of forest area as per (Jacobson 2007). The cost of establishing trees under silvopasture scenario was $127.63/acre for 2022 obtained from MD EQIP Code 381.

Starting year 2023, all forest management practices costs were increased by 1.69% per year to account for inflation. The percentage chosen to account for inflation is based upon the average annual inflation rate estimated between the calendar years 2007 to 2017.

Table 5. Forest management practices costs in Maryland (Source: Environmental Quality Incentives Program's (EQIP) payment schedule for Maryland 2022).

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 (Average of hand site prep and mechanical heavy)
Stand establishment cost in clearcut areas	612	$797.73/acre for hardwood species and $380.97/acre for softwood species
Afforestation cost	612	$696.02/acre
Restocking cost	612	$380.97/acre
Fencing cost	382	$393/acre
Silvopasture planting cost	381	$128/acre

Results and Discussion

Area and volume harvested under different scenarios

The first objective of this project was to quantify the volume of timber products resulting from the HWPs model under business as usual and alternative carbon management scenarios. But before moving on to the estimate of area and volume harvested under each forest management scenario, it should be noted that the total forest area projected by CBM-CFS models under BAU and all the alternative carbon management scenarios increased from 2023 to 2100 (Appendix A). The highest increase in projected forest area was estimated under portfolio scenario, followed by silvopasture, and both cases of scaled up afforestation scenarios.

The total forest area harvested each year under BAU and alternative carbon management scenarios from 2023 to 2100 and volume harvested each year under the same scenarios are listed in Appendix B and C respectively. The total forest area harvested per year under extended rotation scenario was lower than that of BAU scenario for the first few years, exceeded the area harvested under BAU scenario from 2031 to 2042, trailed close to it for the next two decades, and was mostly below BAU scenario for the rest of the time frame considered. Volume harvested under extended rotation scenario was slightly lower than that of BAU scenario for the most part except for the timeframe between 2083 and 2092 when the volume harvested under extended rotation slightly exceeded that of BAU scenario. Area and volume harvested under extended rotation alternative scenario were mostly below that of BAU scenario except for the decade between early 2080s and 2090s where volume harvested under extended rotation alternative scenario was more than that of BAU scenario. Since both cases of extended rotation scenarios push back the rotation age of hardwood stands in Maryland by 30 years and softwood stands by 20 and 40 years respectively, it seems logical to see lower volume harvested under extended rotation scenarios compared to BAU scenario in the initial years. However, with the increase in time, forest stands are expected to grow and accrue more biomass which could be available for harvest by the time they reach the new rotation age. The growth of a forest stand depends upon myriad factors ranging from nutrient availability to physical site conditions and stand age. The growth rate of a young forest stand is much higher than that of a mature stand which is well represented by the sigmoid shaped growth curve of forest stands. Forest inventory and analysis data for Maryland shows that the forests in the state are dominated by mature stands, thus extending rotation age in such stands may not result in increased growth over time which could be available for harvest. This could be the reason for low harvest volume in extended rotation scenarios in the later years.

Area harvested each year under all four cases of afforestation scenarios were close to that of BAU scenario till 2075 after which slight variation in area harvested was observed till 2090 before resuming similar trends in the later years. Volume harvested under all four cases of afforestation scenarios were also close to that of BAU scenario for the most part with slightly more volume harvested under scaled up afforestation scenarios compared to BAU scenario in the last five years. Area harvested under both cases of restocking scenarios were also close to BAU scenario for the most part except for the window between 2076 to 2090. During that period, the area harvested under both cases of restocking scenarios were lower than that of BAU scenario for the first couple of years and exceeded it after that. Volume harvested under restocking scenarios were close to BAU scenario for the entire time frame considered. These findings suggest that intensive afforestation and restocking of understocked forest stands do not necessarily yield higher timber volume compared to the business-as-usual forest practices in Maryland.

Both the area and volume harvested under TSI scenario almost consistently exceeded that of BAU scenario for the entire duration considered except for a few years where volume harvested under BAU scenario slightly exceeded that of TSI scenario. This makes sense as area thinned increases under TSI scenario compared to BAU scenario, and due to forest management prescriptions implemented under TSI scenario, the growth of the remaining forest stand is likely to improve thus yielding more volume compared to BAU scenario.

Area harvested each year under reduced deforestation scenario was also close to that of BAU scenario for the most part except for a period between 2076 to 2090, where area harvested fluctuated before settling into a similar harvest level in the later years. There was not much difference in the annual volume harvested between reduced deforestation and BAU scenarios. Under reduced diameter limit cut scenario, the area harvested was close to that of BAU scenario for the first decade but exceeded after that except for a few years in between where area harvested under BAU scenario was more than that of reduced DLC scenario. Volume harvested under reduced DLC scenario slightly exceeded that of BAU scenario for the most part. Area and volume harvested each year under controlled deer browse scenario resembled that of BAU scenario throughout the timeframe considered. In case of Silvopasture scenario, annual area harvested trailed close to that of BAU scenario till 2075, was lower than BAU scenario for the next decade, exceeded it for the next five years and was slightly less than that under BAU scenario for majority of the remaining timeframe. The volume harvested under both scenarios were however close to each other for the entire duration considered. Area harvested under portfolio scenario was lower than that of BAU for the first few years and exceeded it for the remaining duration except between 2082 to 2085 when the area harvested under BAU exceeded that of portfolio scenario. Volume harvested under portfolio scenario was also less than that under BAU for the first several years, closely followed it until 2082, exceeded it for next decade and was slightly below BAU for most of the remaining period until 2100. Area and volume harvested under no harvest scenario were much less than that of BAU scenario as expected.

Of the timber products harvested each year under all scenarios in Maryland, the majority were pulpwood (68% on average), followed by logs (25%), composite panels (4%), bioenergy (2%), and pole, posts, and pilings (1%) respectively.

For financial analysis, we considered the total forest area and volume harvested under each management scenario for four different time frames, short term (starting from 2023 to 2032), medium term (starting from 2023 to 2050), medium-long term (starting from 2023 to 2070) and long term (starting from 2023 to 2100). The results obtained are presented in Figures 1 and 2 and Tables 6 and 7 respectively. Table 6 lists the total forest area harvested under different carbon management scenarios at four different timeframes and Figure 1 presents cumulative area harvested under different scenarios. Table 7 lists the total volume of wood products generated under different carbon management scenarios including BAU scenario and Figure 2 shows the cumulative volume harvested under all scenarios.

Under BAU scenario, 255 thousand acres of forest area was harvested in the short-term generating 19 million tons of timber volume in Maryland. In the medium term, the total forest area harvested under BAU scenario increased to reach 678 thousand acres with the volume production of 54 million tons. In the medium-long term, the total forest area harvested under BAU was 1.1 million acres with the volume production of 93 million tons and in the long term, the area harvested totaled 1.9 million acres with the volume production of 147 million tons.

In the short term, the total forest area harvested ranged from a high of 306 thousand acres in timber stand improvement scenario (20% higher than the area harvested in the BAU scenario) to a low of 71 thousand acres in no harvest scenario followed by 246 thousand acres under extended rotation alternative scenario (3.6% lower than the area harvested in BAU scenario for the same duration). Apart from timber stand improvement, portfolio, reduced diameter limit cut, silvopasture, afforestation 2030, controlled deer browse, restocking (both scenarios) and afforestation scale up 2030 had more forest area harvested compared to the BAU scenario in the short term (Table 6). In the medium term, the total forest area harvested was the highest for TSI at 813 thousand acres (~20% more than in BAU) followed by portfolio, reduced diameter limit cut, and extended rotation scenarios while the lowest area was harvested under no harvest scenario (188 thousand acres) followed by extended rotation alternative scenario (661 thousand acres, which is 2.5% lower than the BAU scenario for the same period). Compared to BAU scenario, less forest area was harvested under no harvest, extended rotation alternative, reduced deforestation, both cases of restocking scenarios, all afforestation scenarios, controlled deer browse, and silvopasture scenarios. In both the medium-long-term and the long-term time frames, the total forest area harvested were the highest for TSI scenario, followed by portfolio, and reduced diameter limit cut in the medium-long term and reduced diameter limit cut followed by portfolio in the long term. The lowest forest area was harvested under no harvest followed by extended rotation alternative scenarios in both the medium-long- and long-term timeframes (Table 6). In the medium long-term timeframe, compared to BAU scenario, lower forest area was harvested under no harvest, extended rotation alternative, both cases of restocking, reduced deforestation, afforestation 2050, afforestation scale up 2030, controlled deer browse and silvopasture scenarios. In the long term, no harvest, both cases of extended rotation, controlled deer browse and afforestation 2050 had less forest area harvested compared to BAU scenario for the same duration.

In terms of the volume harvested, in the short term, the highest volume was harvested under TSI scenario at 20.2 million tons (~5% more than that produced under BAU scenario) followed by silvopasture, scaled up afforestation till 2030, and controlled deer browse scenarios respectively (Table 7). Other scenarios that yielded higher volume compared to BAU in the short term include both cases of restocking and afforestation scenarios until 2030 and 2050. The lowest volume in the short term was harvested under no harvest scenario followed by extended rotation alternative scenario (17.5 million tons which is 9.4% less than that harvested under BAU scenario for the same duration), extended rotation and portfolio scenarios (Table 7). In the medium-term, the total volume harvested was again the highest for TSI scenario followed by controlled deer browse, reduced diameter limit cut and silvopasture respectively. Volume harvested under these four scenarios were higher than that harvested under BAU scenario in the medium term.

In both medium-long term and long-term time frames, the volume harvested was the highest under TSI scenario followed by reduced DLC. Other scenarios that yielded higher volume compared to BAU in the medium-long term included controlled deer browse, while in the long term included reduced DLC, scaleup afforestation until 2030, and alternative restocking scenarios. Irrespective of the time frame considered, the lowest volume was harvested under no harvest scenario followed by extended rotation alternative and extended rotation scenarios respectively (Table 7). The range in volume harvested under long term time frame spanned from 152 million tons to 57 million tons.

Table 6. Total forest area undergoing harvest (in thousand acres) under business-as-usual and alternative carbon management scenarios in Maryland at four different timeframes.

Scenarios	Harvested forest area (in thousand acres) at the specified time frame			
	2023 to 2032	2023 to 2050	2023 to 2070	2023 to 2100
Baseline	255	678	1,144	1,907
Extended Rotation	253	689	1,145	1,877
Extended Rotation Alt.	246	661	1,098	1,826
afGGRA2030	256	678	1,147	1,912
afGGRA2050	253	671	1,141	1,899
afSU2030	255	674	1,132	1,917
afSU2050	253	676	1,145	1,923
Restock	256	674	1,139	1,921
Restock Alt	255	670	1,132	1,918
TSI	306	813	1,397	2,309
Reduced Def	248	667	1,133	1,924
Reduced DLC	260	719	1,327	2,269
Control DB	256	674	1,142	1,894
Silvopasture	257	677	1,144	1,917
Portfolio	267	801	1,346	2,218
No Harvest	71	188	303	469

afGGRA2030 = Increasing afforestation (+350 acres/year till 2030)
afGGRA2050 = Increasing afforestation (+350 acres/year till 2050)
afSU2030 = Increasing afforestation scale up (+3500 acres/year till 2030)
afSU2050 = Increasing afforestation scale up (+3500 acres/year till 2050)

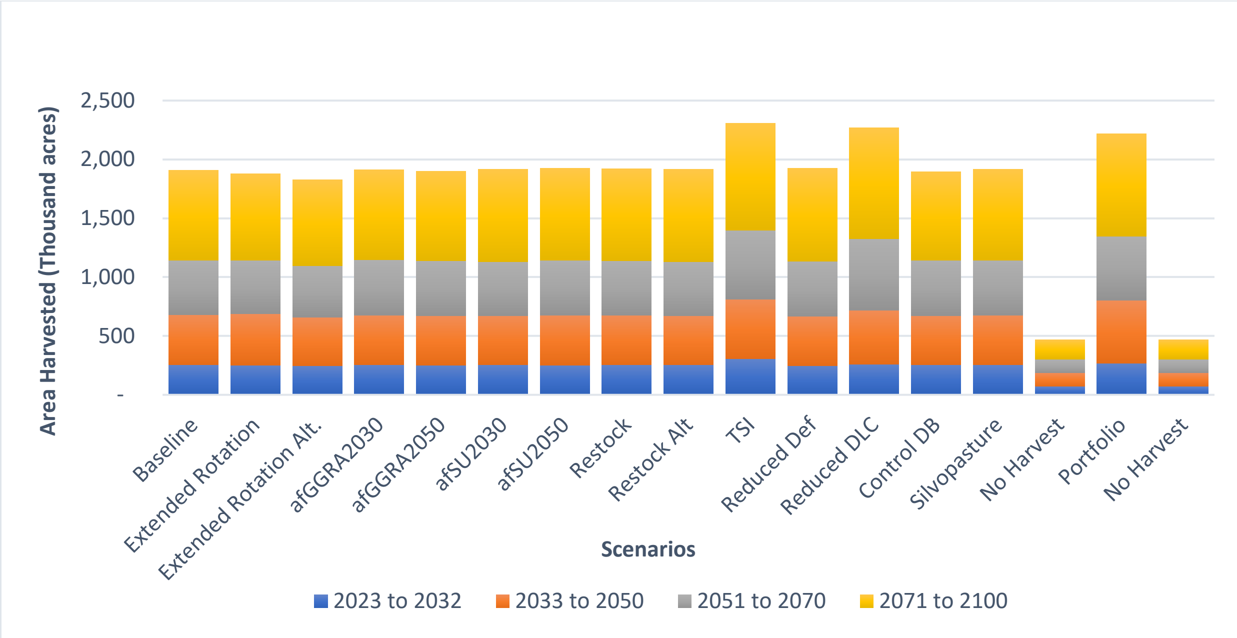


Figure 1. Cumulative area of forest undergoing harvest treatment under business-as-usual and alternative management scenarios in Maryland at four different time frames.

Table 7. Volume of timber products harvested (in Million tons-US) under business-as-usual and alternative carbon management scenarios in Maryland at four different time frames.

Scenarios	Harvested timber products (in million tons) at the specified time frame			
	2023 to 2032	2023 to 2050	2023 to 2070	2023 to 2100
Baseline	19	54	93	147
Extended Rotation	18	51	88	141
Extended Rotation Alt.	17	49	85	138
afGGRA2030	19	54	92	147
afGGRA2050	19	54	92	146
afSU2030	20	54	92	149
afSU2050	19	54	92	147
Restock	19	54	92	147
Restock Alt	19	54	92	147
TSI	20	57	96	152
Reduced Def	19	54	92	147
Reduced DLC	19	55	94	151
Control DB	19	55	93	147
Silvopasture	20	55	92	146
Portfolio	18	53	91	146
No Harvest	9	23	37	57

afGGRA2030 = Increasing afforestation (+350 acres/year till 2030)
afGGRA2050 = Increasing afforestation (+350 acres/year till 2050)
afSU2030 = Increasing afforestation scale up (+3500 acres/year till 2030)
afSU2050 = Increasing afforestation scale up (+3500 acres/year till 2050)

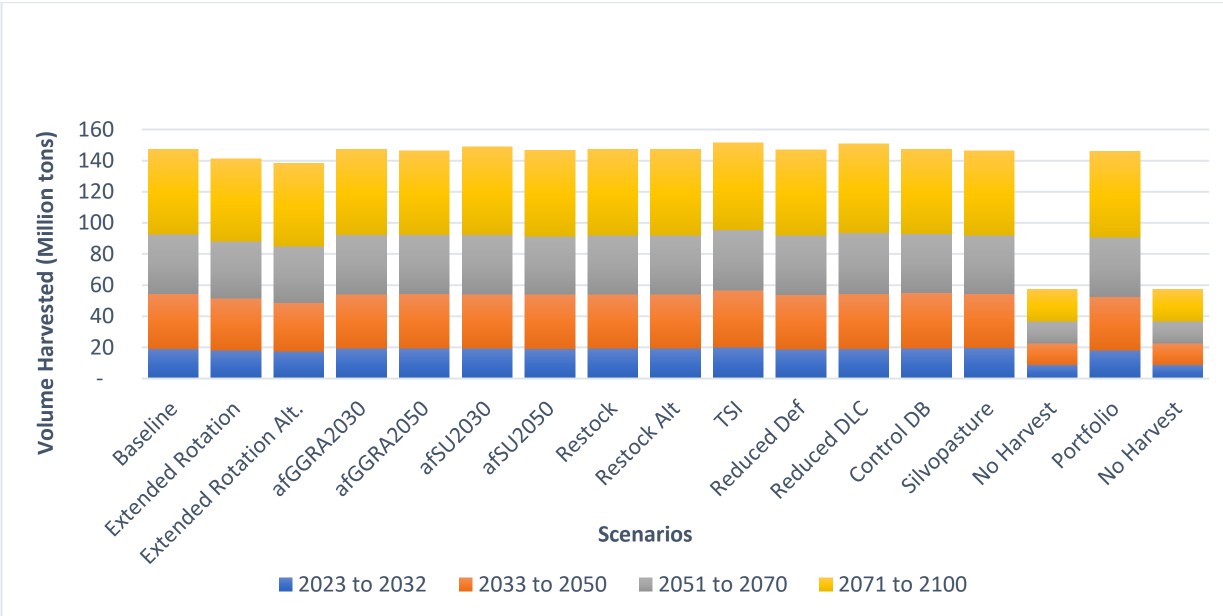


Figure 2. Cumulative volume of timber products harvested under business-as-usual and alternative management scenarios in Maryland at four different time frames.

Appendix D through G show the percentage change in volume harvested under alternative carbon management scenarios compared to BAU except for no harvest scenario for four timeframes considered. Compared to BAU scenario, the total volume of timber products harvested was consistently higher during all four timeframes considered under TSI scenario. For reduced diameter limit cut scenario, the total volume harvested was more than that under BAU for medium, medium-long term and long-term time frames but not so under short-term timeframe. Control deer browse scenario also yielded higher volume harvested compared to BAU under three out of the four-time frames (short, medium, and medium-long term). Compared to BAU, the total volume harvested was consistently lower in no harvest, both scenarios of extended rotation, scaled up afforestation until 2050, portfolio, and reduced deforestation in all four timeframes considered. Restocking understocked forest stands and afforestation scenarios did not consistently increase volume harvested compared to business-as-usual practices in Maryland. Instead, forest management practices such as timber stand improvement and reduced diameter limit cut scenarios seemed to generate more volume for harvest compared to BAU scenario in the state. Silvopasture scenario, though produced slightly more volume than BAU in the short- and medium-term timeframe, did not consistently produce higher volume in the medium-long term and long-term compared to BAU scenario in Maryland.

Financial tradeoffs of timber products harvested under alternative management scenarios compared to BAU without considering carbon emissions using NPV criteria

The second objective of this project was to quantify the financial tradeoffs of carbon and timber products resulting from the HWPs model under different carbon management scenarios compared to BAU. For this, we estimated the total revenue, and total costs associated with different carbon management scenarios including BAU as stated earlier. Next, for four different timeframes (short, medium, medium-long term and long term), we estimated the net present value obtained from forests in Maryland.

The NPV generated under all carbon management scenarios considered was positive meaning that the present value of revenues obtained under each scenario outweighed the costs incurred for implementing that scenario. Table 8 lists the NPV generated from forests in Maryland under different carbon management scenarios without considering the carbon emission associated with each management scenario. Figure 3 shows the cumulative NPV without considering carbon emission at four timeframes considered.

Table 8. Net present value estimated from Maryland's forests under different management scenarios including business-as-usual for four time periods without considering carbon emission.

Scenarios	Net Present Value (NPV) in million dollars			
	2023 to 2032	2023 to 2050	2023 to 2070	2023 to 2100
Baseline	259	613	881	1,119
Extended Rotation	246	575	836	1,072
Extended Rotation Alt.	243	568	831	1,067
afGGRA2030	259	607	876	1,116
afGGRA2050	262	612	878	1,114
afSU2030	249	598	866	1,115
afSU2050	236	563	827	1,069
Restock	255	602	870	1,111
Restock Alt	257	597	863	1,105
TSI	249	589	849	1,084
Reduced Def	249	605	873	1,113
Reduced DLC	258	606	864	1,107
Control DB	257	605	871	1,103
Silvopasture	268	608	869	1,103
Portfolio	219	520	773	1,005
No Harvest	111	263	374	472

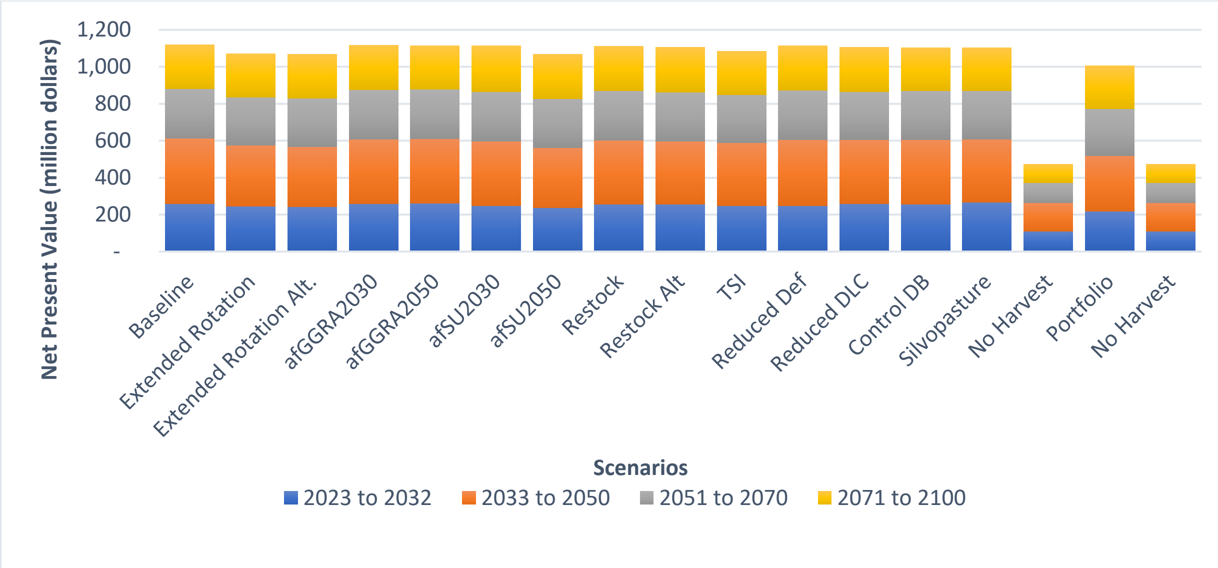


Figure 3. Cumulative net present value (without considering carbon benefits) estimated from Maryland's forests under various carbon management scenarios at four different timeframes.

The NPV generated under BAU scenario was $259 million in the short-term time frame (2023 to 2032). It increased to $613 million in the medium term (2023 to 2050), $881 million in the medium-long term (2023 to 2070) and $1,119 million in the long term (2023 to 2100). In the short-term, the NPV generated under alternative carbon management scenarios ranged from a high of $268 million under silvopasture to a low of $111 million under no harvest scenario. Apart from silvopasture scenario, other management scenarios that yielded higher NPV compared to baseline in the short term included afforestation until 2050 and 2030 respectively. All other alternative management scenarios yielded lower NPV compared to BAU in the short term. Though TSI, scaled up afforestation until 2030, controlled deer browse and both cases of restocking scenarios yielded higher volume in the short term compared to BAU scenario, the NPV generated under these scenarios were lower than that under BAU because of the higher costs associated with implementing these scenarios compared to BAU.

In the medium-term, medium-long term, and long-term, BAU scenario yielded the highest NPV compared to all other management scenarios. Though volume harvested in alternative management scenarios such as TSI, reduced DLC, controlled deer browse, silvopasture, scaled up afforestation until 2030 and alternative restocking scenarios were higher than that harvested under BAU scenario in the medium, medium long term and long-term time frames, the costs incurred were also higher compared to BAU and so these scenarios yielded lower NPV compared to BAU in Maryland. Irrespective of the timeframe considered, the lowest NPV was obtained under no harvest followed by portfolio scenario. Appendix H through K show percentage change in NPV under different carbon management scenarios compared to BAU without considering carbon emissions at four timeframes considered.

Financial tradeoffs of timber products harvested under alternative management scenarios compared to BAU while taking into consideration carbon emissions associated with each carbon management scenario.

Next, we re-estimated the NPV considering carbon emissions associated with each alternative carbon management scenarios under emission 64 (Table 9) and emission 84 (Table 10) leakage factors. Figures 4 and 5 show the cumulative NPV with carbon under emission 64 and emission 84 leakage factors at four timeframes considered.

Table 9. Net present value estimated from Maryland's forests under business-as-usual and alternative management scenarios while accounting for carbon emissions using emission 64 leakage factor.

Scenarios	Net Present Value (NPV) in million dollars			
	2023 to 2032	2023 to 2050	2023 to 2070	2023 to 2100
Baseline	$ 259	$ 613	$ 881	$ 1,119
Extended Rotation	$ 252	$ 593	$ 855	$ 1,088
Extended Rotation Alt.	$ 245	$ 573	$ 836	$ 1,070
afGGRA2030	$ 259	$ 608	$ 876	$ 1,116
afGGRA2050	$ 267	$ 620	$ 888	$ 1,124
afSU2030	$ 258	$ 612	$ 883	$ 1,133
afSU2050	$ 249	$ 594	$ 865	$ 1,110
Restock	$ 257	$ 604	$ 874	$ 1,114
Restock Alt	$ 261	$ 601	$ 869	$ 1,112
TSI	$ 244	$ 578	$ 834	$ 1,067
Reduced Def	$ 249	$ 604	$ 872	$ 1,113
Reduced DLC	$ 259	$ 606	$ 866	$ 1,110
Control DB	$ 263	$ 615	$ 885	$ 1,117
Silvopasture	$ 282	$ 641	$ 915	$ 1,160
Portfolio	$ 237	$ 565	$ 829	$ 1,071
No Harvest	$ 102	$ 246	$ 345	$ 424

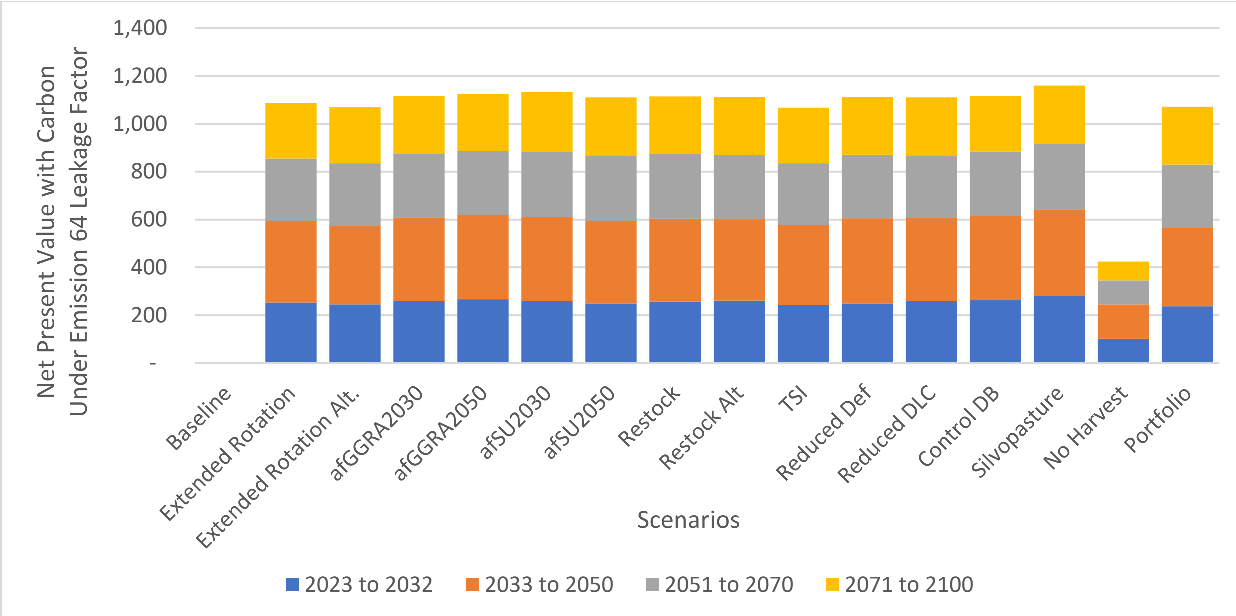


Figure 4. Cumulative net present value estimated from Maryland's forests under various carbon management scenarios considering carbon emissions under emission 64 leakage factor.

Table 10. Net present value estimated from Maryland's forests under business-as-usual and alternative management scenarios while accounting for carbon emissions using emission 84 leakage factor.

Scenarios	Net Present Value (NPV) in million dollars			
	2023 to 2032	2023 to 2050	2023 to 2070	2023 to 2100
Baseline	$ 259	$ 613	$ 881	$ 1,119
Extended Rotation	$ 252	$ 593	$ 854	$ 1,088
Extended Rotation Alt.	$ 245	$ 572	$ 834	$ 1,068
afGGRA2030	$ 260	$ 608	$ 877	$ 1,116
afGGRA2050	$ 267	$ 620	$ 888	$ 1,125
afSU2030	$ 258	$ 612	$ 883	$ 1,133
afSU2050	$ 249	$ 594	$ 866	$ 1,110
Restock	$ 257	$ 604	$ 874	$ 1,114
Restock Alt	$ 261	$ 601	$ 870	$ 1,112
TSI	$ 244	$ 578	$ 835	$ 1,068
Reduced Def	$ 249	$ 604	$ 872	$ 1,113
Reduced DLC	$ 260	$ 606	$ 867	$ 1,111
Control DB	$ 278	$ 648	$ 931	$ 1,176
Silvopasture	$ 297	$ 675	$ 962	$ 1,219
Portfolio	$ 219	$ 520	$ 773	$ 1,005
No Harvest	$ 102	$ 243	$ 339	$ 415

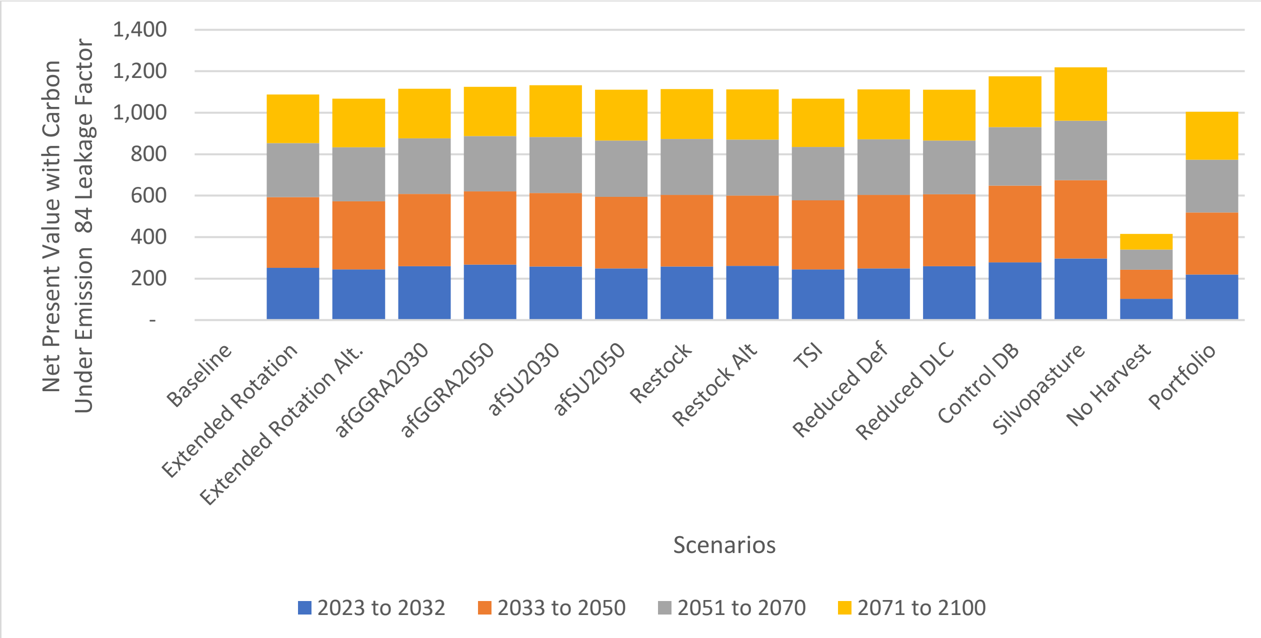


Figure 5. Cumulative net present value estimated from Maryland's forests under various carbon management scenarios considering carbon emissions under emission 84 leakage factor.

Compared to the NPV estimated without considering carbon emissions, the NPV with carbon (under emission 64 leakage factor) was higher in case of all other scenarios except no harvest, TSI, and reduced deforestation. The NPV generated under two alternative carbon management scenarios (Silvopasture and afforestation until 2050) were consistently higher than that under BAU at all time frames considered when carbon emissions were considered while estimating NPV. The NPV with carbon under no harvest, portfolio, both cases of extended rotation, both cases of restocking, scaled up afforestation until 2050, and reduced deforestation were consistently lower than the NPV under BAU at all time frames considered. The NPV with carbon was the highest under silvopasture scenario at all time frames. Other scenarios that had higher NPV with carbon compared to BAU in the short term included controlled deer browse, alternative restocking scenario, afforestation until 2030, and reduced diameter limit cut. Controlled deer browse scenario also yielded higher NPV with carbon under emission 64 leakage factor in the medium and medium-long term but not in the long term. In the long term, apart from silvopasture and afforestation until 2050 scenarios, scaled up afforestation until 2030 scenario also yielded higher NPV compared to BAU. The NPV with carbon under emission 64 leakage factor were the lowest for no harvest scenario at all time frames considered, followed by portfolio scenario in the short, medium and medium long terms and TSI scenario in the long term.

When carbon emissions under emission 84 leakage factor were accounted for while estimating the NPV, the NPV generated under most of the alternative carbon management scenarios increased except for no harvest, TSI, and reduced deforestation scenarios. The NPV with carbon under emission 84 leakage factor were consistently higher than the NPV under BAU for three alternative carbon management scenarios (Silvopasture, controlled deer browse, and afforestation until 2050) and lower than the NPV under BAU for eight scenarios (No harvest, portfolio, TSI, reduced deforestation, both cases of extended rotation, and scaled up afforestation until 2050). The NPV with carbon (under emission 84 leakage factor) was the highest under silvopasture, followed by controlled deer browse at all time frames considered. The lowest NPV with carbon at all time frames considered were noted under no harvest scenario followed by the portfolio and TSI scenarios respectively in the short and long term and portfolio followed by extended rotation scenarios in the medium and medium long term.

Three scenarios that had lower NPV compared to BAU when carbon emission was not accounted for had higher NPV than BAU when carbon emissions were taken into consideration while estimating NPV under emission 84 leakage factor. These included afforestation until 2050, controlled deer browsing and silvopasture scenarios.

Figures 6 through 9 show NPV with and without considering carbon emissions under short, medium, medium-long, and long-term timeframes respectively.

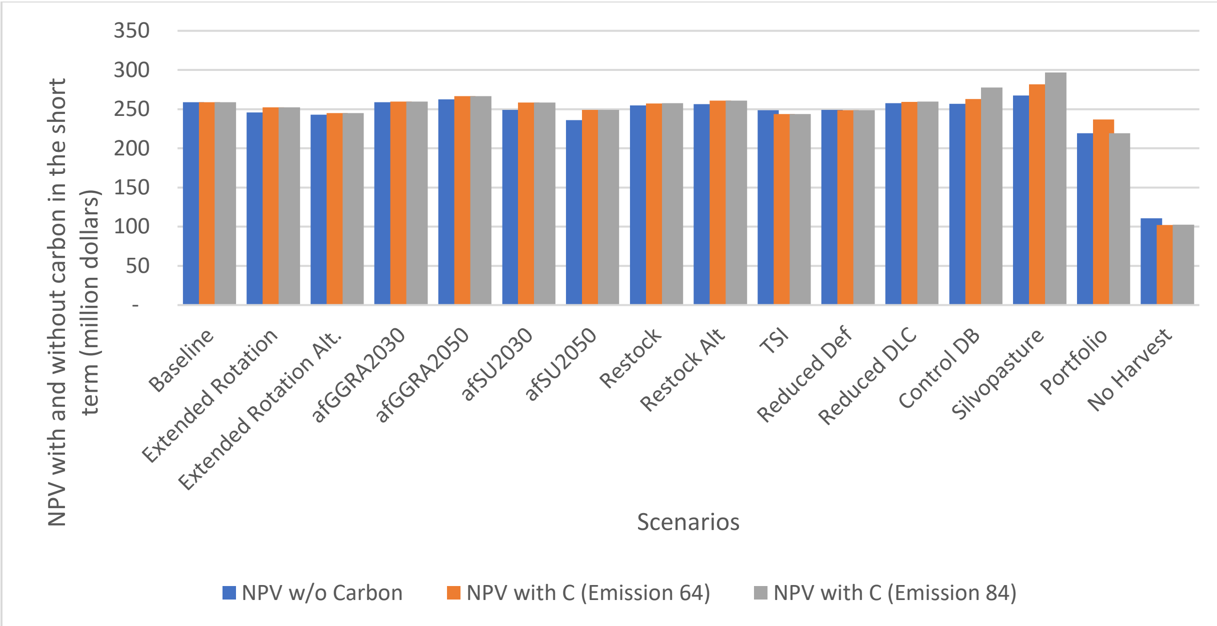


Figure 6. Net present value estimated with and without accounting for carbon emissions in Maryland under various carbon management scenarios in the short-term time frame (2023 to 2032).

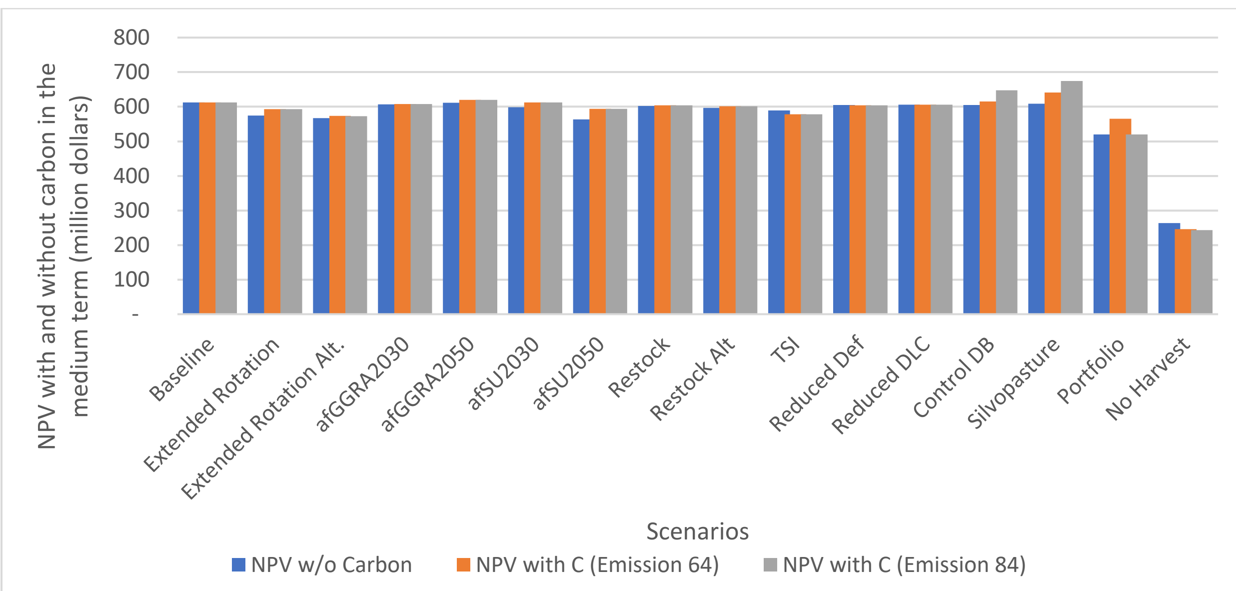


Figure 7. Net present value estimated with and without accounting for carbon emissions in Maryland under various carbon management scenarios in the medium-term time frame (2023 to 2050).

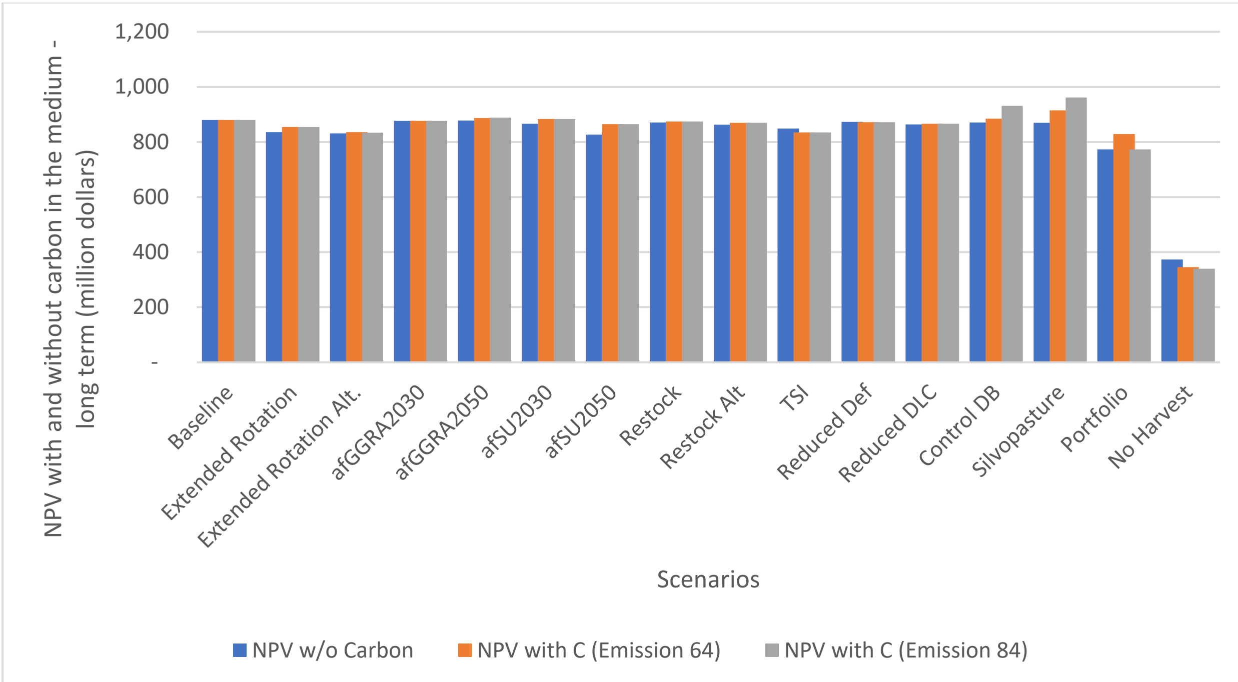


Figure 8. Net present value estimated with and without accounting for carbon emissions in Maryland under various carbon management scenarios in the medium-long term time frame (2023 to 2070).

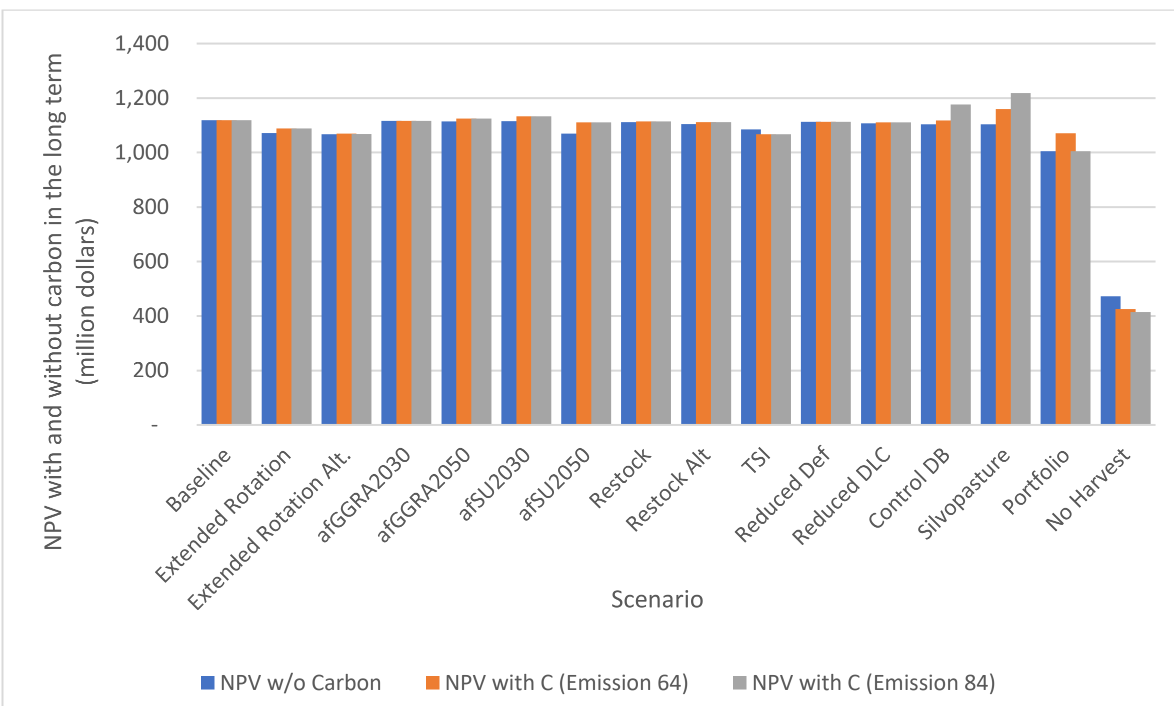


Figure 9. Net present value estimated with and without accounting for carbon emissions under various carbon management scenarios in the long-term time frame (2023 to 2100).

Sensitivity Analysis

Sensitivity analysis was conducted using a range of discount rates (3% to 15%), carbon prices ($5 to $100) and timber prices (both increase and decrease) to assess how NPV under different carbon management scenarios reacted to changing parameters. The results obtained are presented in figures 10 through 14. Figure 10 depicts the change in NPV when interest rate is increased from 3% to 15%. It can be noted that as interest rate increases, NPV decreases. This is because as the interest rate increases, the present value of future revenue decreases since higher interest rate implies greater discounting of future cash flows. The rate of decline in NPV under different carbon management scenarios with increasing interest rate was noted to be constant. This is because the CBM-CFS model (which is an ecological model) does not consider market variables when predicting timber harvests. Timber harvest volumes in the CBM-CFS model do not change with changing interest rate. Market-based model for predicting timber harvests could provide a more realistic estimation of how volume harvested changes with changing interest rates.

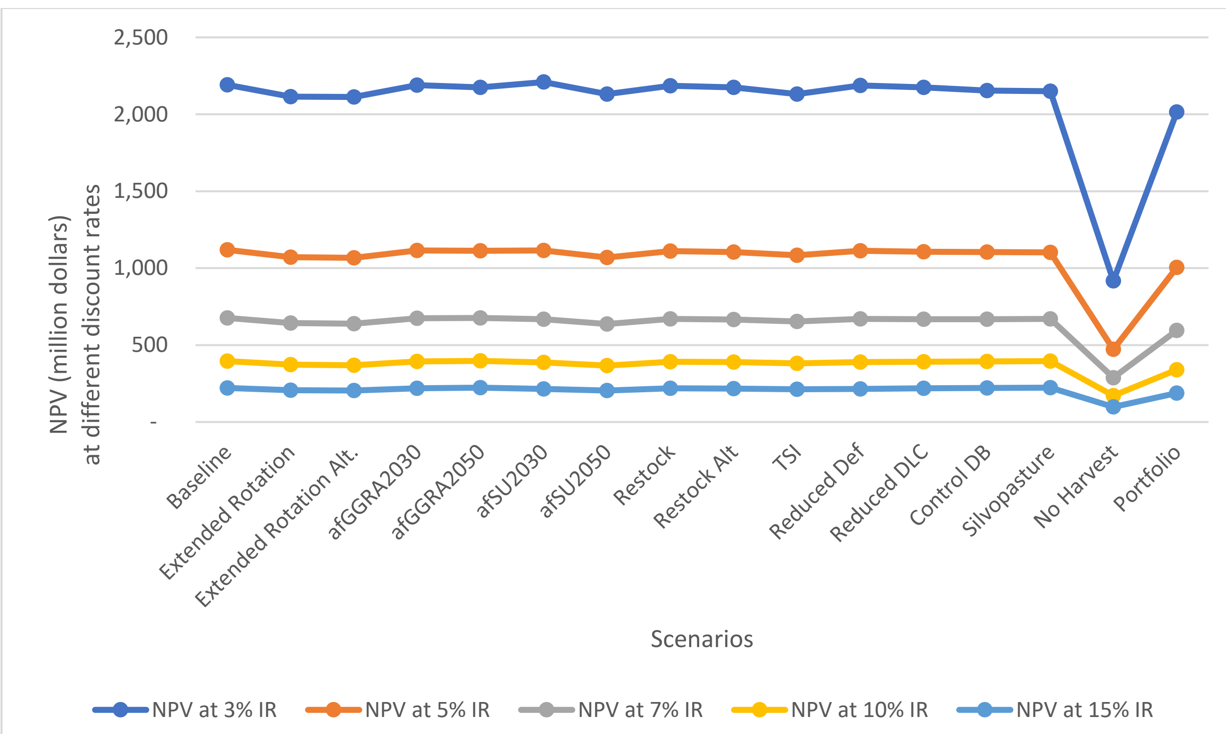


Figure 10. NPV under different carbon management scenarios at varying interest rates in Maryland (2023 to 2100).

Sensitivity analysis was also conducted by changing the market price of carbon from $5 to $100, the results of which are presented in Figure 11. It was noted that with the increase in the price of carbon, the NPV increased in most of the alternative carbon management scenarios except no harvest, and TSI. This is because total carbon emission under emission 64 leakage factor was the highest for no harvest scenario followed by the TSI scenario. All other scenarios except no harvest, TSI, extended rotation alternative pine and afforestation until 2030 had negative emissions in the long-term time frame. Therefore, with the increase in the price of carbon, the revenue generated under these scenarios increased owing to carbon benefits and hence the NPV increased.

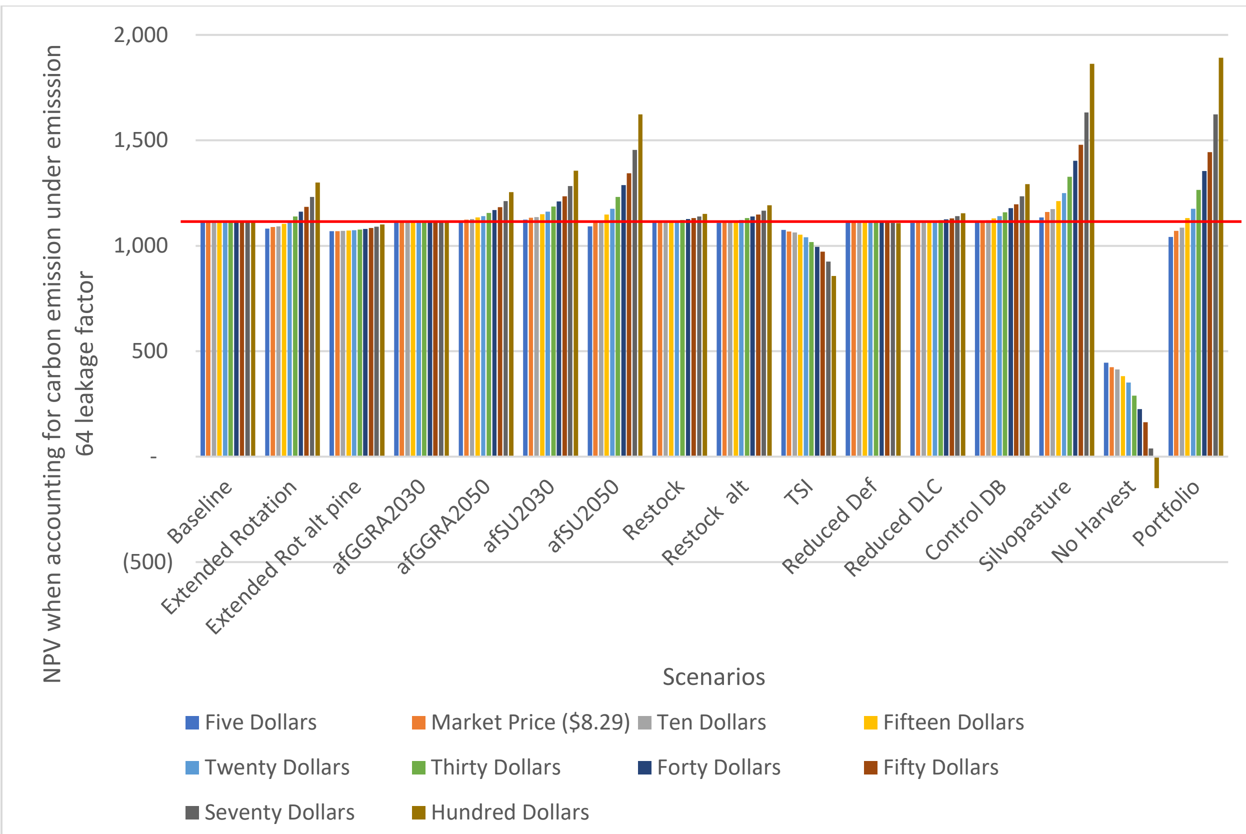


Figure 11. NPV under different carbon management scenarios at varying carbon prices in Maryland (2023 to 2100).

Sensitivity analysis was also conducted to assess the change in NPV resulting from the change in stumpage prices. For this, five increasing stumpage price scenarios and five decreasing stumpage price scenarios compared to the baseline were considered. In the base case scenario for

Maryland, the stumpage price of hardwood species increased by 3% every year and that of softwood species by 1% every year until 2032 and by 2.5% every year starting 2033. For conducting sensitivity analysis with increasing price, in addition to the base case, the stumpage price of hardwoods was increased by 1% every year till it reached 8% and for softwoods it was increased by 0.5% every year. Likewise, for conducting sensitivity analysis with decreasing price, stumpage price for both hardwoods and softwoods were decreased by 1% every year from the base case level till the stumpage price was reduced by 5 percent points for both hardwoods and softwoods. The results obtained from increasing and decreasing stumpage price analyses are presented in Figures 12 and 13 respectively. The NPV increased with increasing stumpage price and decreased with decreasing stumpage price for all scenarios. With slight increase in the stumpage price, the NPV generated under scaled up afforestation until 2030, and reduced DLC scenarios exceeded the NPV generated under BAU. The NPV generated under TSI, and restocking scenarios exceeded that under BAU when the stumpage price was increased considerably (i.e., by 5 percent points). The NPV generated under other scenarios such as portfolio, silvopasture, controlled deer browse, both cases of extended rotation, and afforestation until 2050, did not exceed the NPV generated under BAU even when the stumpage price was increased by five percent points. On the contrary, when stumpage price declined below the base line price, the NPV generated under none of the alternative carbon management scenarios exceeded that generated under BAU.

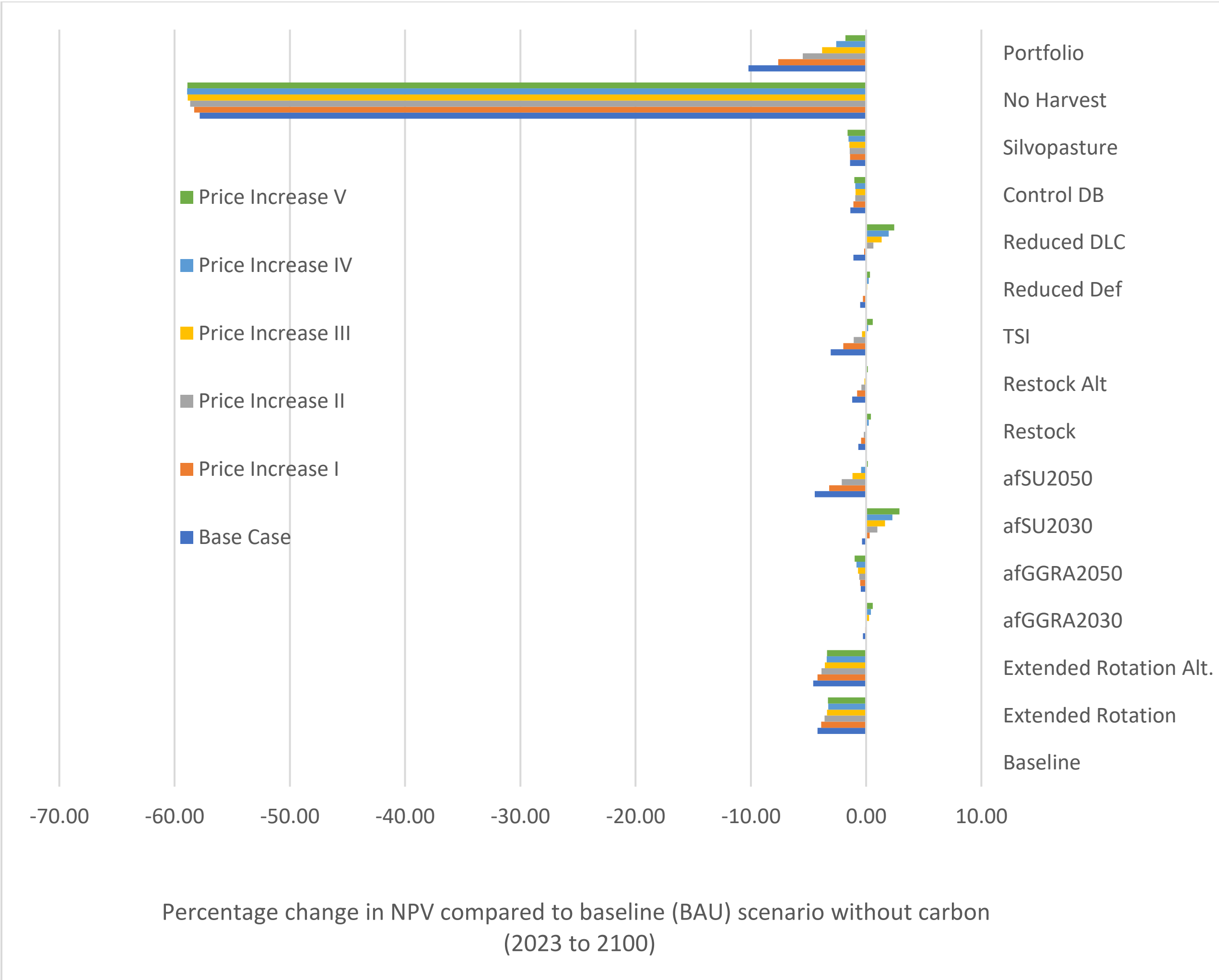


Figure 12. Percentage change in NPV under different carbon management scenarios compared to BAU scenario when stumpage price is increased in the long term.

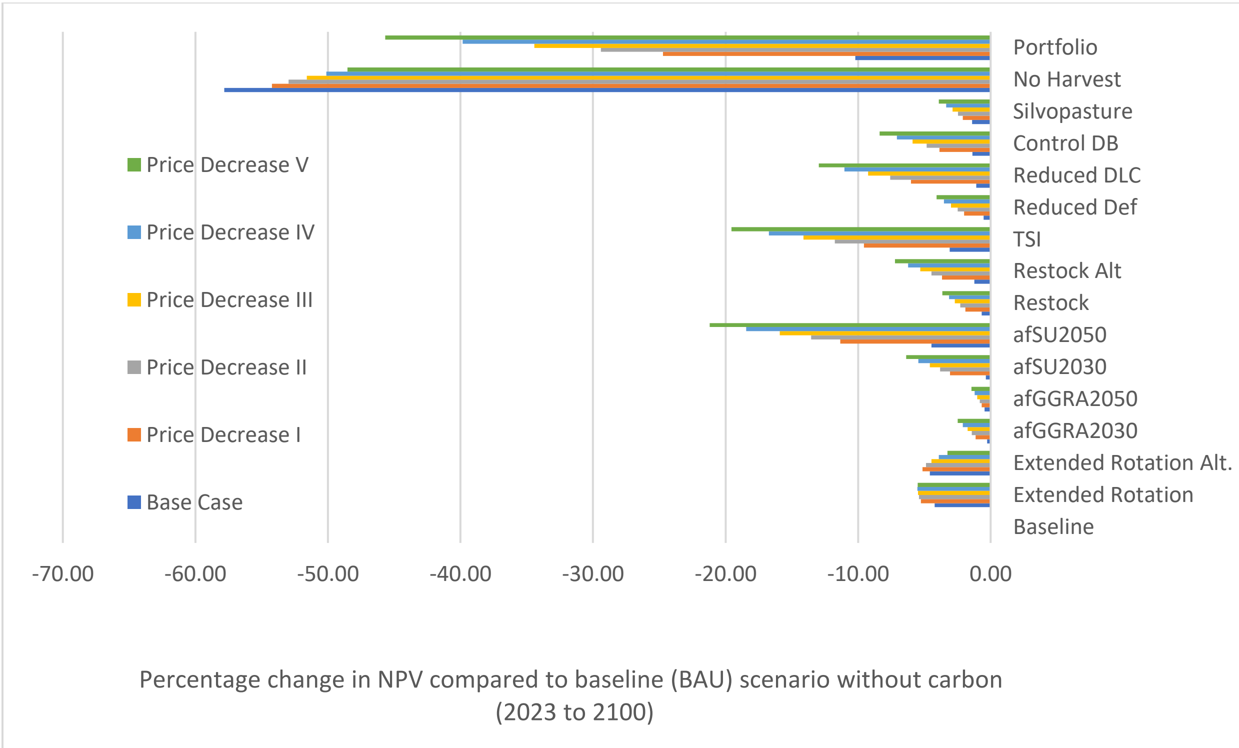


Figure 13. Percentage change in NPV under different carbon management scenarios compared to BAU scenario when stumpage price is decreased in the long term.

Key Takeaways

- NPV is positive under all scenarios considered meaning that economically all scenarios are feasible to undertake without incurring a loss in investment
- Though volume harvested under TSI and reduced DLC scenarios in Maryland were higher than that under business-as-usual scenario, the NPV generated under these scenarios (without considering carbon emissions) were not higher than the NPV generated under BAU scenario.
- When carbon emissions associated with the alternative carbon management scenarios were taken into account, the NPV (with carbon) for silvopasture, and afforestation until 2050 scenarios exceeded the NPV generated under BAU scenario in the long term. Likewise, when carbon emissions were accounted for using emission 84 leakage factor, then the NPV (with carbon) under silvopasture, controlled deer browse, and afforestation until 2050 scenarios exceeded the NPV under BAU scenario in the long term.
- For scenarios like portfolio, extended rotation, afforestation, and controlled deer browse to yield higher NPV compared to the BAU scenario, the market price of carbon has to me higher than the current market price (at least $15 for portfolio scenario and $30 for extended rotation scenario).
- For NPV generated under reduced DLC and TSI scenarios to exceed the NPV generated under BAU scenario, the stumpage price for timber products needs to be higher than the current stumpage price (at least two percentage points higher than the current stumpage price for reduced DLC scenario and five percentage points higher than the current stumpage points for TSI scenario).

References

Bullard, S.H., and T.J. Straka. 1998. Basic Concepts in Forest Valuation and Investment Analysis. Preceda, L.L.C.

Dickens, D., D. Clabo, D. Moorhead, and C. Waldrop. 2021. Growing poles in southern pine stands. University of Georgia. Warnell school of forestry and natural resources. Publication WSFNR-21-70C. 6p.

Dickmann, D., and R. Melvin. 1997. Managing rep pine plantations for utility poles. Michigan State University. Department of Forestry Extension Bulletin E-2612. 10p.

Hoover, K., and A.A. Riddle. 2022. U.S. Forest carbon data: In brief. Congressional Research Service. R46313. Available online at: https://crsreports.congress.gov/product/pdf/R/R46313. Last accessed 11/1/2022.

Jacobson, M. 2022. Timber prices: 10-year summary of price trend percentages. Available online at: https://extension.psu.edu/timber-prices-10-year-summary-of-price-trend-percentages. Last accessed 11/1/2022.

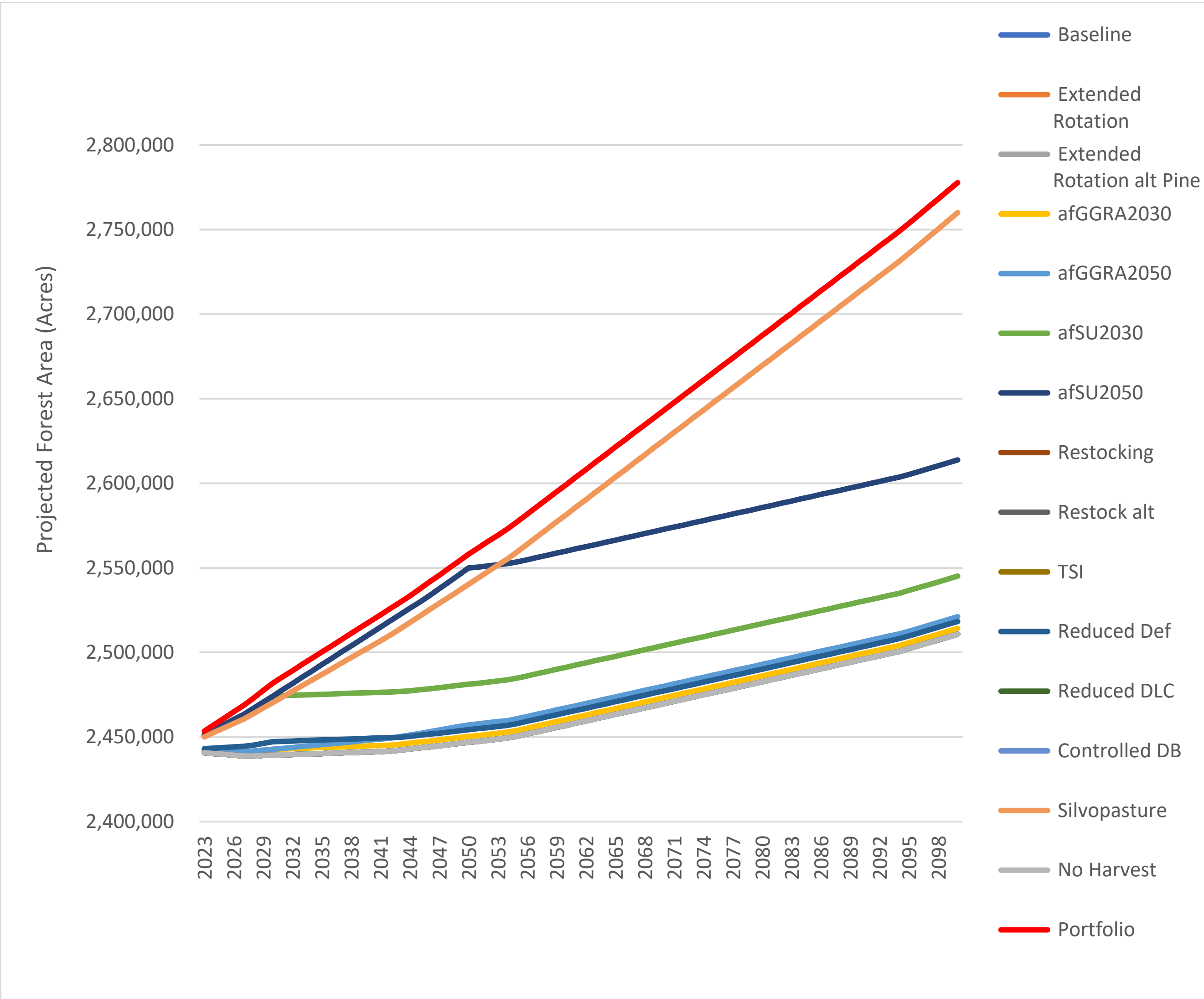
Jacobson, M. 2007. Forest Finance 2: Fencing for Forest Regeneration: Does It Pay?. Available online at: https://extension.psu.edu/forest-finance-2-fencing-for-forest-regeneration-does-it-pay#:~:text=Introduction,regenerate%20naturally%20after%20a%20harvest.. Last accessed 11/2/2022.

Smith, J.E., L.S. Health, K.E. Skog, and R.A. Birdsey. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. United States Department of Agriculture, Forest Service. General Technical Report NE- 343. 222p.

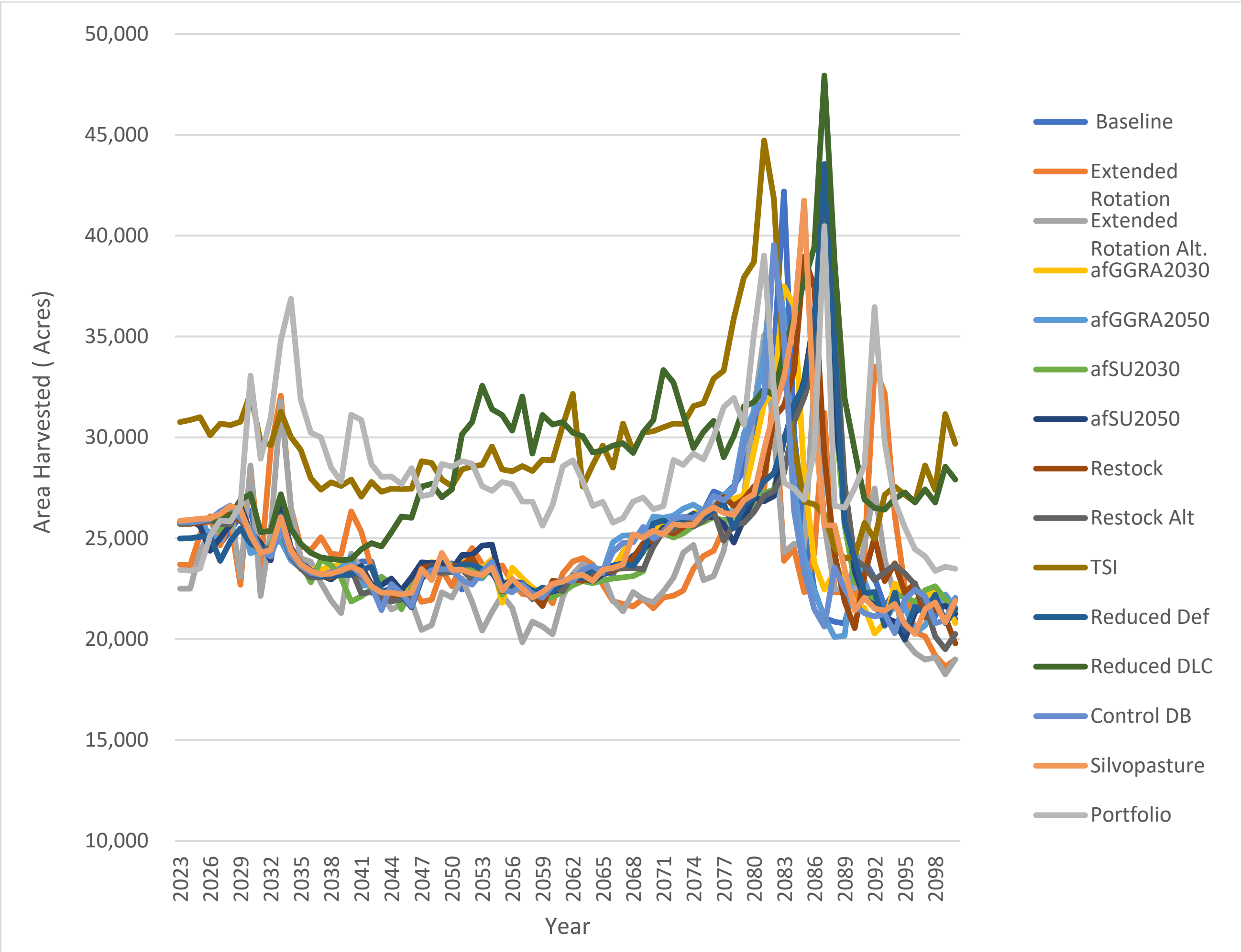
Winn, M.F., L.A. Royer., J.W. Bentley, R.J. Piva, T.A. Morgan, E.C. Berg, and J.W. Coulston. 2020. Timber products monitoring: Unit of measure conversion factors for roundwood receiving facilities. United States Department of Agriculture, Forest Service. General Technical Report SRS- 251. 154p.

Appendices

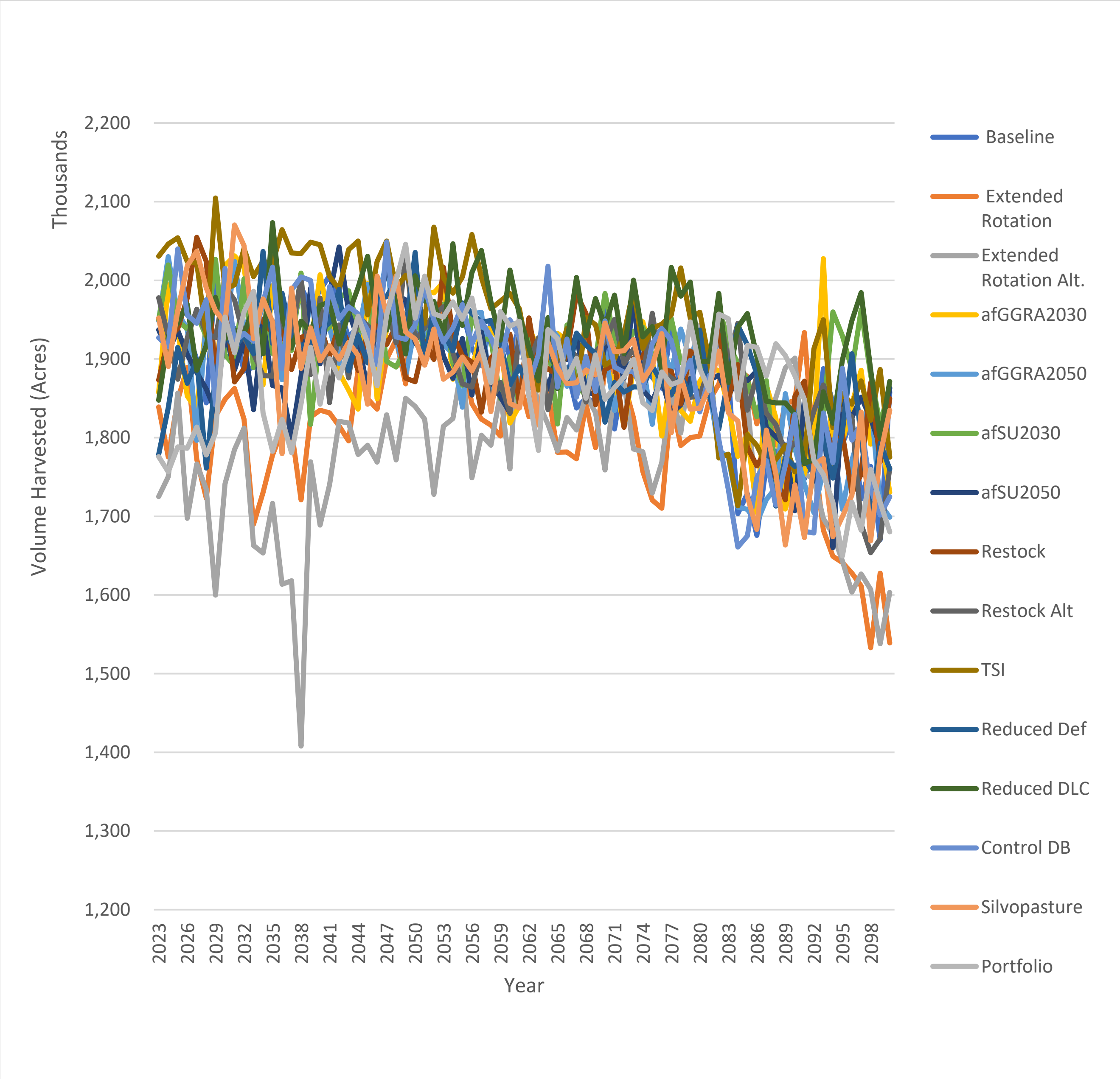
Appendix A. Projected forest area in Maryland (in million acres) under BAU and alternative carbon management scenarios from year 2023 to 2100 modeled using CBM-CFS.



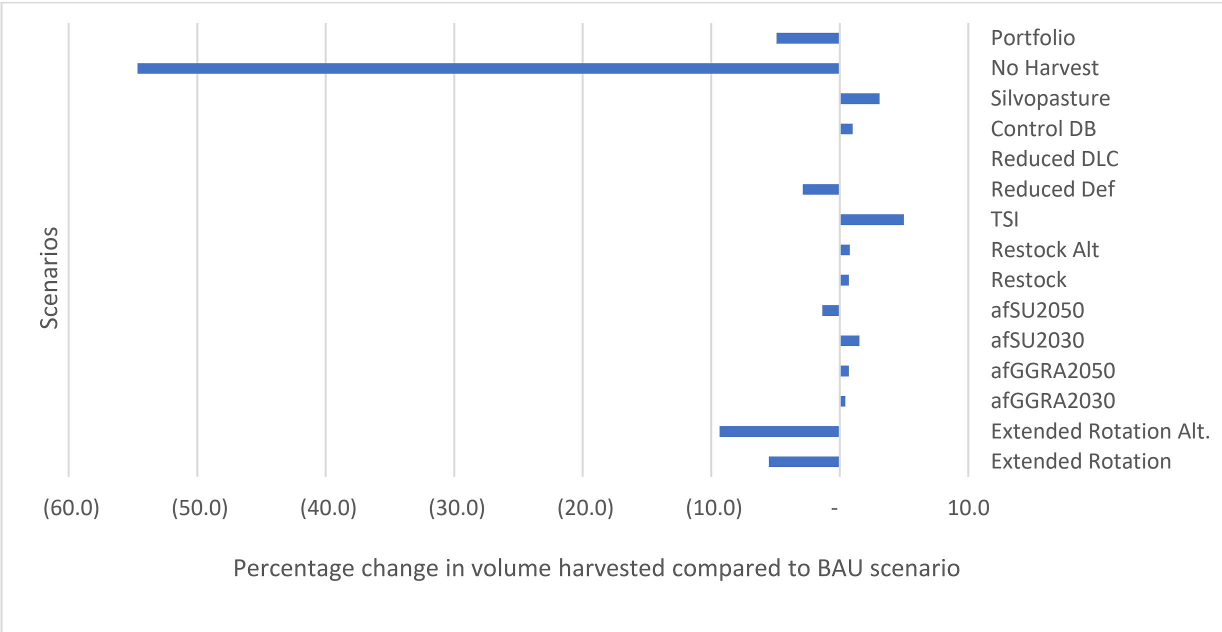
Appendix B. Forest area (in acres) harvested each year under different carbon management scenarios in Maryland from the year 2023 to 2100.



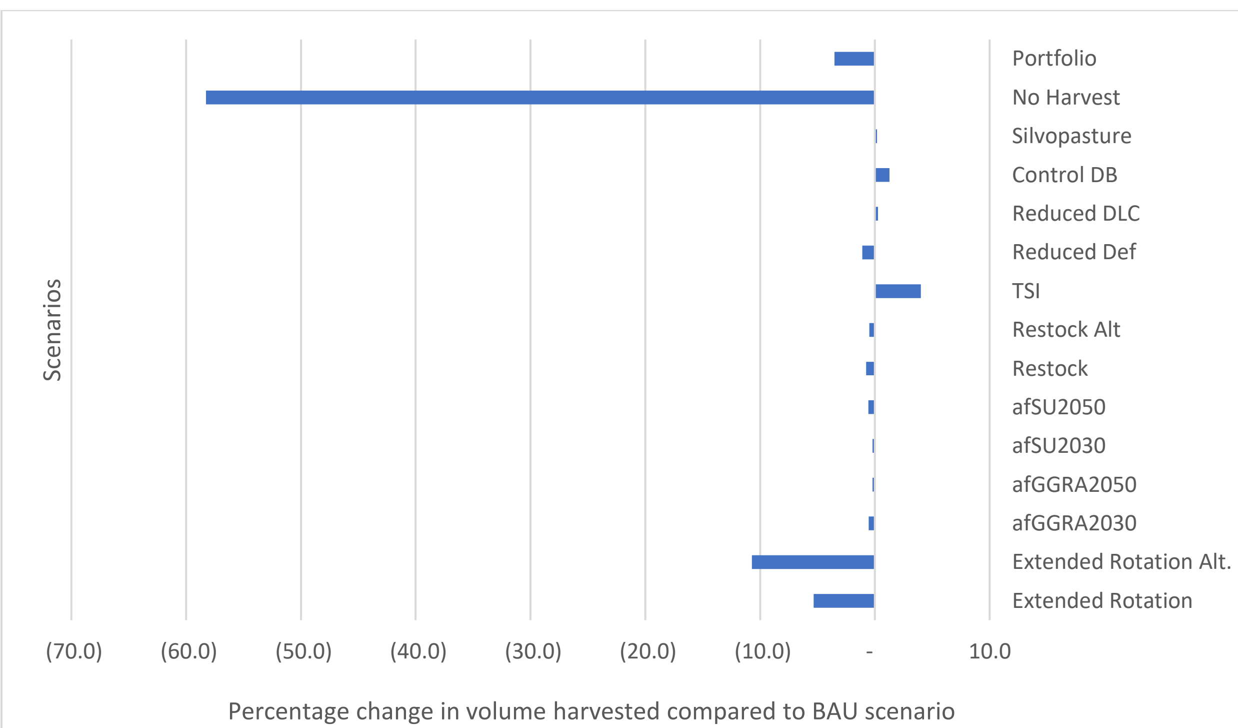
Appendix C. Volume of timber products harvested annually (in tons) under different carbon management scenarios in Maryland from year 2023 to 2100.



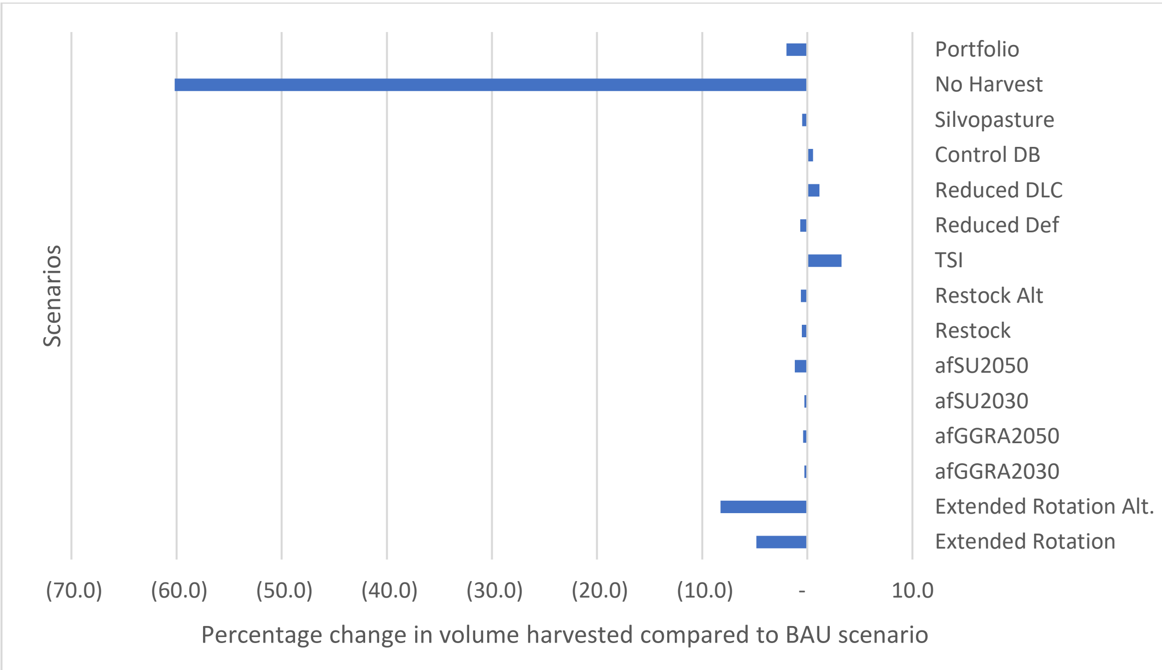
Appendix D. Percentage change in volume harvested under alternative carbon management scenarios compared to baseline for short term time frame (2023 to 2032) in Maryland.



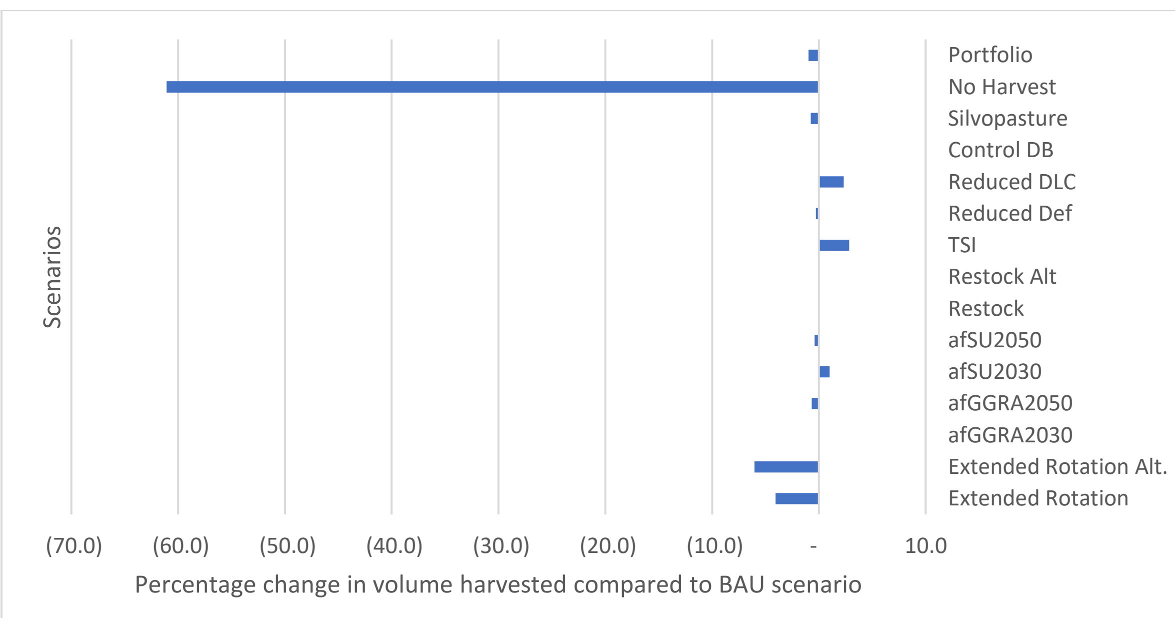
Appendix E. Percentage change in volume harvested under alternative carbon management scenarios compared to baseline for medium term time frame (2023 to 2050) in Maryland.



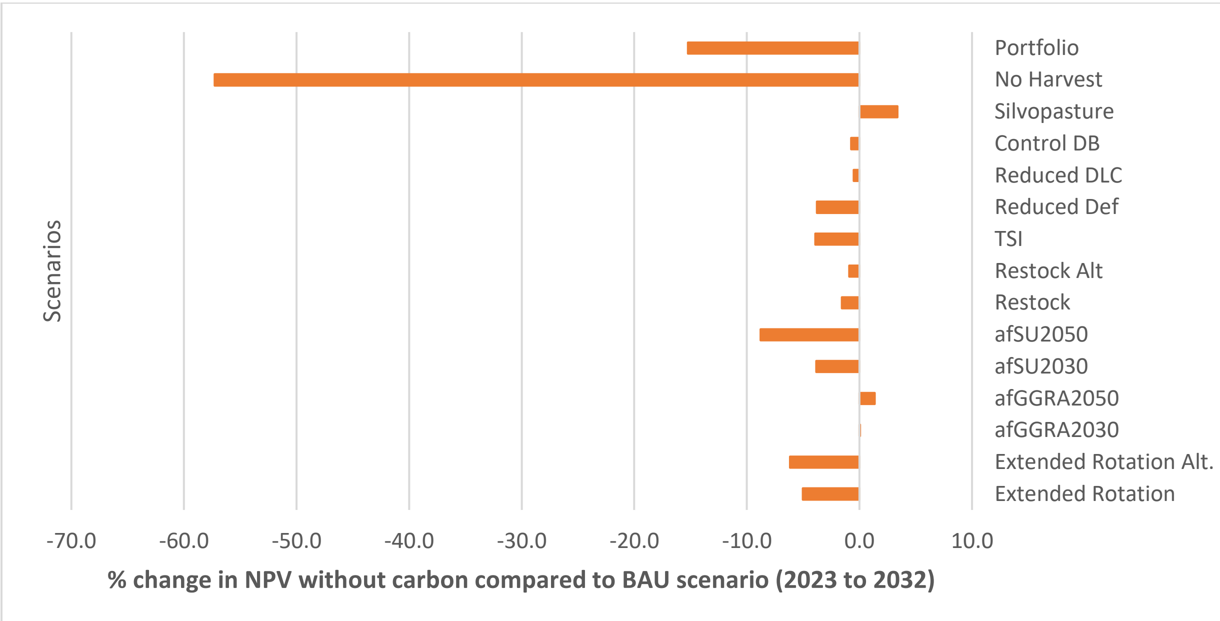
Appendix F. Percentage change in volume harvested under alternative carbon management scenarios compared to baseline for medium-long term time frame (2023 to 2070) in Maryland.



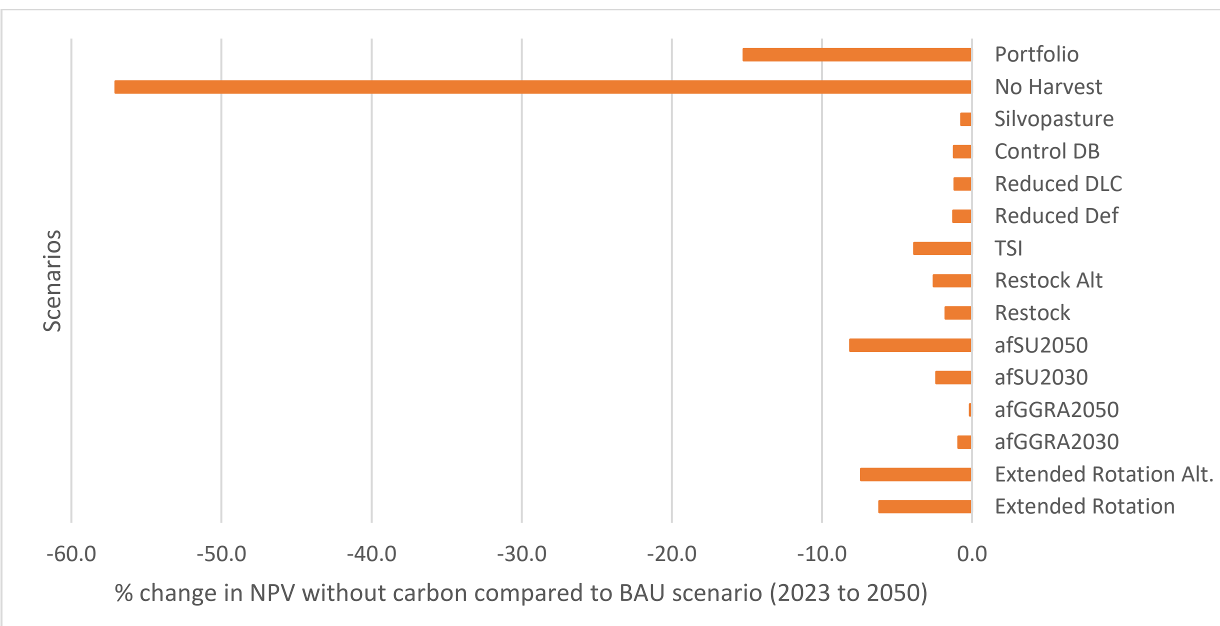
Appendix G. Percentage change in volume harvested under alternative carbon management scenarios compared to baseline for long term time frame (2023 to 2100) in Maryland.



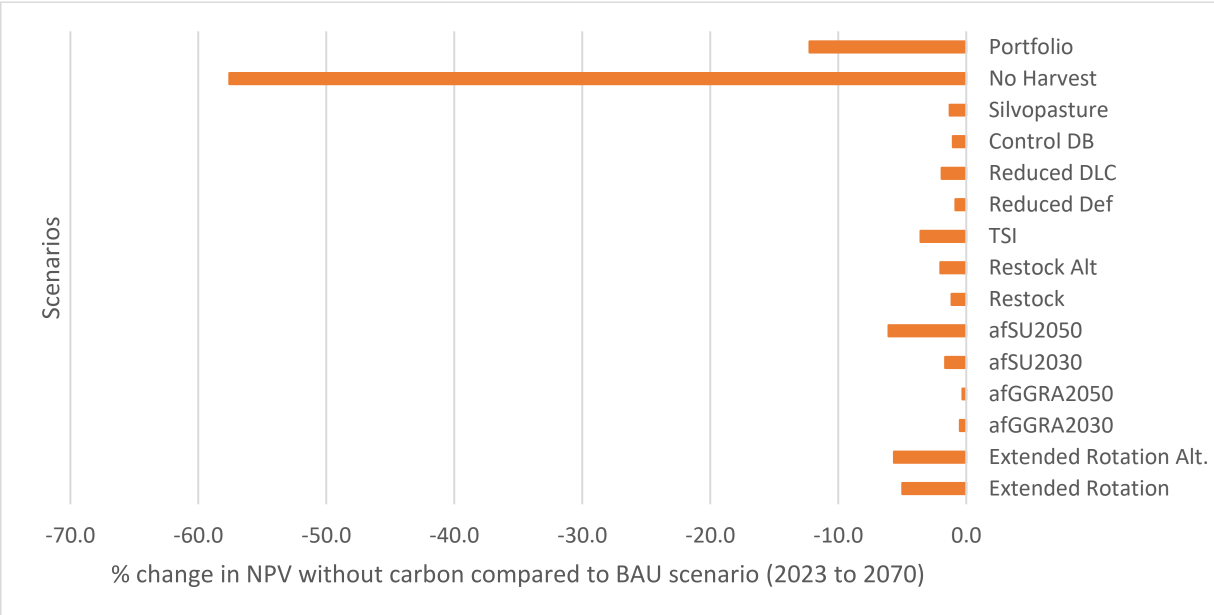
Appendix H. Percentage change in net present value (NPV) without carbon under alternative carbon management scenarios compared to baseline for short term time frame (2023 to 2032).



Appendix I. Percentage change in net present value (NPV) without carbon under alternative carbon management scenarios compared to baseline during medium term time frame (2023 to 2050).



Appendix J. Percentage change in net present value (NPV) without carbon under alternative carbon management scenarios compared to baseline during medium-long term time frame (2023 to 2070).



Appendix K. Percentage change in net present value (NPV) without carbon under alternative carbon management scenarios compared to baseline during long term time frame (2023 to 2100).