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# Estimating a Regional Economic Conservation Benefit of Using Domestic Hardwoods vs. Apitong for Trailer Decking: A Case Study on US Army Use

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**Abstract:** United States Army trucks and trailers use an estimated one million board feet (2381 cubic meters) of a critically endangered tropical hardwood, apitong (*Dipterocarpus* spp.), from southeast Asian rainforests, for wood decking annually. However, their purchasing specifications require the use of domestic hardwoods for decking, floorboards, and platforms. Several US hardwood species, including northern red oak (*Quercus rubra*), white oak (*Quercus alba*), hickory (*Carya* spp.), black locust (*Robinia pseudoacacia*), and sugar maple (*Acer saccharum*) could serve as viable substitutes. They have comparable strength properties to apitong, and there is an abundant and sustainable feedstock based on the United States Forest Service Forest Inventory Analysis (USFS FIA) database. The economic impact in New York State of manufacturing the decking panels in Onondaga County from three selected species: hickory, white oak, and black locust, was estimated using IMPLAN. The economic impact could be as high as $27 million, creating 128 full-time equivalent (FTE) jobs. Equally important to providing local and regional economic benefits, domestically sourced decking panels also contributes to the preservation of tropical rainforests, particularly when the entire decking market is considered (beyond the US Army), which includes wood decking consumption by other government agencies at various levels and the private sector.

**Keywords:** endangered tropical hardwoods; trailer decking; IMPLAN; expenditure pattern



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## 1. Introduction

Apitong, or keruing, (*Dipterocarpus* spp.) refers to an estimated 75 commercial species of the genus *Dipterocarpus* from the Dipterocarpaceae family native to the Asian tropics [1,2]. *Dipterocarpus* species can be found throughout southeast Asia, including the forests of Burma, Cambodia, China, India, Indonesia, Laos, Malaysia, the Philippines, Sri Lanka, Thailand, Vietnam, and others [3,4]. All 75 species share similar anatomical features and are marketed mostly under a single vernacular name: apitong (sometimes keruing) [2]. Usually reaching heights of 40 to 60 m, apitong is an evergreen tree with a clear cylindrical bole, measuring up to nearly 21 m in length, with trunk diameters of 100 to 150 cm [2,4,5].

Apitong is used widely in the wood products industry for general construction and boat building, as well as for flooring, pallets, chemical processing equipment, veneer, plywood, railroad crossties, truck floors, and boardwalks [6]. In the US, the species is considered to be one of the most popular exotic hardwood species, and has been the "undisputed" choice for truck and trailer flooring (decking) since the 1960s [7]. The US Army is one of the biggest users of apitong, currently utilizing wood panels derived from it as decking for many of their vehicles and trailers [8,9]. A primary supplier of military trailer flooring, reports suggest that the majority of rough kiln-dried apitong lumber comes from tropical rainforests in Malaysia and Indonesia [10].

Tropical rainforests are among the most biologically diverse ecosystems on earth, as well as the most exploited and endangered. Moreover, Hughes [11] notes that southeast

Asia is one of the most biotically threatened regions in the world, despite its status as a global hotspot for biodiversity. For instance, according to Gan, Cashore, and Stone [12], Malaysia and Indonesia are estimated to source 65% and 25% of their respective logs and wood products illegally. By importing apitong lumber, the US is potentially contributing to the unsustainable logging of tropical rainforests. As highlighted in several studies, illegal timber extraction and habitat destruction are resulting in the exploitation of apitong species in different habitats across the Indo-Malayan region, with limited conservation efforts to date [13–16]. Making matters more challenging, the species flowers supra-annually, primarily during community-wide general flowering events when the entire forest suddenly flowers in a brief "Spring" after several years of little reproductive activity. Less than 3% of plant species flower at any particular time during the intervals between general flowerings, which last from 1 to 10 years [17]. Due to these long gaps between seed years, natural apitong regeneration cannot keep pace with the level of exploitative harvesting [4].

Apitong conservation efforts are further complicated by the difficulty to differentiate individual species by the wood characteristics of sawn boards, which in turn presents challenges in identifying specific tree species. This is concerning for several reasons, including the difference in sustainability status among the species. Unfortunately, there is no listing of these species in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) yet [18], but there are 61 species of the *Dipterocarpus* genus found in south and southeast Asia listed in various categories (16 critically endangered, 19 endangered, 11 vulnerable, 10 near threatened, and 5 of least concern) on the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN) (Appendix A) [19].

The US Army uses trailers for the transport of supplies, equipment, and vehicles. For a variety of reasons, wood is an excellent decking material for heavy equipment haulers. In addition to providing a compliant surface, wood allows tracked and wheeled vehicles to grip the deck and to not slip off. Additionally, wood provides a good surface for nailing and tying down. It is sometimes necessary to modify trailers, and the ability to modify is enhanced due to the exceptional construction properties of wood [20].

Apitong is considered a preferred species for trailer decking due to its superior characteristics, including hardness, rupture and crushing strength, elasticity, and availability in long, clear lengths [8,20,21]. Furthermore, the wooden decks must withstand extreme wear and tear associated with US military use, as well as exposure to sunlight, heat, rain, fungi, and insects. Although apitong meets these criteria, it is important to note that Commercial Item Description (CID) A-A-52520B specifies that "floorboards and platforms shall be constructed from domestic hardwoods". The US Army Combat Capabilities Development Command, Ground Vehicle Systems Center (DEVCOM-GVSC) is currently working with the USDA Forest Service, US Army Tropic Regions Test Center, and academia to test and develop different species of wood with updated, commercially accepted treatment options with the goal of updating the CID to include more species. In the past, domestic hardwoods have been used as truck and trailer decking. Several domestic species, including hickory (*Carya* spp.), sugar maple (*Acer saccharum*), white oak (*Quercus alba*.), black locust (*Robinia pseudoacacia*), and northern red oak (*Quercus rubra*), have strength properties comparable to apitong (Table 1).

By domestically sourcing hardwood lumber species, the US Army could reduce harvesting pressure on these endangered tropical hardwood species. Moreover, domestic procurement and processing will generate economic and employment benefits within the country. It has been recognized that the use of tropical species is in contrast with US Army specifications, and alternatives have been sought since as early as 2000 [20], yet apitong is still used as decking for the US Army's trailers. In recent studies, Khademibami et al. [21] and Khademibami et al. [8] identified the issue and studied the mechanical properties of domestic species, including hickory, red oak, and white oak, which could be suitable alternatives to apitong for trailer decking. To date, however, no study has evaluated the economic impacts of replacing apitong panels with domestic species.

**Table 1.** Physical strength properties of noted hardwoods at 12% moisture content [6].

| Species | Specific Gravity (G) | Modulus of Elasticity (MPa) [a] | Side Hardness (Newton) | Modulus of Rupture (R) (MPa) [a] | Crushing Strength (MPa) [a] |
|---|---|---|---|---|---|
| *Hickory* | 0.66 | 12,300 | 8100 | 118 | 62.3 |
| *Black locust* | 0.69 | 14,100 | 7600 | 134 | 70.2 |
| *Sugar maple* | 0.63 | 12,600 | 6400 | 109 | 54.0 |
| *Northern red oak* | 0.63 | 12,500 | 5700 | 99 | 46.6 |
| *White oak* | 0.68 | 12,300 | 6000 | 105 | 51.3 |
| *Apitong* | 0.74 | 14,300 | 5600 | 137.2 | 72.4 |

[a] Megapascals.

This case study, based in New York state (NYS), examines the economic impact of replacing apitong used by the US Army with native hardwood species products that generally meet US Army specifications. Among the five noted species of Table 1, three species were selected for economic impact analysis: hickory, white oak, and black locust. These species were selected based on the comparability of their properties to apitong and on the limited research that has been conducted on domestic alternatives to apitong.

Khademibami et al. [8] examined ash (*Fraxinus* spp.), hickory, red oak, sweetgum (*Liquidambar styraciflua*), and white oak for abrasion and hardness as potentially sustainable alternatives to apitong and for general use in high-wear environments such as trailer decking. Based on their results, white oak exhibited the highest wear resistance, while hickory was superior with respect to hardness. In addition, the National Wood Flooring Association (NWFA) [22] identified white oak as meeting all the requirements for decking US military trucks. Kamprath [23] also recommended white oak decking to the US Army as a temporary solution. Black locust was considered as a potential alternative due to its superior wood characteristics (Table 1), as it is one of the strongest and stiffest domestic woods with exceptional water and rot resistance [24–26]. In fact, Black Locust Lumber [27] markets the species as the "Rolls Royce" of hardwoods.

Specifically, the objectives of this study are to determine the availability and sustainability of the noted species in NYS, and to estimate the economic impact of using domestic hardwoods instead of apitong. It is imperative to note that our case study represents only one small part of the supply chain with respect to the use of apitong. In addition to the US Army, apitong is the species of choice for truck and trailer decking for several US governmental agencies at the federal, state, and local levels, as well as companies in the private sector.

## 2. Materials and Methods

### *2.1. Feedstocks*

Several hardwood species with desired physical property characteristics, such as sugar maple, bitternut hickory, white oak, northern red oak, and black locust, are potentially available in NYS. This availability was determined using the latest available data (2022) from the USDA Forest Service Forest Inventory Analysis (FIA) database, which includes both total volumes and current growth-to-harvest ratios.

### *2.2. Regional Economic Conservation Benefits*

#### 2.2.1. Estimating Market Potential

To determine the annual estimated volume of apitong used by the US Army, we attempted to reach out via the Freedom of Information Act (FOIA). Since 1967, the FOIA has provided members of the public with the right to request access to records from any federal agency of the US. It is often described as the law that keeps citizens more aware of their government. Federal agencies are required to share any information requested under the FOIA unless it falls under one of nine exemptions which protect interests such as personal privacy, national security, and law enforcement. Unfortunately, our requests

were rejected because the specificity was deemed unreasonable. As one government official stated, "we were seeking the equivalent of a needle in a haystack". We then turned to our local US congressman (New York's 24th Congressional district based in Syracuse, NY, USA), and they were able to connect us with the correct US Army personnel who could provide an annual estimated volume for apitong decking.

#### 2.2.2. Economic Impacts in NYS

NYS was chosen as the base of this study, as it is one of the largest northeastern states and is home to all the noted domestic hardwood species with similar strength properties to apitong. As of 2021, the state is estimated to have a nominal gross domestic product of 1.85 trillion US dollars, with 517 total North American Industry Classification System (NAICS) industries and approximately 11.77 million total jobs [28]. NAICS is a classification system used by the government and businesses in Canada, Mexico, and the United States of America that groups business establishments with similar production processes together (https://www.census.gov/naics/ accessed on 5 July 2023).

By using lumber manufactured from trees grown in NYS rather than outsourcing it to an imported species, a potential change will be introduced to the state's economy. The estimated regional economic impacts of manufacturing decking panels using domestic hardwoods by a NYS-based manufacturer were determined using IMPLAN (Version 7.2) which is an input–output (I–O) model. An I–O model describes the structure of a regional economy by the links among production, income distribution, consumption, savings, investment, and trade [29]. It is these linkages that are used to estimate regional economic impacts which is a standard use of the input–output models [29]. Regional economic input–output analysis is designed to examine the economic impact of "What If" scenarios associated with policy or other areas such as ecological restoration [30] and invasive species [31], which makes it an appropriate method for this study.

IMPLAN, an economic impact analysis software and data system, contains data for 546 distinct production or industrial sectors for the national, state, and county level economy that are categorized according to the NAICS [28,32]. The detailed information provided for each industry sector includes the dollar values of outputs produced and inputs used from other sectors, value added, employment, imports and exports, final demand by households and governments, capital investment, business inventories, marketing margins, and inflation factors (deflators). Regional economic data for states or counties is derived from a national technology matrix and the smaller the scale, the less "accurate" the modified technology matrix will be in terms of intermediate factor inputs [29].

IMPLAN allows users to download these detailed datasets and work with them by making desired modifications. For this project, we used IMPLAN's expenditure patterns for a sector defining the dollar value spent in other sectors within the economy for purchasing goods and services used in producing its output. Such values can be obtained from IMPLAN in terms of industries as well as commodities. An industry can produce more than one commodity, and commodities are goods or services that can be produced by more than one industry or institution [33]. If a commodity used in a production process is produced by more than one industry (for example: electricity), then using a commodity expenditure pattern will better capture the economic impacts of changes in production levels. If the commodity is produced primarily by a single industry, then using an industry expenditure pattern will capture the economic impacts of changes in production levels. For this project, the targeted product (decking panels) is primarily produced by a single industry. Nevertheless, analysis was performed with both the industry-based and commodity-based expenditure data in order to account for any potential shortcomings associated with extracting intermediate factor input data from a county-level technology matrix.

After touring several New York primary and secondary wood manufacturers, and discussing issues with managers, a company based in Onondaga county was identified as a plausible manufacturer of US Army specified decking panels. The IMPLAN sector which incorporates this industry is Sector 139: Other millwork, including flooring. The cor-

responding commodity is 3139: other millwork, including flooring. The NAICS industries included under sector 139 are given in Appendix B. As the chosen company was the only one that falls under sector 139 and produces commodity 3139 for the county, the IMPLAN expenditure pattern of that sector could be associated with that specific company.

Sector 139's expenditure data on intermediate factors of production in terms of industries and commodities were obtained using the 2021 data year. Further, the expenditures were modified to better reflect reality by deleting some expenditures that did not make sense. For instance, the deleted expenditures were for industries such as "Poultry and egg production", "Metal mining services", etc. The modification was completed using the expertise of the authors in consultation with industry professionals and IMPLAN staff. Clouse [34] has confirmed this approach of modifying an industry's expenditure pattern to reflect specific information.

After the modification, technical coefficients for Sector 139 were calculated using Equation (1). A technical coefficient refers to the numerical relationship between the output of one sector and the input it requires from other sectors. It can be defined as the per dollar expenditure on each input necessary to produce one dollar of output.

$$Technical\ Coefficients\ (a_i) = \frac{Expenditure\ on\ indiustry\ (commodity)\ \text{“i”}}{Total\ Expenditure\ of\ Sector\ 139} \quad (1)$$

Based on communications with trailer decking manufacturers and distributors, and price information given on the websites of leading suppliers of the country, such as Trailerdecking.com (accessed on 23 March 2023), the final product price for apitong trailer decking panels for the first quarter of 2023 was estimated to be around $9 per board foot (bft) ($3780 per cubic meter ($m^3$) converting as 1 $m^3$ = 35 cubic feet = 420 board feet) [35]. The dimensions of the decking panels vary widely based on the use and type of vehicle. For uniformity, the product price estimations in this study are based on approximate dimensions of 2 inch (5.1 cm) thick by 8 inch (20.3 cm) wide panels. Thus, all the product prices hereafter (both apitong and local hardwood decking panels) are for 2 × 8 panels.

The economic benefits of using domestic alternatives to apitong were derived from scenarios for hickory, white oak, and black locust. Based on *Hardwood Review* reports [36–38], the Hardwood Market Report [39], Robi Decking [40], and price information from other leading manufacturers and suppliers, the price of 2 × 8 kiln-dried lumber was estimated at $3, $5, and $11 per board foot for hickory, white oak, and black locust, respectively. Adding the manufacturing costs for making the final decking panels from lumber based on Lin et al. [41] (consumer price index (CPI) adjusted), the price of the final decking panels was estimated to be $4 per bft ($1680 per cubic meter ($m^3$)), $6 per bft ($2520 per $m^3$), and $12 per bft ($5040 per $m^3$), for hickory, white oak, and black locust, respectively. These price points are based on the National Hardwood Lumber Association grade of "First and Seconds" (FAS) [42,43].

After determining the final output price and the required output volume (i.e., the US Army demand for apitong), we calculated the total final output value. Based on those values, new expenditure patterns of Sector 139 were calculated using Equation (2) with the technical coefficients calculated from Equation (1).

$$\begin{aligned} New\ Expenditure\ Pattern\ (x_i) \\ = Technical\ coefficient\ for\ industry\ (commodity)\ \text{“i”} \\ \times Total\ final\ output\ value \end{aligned} \quad (2)$$

The new expenditure patterns were reassessed for their proximity to the industry expenses and then entered into IMPLAN for the three different species scenarios to estimate the economic impacts in NYS. A total of six IMPLAN analyses were run with commodity-based and industry-based expenditures for each of the three price scenarios. The direct, indirect, and induced impacts were determined in terms of employment, total output, labor income, and value added (value added is akin to gross domestic product (GDP) or, at the

New York level, gross state product (GSP)). Direct impact can be defined as the immediate effects of changes in the final demand on production. Similarly, indirect effects are those that result from industry-to-industry purchases in the supply chain that emerge from the initial industry input purchases. Further, induced effects refer to the economic impacts of households spending labor income earned from the direct and indirect effects.

## 3. Results and Discussions

### 3.1. Feedstock Availability

Figure 1 illustrates the net sawlog volume of the noted species in New York, obtained from the USFS FIA database (2022). Among the species, sugar maple has the highest sawtimber volume with an estimated 30 billion board feet (approximately 72 million cubic meters), followed by northern red oak, white oak, bitternut hickory, and black locust.

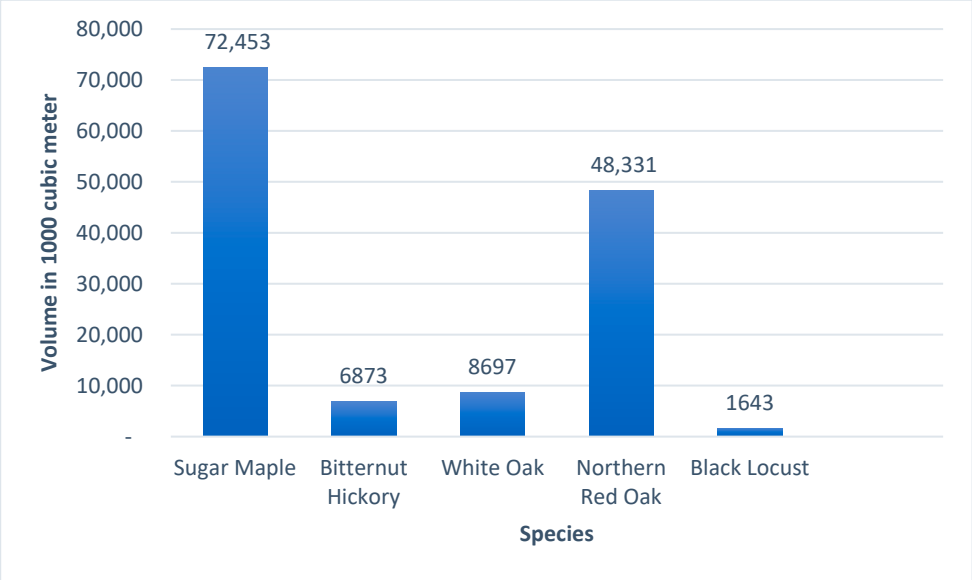


**Figure 1.** Net sawlog volume of sawtimber trees for the noted species, in cubic meters, on timber land in New York [44].

Further, data on average annual net growth and harvest removal volumes were also obtained from the USFS FIA database [44]. Using the growth and harvest values, growth-to-harvest ratios were calculated in order to assess long-term sawtimber availability for each species (Table 2).

**Table 2.** Feedstock availability of the noted species in New York State [44].

| Species | Growth [a] | Harvest [b] | Growth to Harvest Ratio |
|---|---|---|---|
| *Sugar maple* | 1,987,249 | 858,922 | 2.31 |
| *Bitternut hickory* | 263,807 | 13,608 | 19.39 |
| *White oak* | 109,370 | 15,213 | 7.19 |
| *Northern red oak* | 1,484,346 | 391,122 | 3.80 |
| *Black locust* | 73,304 | 6191 | 11.84 |

[a] Growth = Average annual net growth of sawlog volume of sawtimber trees, in cubic meters, on timberland.
[b] Harvest = Average annual harvest removals of sawlog volume of sawtimber trees, in cubic meters, on timberland.

The results indicate that just within NYS, there is a sustainable supply of sugar maple, bitternut hickory, white oak, northern red oak, and black locust stumpage for hardwood decking. We recognize that the volume of wood in the forest may not always be available or accessible. Based on our observation and communication with the primary manufacturers, this might be the case, especially for species such as black locust. However, the demand in

this case is a very small percentage of the total volume and the growth-to-harvest ratio is good for all species. Thus, this conclusion is deemed to be appropriate. NYS is growing 2 times as much sugar maple, 3 times more northern red oak, 7 times more white oak, 11 times more black locust, and 19 times more bitternut hickory than is being harvested.

### 3.2. Regional Economic Conservation Benefit

Based on our inquiry to the US Army seeking the wood decking requirements for US Army trailer systems, we found that "all the US Army Trailers consume an estimated 1 million board feet (MMBF) (2381 $m^3$) per year based on demand data of the board kits and their dimensions" [45]. Consequently, the final output value was estimated to be \$12,000,000, \$6,000,000, and \$4,000,000 for the products manufactured from black locust, white oak, and hickory, respectively.

#### 3.2.1. Scenario 1: Hickory

The IMPLAN results showing the economic impact in NYS of manufacturing 1 MMBF (2381 $m^3$) of decking panels by an Onondaga county-based manufacturer with a final product price of \$4 per bf (\$1680 per $m^3$), are shown in Tables 3 and 4.

**Table 3.** IMPLAN output summary for the commodity expenditure approach.

| Impact | Employment (Number of Jobs) | Labor Income (USD) | Value Added (USD) | Output (USD) |
|---|---|---|---|---|
| Output Summary for Black Locust (Final Product Price: \$5040 per $m^3$) | | | | |
| 1—Direct | 53 | 3,309,199 | 4,012,805 | 12,000,000 |
| 2—Indirect | 43 | 3,017,194 | 4,431,868 | 10,606,236 |
| 3—Induced | 21 | 1,624,698 | 2,883,808 | 4,356,700 |
| Total | 117 | 7,951,092 | 11,328,481 | 26,962,936 |
| Output Summary for White Oak (Final Product Price: \$2520 per $m^3$) | | | | |
| 1—Direct | 26 | 1,654,600 | 2,006,403 | 6,000,000 |
| 2—Indirect | 22 | 1,508,597 | 2,215,934 | 5,303,118 |
| 3—Induced | 10 | 812,349 | 1,441,904 | 2,178,350 |
| Total | 59 | 3,975,546 | 5,664,240 | 13,481,468 |
| Output Summary for Hickory (Final Product Price: \$1680 per $m^3$) | | | | |
| 1—Direct | 18 | 1,103,066 | 1,337,602 | 4,000,000 |
| 2—Indirect | 14 | 1,005,731 | 1,477,289 | 3,535,412 |
| 3—Induced | 7 | 541,566 | 961,269 | 1,452,233 |
| Total | 39 | 2,650,364 | 3,776,160 | 8,987,645 |

**Table 4.** IMPLAN output summary for the industry expenditure approach.

| Impact | Employment (Number of Jobs) | Labor Income (USD) | Value Added (USD) | Output (USD) |
|---|---|---|---|---|
| Output Summary for Black Locust (Final Product Price: \$5040 per $m^3$) | | | | |
| 1—Direct | 53 | 3,309,199 | 4,012,805 | 12,000,000 |
| 2—Indirect | 55 | 3,889,322 | 5,679,303 | 10,612,051 |
| 3—Induced | 24 | 1,869,576 | 3,318,455 | 5,013,341 |
| Total | 131 | 9,068,097 | 13,010,563 | 27,625,392 |
| Output Summary for White Oak (Final Product Price: \$2520 per $m^3$) | | | | |
| 1—Direct | 26 | 1,654,600 | 2,006,403 | 6,000,000 |
| 2—Indirect | 27 | 1,945,556 | 2,840,869 | 5,308,756 |
| 3—Induced | 12 | 937,148 | 1,663,417 | 2,512,999 |
| Total | 66 | 4,537,303 | 6,510,688 | 13,821,755 |
| Output Summary for Hickory (Final Product Price: \$1680 per $m^3$) | | | | |
| 1—Direct | 18 | 1,103,066 | 1,337,602 | 4,000,000 |
| 2—Indirect | 18 | 1,296,441 | 1,893,101 | 3,537,350 |
| 3—Induced | 8 | 623,192 | 1,106,152 | 1,671,114 |
| Total | 44 | 3,022,699 | 4,336,854 | 9,208,464 |

The total impact in terms of employment is 39 (38 Full time equivalents (FTE)) for the commodity expenditure approach, and 44 (43 FTE) for the industry expenditure approach (Employment in IMPLAN is annual average employment value and follows the same definition as Bureau of Labor Statistics and Bureau of Economic Analysis; not equal to full time equivalents [46]). Similarly, the total impact for the commodity approach in terms of labor income, value added, and output is $2,650,364, $3,776,160, and $8,987,645, respectively. The impact is similar to the industry expenditure approach. This is consistent with defining purchasing intermediate factor inputs using a commodity vs. industry approach [33].

#### 3.2.2. Scenario 2: White Oak

The IMPLAN results showing the economic impact in NYS of manufacturing white oak decking panels by an Onondaga county-based manufacturer with a final product price of $6 per bf ($2520 per $m^3$) are shown in Tables 3 and 4.

For the commodity expenditure approach, the total employment impact is 59 (58 FTE), while for the industry expenditure approach, it is 66 (65 FTE). Similarly, the total impact for the commodity approach in terms of labor income, value added, and output is $3,975,546, $5,664,240, and $13,481,468, respectively. Using the industry expenditure approach, the impact is similar in terms of output value, and approximately one million dollars more in terms of labor income and value added.

#### 3.2.3. Scenario 3: Black Locust

The IMPLAN results showing the economic impact in NYS of manufacturing black locust decking panels in Onondaga county with a final product price of $12 per bf ($5040 per $m^3$) with the modified expenditure pattern for Sector 139 in IMPLAN is shown in Tables 3 and 4.

The total impact in terms of employment is 117 (114 FTE) for the commodity expenditure approach and 131 (128 FTE) for the industry expenditure approach. Similarly, the total impact for the commodity approach in terms of labor income, value added, and output is $7,951,092, $11,328,481, and $26,962,936, respectively. Using the industry expenditure approach, the impact was found to be approximately two million dollars more in terms of value added, and approximately one million dollars more in terms of labor income and output.

The IMPLAN output summaries from Tables 3 and 4 show that manufacturing decking panels domestically using local hardwood species would provide regional economic benefits in terms of additional output, value added, and employment regardless of where the decking panels are manufactured. With respect to this case study, the economic impact in NYS could be as high as $27 million while adding around 131 (128 FTE) new jobs. However, equally important, these regional economic benefits are the result of the conservation of endangered tropical tree species within the genus of *Dipterocarpus*, no matter which domestic hardwood species is chosen to replace apitong. Thus, in addition to promoting the US forest products industry, the US Army could be assured that the decking is sourced from sustainably managed timberlands. Nonetheless, it is likely that the impacts may differ if decking panels are manufactured in different regions as the results are highly dependent on the overall region's economic structure.

Apitong has been used for decades due to its excellent properties and suitability for outdoor applications [47]. We are not claiming that any of the domestic hardwoods are more effective than apitong. In fact, this study started with the aim of exploring the use of lower grade domestic hardwoods as alternatives to apitong. After discussions with experts and flooring manufacturers and a review of the specification CID A-A-52520 and other relevant literature, it became apparent that lower grade hardwoods would not be suitable for trailer decking due to wear and tear requirements associated with US military use. Even high-grade lumber from species such as oak, hickory, or black locust are not perfect substitutes for apitong. Rather, these domestic hardwood species could sufficiently meet (not necessarily exceed) specifications [8].

According to US Army Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs [48], apitong decking is typically replaced up to five times during the 40-year lifecycle of a trailer. The proposed domestic species alternatives may require more frequent replacement/maintenance than apitong decking. In that case, the economic impact will be much greater than that estimated in this study. It is, however, important to note that the replacement frequency of trailer decks varies significantly based on geography, degree of exposure, and types of use. While requirements for more replacement/maintenance may not be optimal for trailer users across all sectors, it will generate more economic activity in the region, and, of course, contribute to the protection of an endangered tropical hardwood. Future studies can test the noted domestic species in experimental settings in order to determine the best alternatives for decking for different types of trucks and trailers. Moreover, engineered synthetic floorboards made from composite materials, metals, polymers, or hybrid materials may also be a suitable alternative to apitong panels [49]. It is necessary to conduct more rigorous studies involving the development of prototypes as well as testing in relevant environments to determine the viability and economic impact of using such materials.

It should be noted that the supply of domestic hardwood stumpage for wood decking, regardless of an increased replacement schedule, is both adequate and sustainable. In addition to NYS, there are several states in the US with significant volumes of sugar maple, northern red oak, white oak, bitternut hickory, and black locust as well as other species which may serve as suitable replacements for apitong. By using the USFS FIA database [42], we have the capacity to monitor growth-to-harvest ratios and ensure the sustainability of the supply chain. However, monitoring the sustainability of apitong is more problematic. Finding the equivalent of FIA data in most countries exporting apitong to the US is challenging, if not impossible. Forest resources cannot be managed effectively without measurement and monitoring, which ultimately results in unsustainable exploitation.

This case study focused exclusively on the US Army's use of apitong due to the lack of data sources for other US military branch users. Based on direct observations and anecdotal evidence, we discovered that apitong is being used for decking by other branches of the US military and other government agencies at the federal, state, and local levels. Moreover, personal communications with trailer decking manufacturers and a review of their websites indicate that apitong is the decking of choice for the private sector as well. Therefore, this case study on the US Army's use of apitong should be considered only the "tip of the iceberg". While we attempted to estimate apitong use via numerous FOIA requests to government agencies, the requests were consistently denied due to tracking difficulties. This illustrates the opaqueness and complexity of this supply chain challenge. Studies in the future can examine the bigger picture, including wood decking consumption from other government agencies and the private sector, as well as assess the acceptance of domestic alternatives to apitong. Further, there is an opportunity for developing more sophisticated and dynamic trade models to be incorporated into this policy analysis, using approaches such as computable general equilibrium models. However, these future research lines would need to build upon the basic analysis provided by this research.

As mentioned above, this study addresses the previously unexplored issue of the economic and environmental benefits derived from substituting ecologically sensitive tropical species for domestic alternatives. It builds upon existing literature on environmental impact policy analyses studies [30,31] by examining the impacts of substitution. While using input–output analysis for this type of study is a standard approach, this research is distinctive in a number of aspects. Firstly, it is the first study to examine the enforcement of an existing policy that specifies the use of domestic hardwood species for US Army trailer decking rather than the existing endangered tropical hardwood. The economic impact analysis conducted in this research, along with the identification of alternative local wood species exhibiting ample availability, effectively illustrates the resource availability and economic benefits. Secondly, the estimated regional economic impacts can be interpreted as regional economic conservational benefits of using suitable domestic hardwoods in

place of apitong. Next, the study incorporates a unique modeling approach, employing a Delphi-modified industry-specific expenditure pattern to estimate region-specific economic impacts resulting from the policy. Nevertheless, the approach used in this study does have limitations such as, data limitations, assumptions such as a static economic environment, and a lack of behavioral response, which are associated with all "What If" policy analyses using input–output models [29].

The study outcomes provide valuable insights for government entities subject to regulatory constraints and commercial entities seeking sustainable practices. Building upon the findings, it is important to consider policy changes that can further encourage the utilization of these domestic alternatives and promote their widespread adoption across all sectors. Enhancing awareness among procurement officers, decision-makers, and stakeholders on the many benefits of sustainable sourcing practices can play a crucial role. Additionally, allocating funding for research and development of alternative products, coupled with collaborative efforts between government, research institutions, and industry stakeholders, can facilitate innovation and promote the effectiveness and competitiveness of domestic hardwoods. By creating a supportive policy framework, the US Army can lead by example and encourage broader adoption of domestic hardwoods, thereby reducing dependence on endangered tropical hardwoods and fostering a more sustainable and resilient supply chain. Consequently, this study serves as a pivotal cornerstone for future research investigations and policy deliberations, aimed at fostering responsible utilization of tropical and domestic forest resources, addressing associated supply chain challenges, and aligning resource management practices with environmental regulations and sustainability objectives.

## 4. Conclusions

This study aimed to estimate the regional economic conservation benefits of replacing apitong used by the US Army for trailer and truck decking with suitable domestic hardwood products of three selected species: hickory, white oak, and black locust. Utilizing the USFS FIA database, the feedstock availabilities of the noted species were determined in terms of available volume and growth-to-harvest ratios in NYS. The availability of stumpage from sustainable sources is not in question, given that the US Army only requires a million board feet (2381 $m^3$) per year. The economic and employment benefits of using domestic hardwoods could be substantial, particularly if the entire decking market is considered, which could be tens of thousands of cubic meters. It is evident that apitong is a popular choice for decking in both the public and private sectors. Finding a suitable replacement for apitong will not only provide economic benefits to the US but will also contribute to the conservation of apitong species across the world's tropical forests.

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## Appendix A

**Table A1.** IUCN Conservation Status of *Dipterocarpus* Species.

| Species | Conservation Status | Species | Conservation Status |
|---|---|---|---|
| *Dipterocarpus indicus* | Endangered | *Dipterocarpus applanatus* | Vulnerable |
| *D. bourdillonii* | Critically Endangered | *D. cornutus* | Critically Endangered |
| *D. kerrii* | Endangered | *D. rigidus* | Critically Endangered |
| *D. obtusifolius* | Near Threatened | *D. semivestitus* | Critically Endangered |
| *D. concavus* | Critically Endangered | *D. dyeri* | Endangered |
| *D. globosus* | Least Concern | *D. tuberculatus* | Near Threatened |
| *D. eurhynchus* | Near Threatened | *D. borneensis* | Near Threatened |
| *D. caudatus* | Least Concern | *D. caudiferus* | Near Threatened |
| *D. geniculatus* | Endangered | *D. lowii* | Near Threatened |
| *D. costulatus* | Near Threatened | *D. validus* | Least Concern |
| *D. retusus* | Endangered | *D. confertus* | Near Threatened |
| *D. costatus* | Vulnerable | *D. cuspidatus* | Critically Endangered |
| *D. intricatus* | Endangered | *D. lamellatus* | Critically Endangered |
| *D. oblongifolius* | Least Concern | *D. humeratus* | Near Threatened |
| *D. fusiformis* | Endangered | *D. hasseltii* | Endangered |
| *D. cinereus* | Critically Endangered | *D. gracilis* | Vulnerable |
| *D. tempehes* | Endangered | *D. turbinatus* | Vulnerable |
| *D. nudus* | Least Concern | *D. acutangulus* | Endangered |
| *D. palembanicus* | Vulnerable | *D. littoralis* | Critically Endangered |
| *D. perakensis* | Endangered | *D. verrucosus* | Near Threatened |
| *D. alatus* | Vulnerable | *D. fagineus* | Critically Endangered |
| *D. baudii* | Vulnerable | *D. hispidus* | Critically Endangered |
| *D. grandiflorus* | Endangered | *D. insignis* | Critically Endangered |
| *D. chartaceus* | Endangered | *D. zeylanicus* | Endangered |
| *D. crinitus* | Vulnerable | *D. sublamellatus* | Endangered |
| *D. glandulosus* | Critically Endangered | *D. rotundifolius* | Endangered |
| *D. elongatus* | Critically Endangered | *D. pachyphyllus* | Vulnerable |
| *D. kunstleri* | Critically Endangered | *D. ochraceus* | Endangered |
| *D. coriaceus* | Critically Endangered | *D. glabrigemmatus* | Endangered |
| *D. conformis* | Endangered | *D. mundus* | Vulnerable |
| *D. stellatus* | Vulnerable | | |

## Appendix B

**Table A2.** NAICS Description of Industries under IMPLAN Sector 139.

| NAICS Code | NAICS Description |
|---|---|
| 321918 | Baseboards, floor, wood, manufacturing |
| 321918 | Brackets, wood, manufacturing |
| 321918 | Clear and finger joint wood moldings manufacturing |
| 321918 | Columns, porch, wood, manufacturing |
| 321918 | Cornices, wood, manufacturing |
| 321918 | Decorative wood moldings (e.g., base, chair rail, crown, shoe) manufacturing |
| 321918 | Door shutters, wood, manufacturing |
| 321918 | Door trim, wood molding, manufacturing |
| 321918 | Exterior wood shutters manufacturing |
| 321918 | Floor baseboards, wood, manufacturing |
| 321918 | Flooring, wood, manufacturing |
| 321918 | Moldings, clear and finger joint wood, manufacturing |
| 321918 | Moldings, wood and covered wood, manufacturing |

**Table A2.** *Cont.*

| NAICS Code | NAICS Description |
|---|---|
| 321918 | Newel posts, wood, manufacturing |
| 321918 | Ornamental woodwork (e.g., cornices, mantels) manufacturing |
| 321918 | Panel work, wood millwork, manufacturing |
| 321918 | Parquet flooring, hardwood, manufacturing |
| 321918 | Parquetry, hardwood, manufacturing |
| 321918 | Planing mills, millwork |
| 321918 | Porch work (e.g., columns, newels, rails, trellises), wood, manufacturing |
| 321918 | Railings, wood stair, manufacturing |
| 321918 | Shutters, door and window, wood and covered wood, manufacturing |
| 321918 | Shutters, wood, manufacturing |
| 321918 | Stair railings, wood, manufacturing |
| 321918 | Stairwork (e.g., newel posts, railings, staircases, stairs), wood, manufacturing |
| 321918 | Trellises, wood, manufacturing |
| 321918 | Trim, wood and covered wood, manufacturing |
| 321918 | Venetian blind slats, wood, manufacturing |
| 321918 | Wainscots, wood, manufacturing |
| 321918 | Weather strip, wood, manufacturing |
| 321918 | Window trim, wood and covered wood moldings, manufacturing |
| 321918 | Wood flooring manufacturing |
| 321918 | Wood moldings (e.g., prefinished, unfinished), clear and finger joint, manufacturing |
| 321918 | Wood shutters manufacturing |

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