EVALUATION OF THE ROLE OF TREES IN REMOVING AIR POLLUTANTS AT SELECTED UNIVERSITIES IN HO CHI MINH CITY USING I-TREE ECO MODEL

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ABSTRACT

Air pollution is one of the most concerns problems currently. The air quality of urban areas depends directly and indirectly on urban vegetation because trees are identified to have ability to remove air pollutants. In this study, I-tree Eco model was used to quantify the removal ability of air pollutants from trees at selected universities in Ho Chi Minh City. Tree species, total tree height, stem diameter at breast height and tree location were collected in 2021. The results showed that the trees on the campus of the International University and the University of Technology removed approximately 10 kg and 14 kg of $PM_{2.5}$/year (equivalent to 1.51 and 2.16 million VND); stored 64 and 92.7 tons of carbon/year (equivalent to 6.63 and 9.55 million VND), and absorbing 13.23 and 27.85 tons of CO_2 equivalent, respectively. *Senegal mahogany* and *Cassia* tree species had the greatest ability to remove fine particle, stored and absorbed carbon among the remaining species of the two universities. In the next 10 years, when all species in the International University and the University of Technology is replaced by *Senegal mahogany* and *Cassia* species, environmental and economic benefits of $PM_{2.5}$ removal, carbon storage and sequestration will increase by 40% compared to the existing species composition.

ĐÁNH GIÁ VAI TRÒ CỦA CÂY XANH TRONG VIỆC LOẠI BỎ CÁC CHẤT GÂY Ô NHIỄM KHÔNG KHÍ TẠI MỘT SỐ TRƯỜNG ĐẠI HỌC CỦA THÀNH PHỐ HỒ CHÍ MINH BẰNG MÔ HÌNH I-TREE ECO

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TỪ KHÓA

Lưu trữ và hấp thụ cacbon
Cây đô thị
Cấu trúc rừng đô thị
Ô nhiễm không khí
I-Tree Eco

TÓM TẮT

Ô nhiễm không khí là một trong những vấn đề đáng quan tâm nhất hiện nay. Chất lượng không khí của khu vực đô thị phụ thuộc trực tiếp và gián tiếp vào thảm thực vật đô thị do cây xanh có khả năng loại bỏ các chất gây ô nhiễm không khí. Nghiên cứu này sử dụng mô hình I-tree Eco được sử dụng nhằm định lượng khả năng loại bỏ chất gây ô nhiễm không khí của cây xanh tại một số trường đại học của Tp. HCM. Loài cây, chiều cao cây, đường kính ngang ngực và vị trí của cây được thu thập vào năm 2021. Kết quả nghiên cứu cho thấy cây xanh trong khuôn viên trường Đại học Quốc tế và Đại học Bách khoa loại bỏ lần lượt khoảng 10 kg và 14 kg $PM_{2.5}$/năm (tương đương 1,51 và 2,16 triệu đồng), lưu trữ 64 và 92,7 tấn carbon/năm (tương đương 6,63 và 9,55 triệu đồng), và hấp thụ 13,23 và 27,85 tấn CO_2 tương đương. Cây xà cừ và cây muồng đen có khả năng loại bỏ bụi, lưu trữ và hấp thụ cacbon lớn nhất. Sau 10 năm tới, khi thay thế toàn bộ các loài cây tại Trường Đại học Quốc tế và Đại học Bách khoa sang cây xà cừ và cây muồng đen, lợi ích môi trường và kinh tế đem lại từ việc loại bỏ bụi $PM_{2.5}$, lưu trữ và hấp thụ carbon sẽ tăng 40% so với thành phần loài hiện hữu.

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1. Introduction

Air pollution has been threatening the health of people all over the world. Estimates show that nine out of ten people breathe air containing high concentrations of pollutants. According to the data of World Health Organization (WHO), more than sixty thousand deaths in Vietnam caused by heart disease, stroke, lung cancer, chronic obstructive pulmonary disease and pneumonia were related to air pollution. The main sources of air pollution in Vietnam include transportation, industry, construction, agricultural production, handicrafts and inefficient waste management [1] [2]. Concentrations of air pollutants in big cities in Vietnam mostly exceed the National Technical Regulation on Ambient Air Quality (QCVN 05:2013) including nitrogen oxides (NO_x), carbon monoxide (CO) and total suspended particulate (TSP) [3]. Particulate matters (PM), especially, $PM_{2.5}$ becomes important risk factors for many diseases of the human. There are 14 days and 175 days which the $PM_{2.5}$ concentration of the largest city such as Ho Chi Minh City (HCMC), exceeded the Vietnam National Standard and WHO guideline in 2016, respectively [4]. The level of $PM_{2.5}$ in big cities in Vietnam was forecasted to increase by 20 to 30% in 2030 because of rapid urbanization and growing economy [5].

In order to reduce air pollution in the current conditions of industrialization and urbanization, many solutions have been researched and applied. In addition to solutions focusing on approaches such as: increasing dispersion, reducing emissions at source or end-of-pipe treatment, studies on the role of urban vegetation and urban plants are also of interest [6]. The air quality of urban areas depends directly and indirectly on urban vegetation because trees are identified to have ability to affect air quality through temperature reduction and other microclimatic effects; removal of air pollutants; energy effects on buildings etc [7]. Trees act as a carbon dioxide (CO_2) reservoir by fixing carbon during photosynthesis and storing carbon in the form of biomass. Trees in urban areas are currently storing carbon, which can be released back into the atmosphere after the tree dies and absorbs it as it grows. Urban trees also influence the air temperature and energy demand of buildings, and thus alter carbon emissions from different urban sources [8] - [10]. The report of Vietnam Environment Administration in 2020 has shown that the total area of green in Ho Chi Minh City is more than 10,300 hectares, but so far, only 445 hectares have been implemented for the trees. The average green area per capita is about 2 m^2, of which the area of green park is only 0.55 m^2 per person. This density of trees does not meet the urban standard because it requires 10 m^2 of tree per capita to ensure fresh air for human. Given the growing expanse of urban areas, trees within these areas have the potential to not only store and sequester carbon but also remove other pollutants from the air [8].

Several models have been used to evaluate the carbon storage and sequestration capacity of trees such as InVest carbon storage and sequestration, Carbon Accounting Model for Forest, etc. However, these models do not take into account the removal capacity of air pollutants, economic benefits as well as forecasting future benefits of trees planted in the study areas. Meanwhile, I-tree is a modern software suite developed by the United Nation Forest Service (USDA Forest Service) under the US Department of Agriculture, the software provides tools to analyze and evaluate the benefits of urban trees. I-Tree tools including I-tree Eco help to assess the structure of urban trees at multiple scales and enhance urban tree management and advocacy efforts by quantifying the environmental services that trees provide. I-tree is superior to other models in providing tools to assess the environmental benefits of trees. In addition, this model can provide in-depth solutions to develop integrated green space management and sustainable urban policies to reduce air pollution [11]. Universities are one of the urban areas which have already been investigated in several previous studies in other countries around the world. However, the researches on the benefits of trees in reducing air pollution in urban areas of Vietnam, especially at universities, have been not published. Furthermore, the I-tree Eco model has only been introduced to state management agencies and interested scientists in Vietnam in 2021. Therefore, this paper aims for studying the role of trees in removing air pollutants at selected universities in Ho Chi Minh City by an application of I-tree Eco model. It also discusses and offers the detail benefits of trees in order to contribute to green spaces management in urban areas.

2. Methods

2.1. Study area

This study was conducted in International University – HCMIU (21 ha, 10°52’42” N and 106°47’58” E) and University of Technology - HCMUT (26 ha; 10°52’53” N and 106°48’18” E) located in Thu Duc City, Ho Chi Minh City, Vietnam. The climate of Ho Chi Minh City is a tropical climate, with a high average humidity, about 78-82%. The average temperature is 28^0C and the mean annual precipitation is 1979 mm [11].

2.2. Data collection method

2.2.1. Primary data collection

Following the protocol of I-tree Eco data collection (www.intreetools.org), field data was collected including diameter at breast height (DBH), tree species, total tree height, and global positioning system (GPS).

Identification the trees to survey: The survey method used for the study was the survey by line (sidewalk crops) and by cluster (forest plantations). All trees with diameter 10 cm or more in the campus of two university were selected for survey.

Identification of DBH: Tree stem diameter at breast height (DBH), which was estimated at 4.5 feet or 1.37 meters above the ground. In this study, the DBH of tree was calculated by the diameter. The diameter was identified by using tape measure and also recorded at 1.37 meters above the ground. For a single-stem tree, just noted the diameter 1 and DBH1 of that tree. In case of a multi-branched tree, note the diameter and DBH of each branch was collected (e.g., DBH1, DBH2).

Identification of tree species: The species of trees were identified in the field or after the field with the help from the experts or website of www.inaturalist.org. For the species could not be identified, a sample was taken, followed by numbered and recorded it in notebook as University # XXX unknown #1, etc. Sequentially number unknowns were in notebook and attempted to identify later.

Identification of total tree height: The total tree height was from the ground to the top of the tree. The clinometer was used to determine the total height of tree. For standing dead trees, downed living trees, or severely leaning trees, height was considered the distance along the main stem from ground to tree top (Do not include dead trees that are lying on the ground.)

Tree location coordinates: Location information of each tree was recorded by GPS device. The latitude and longitude of the tree was recorded in each university.

2.2.2. Secondary data collection

The secondary data consisted of precipitation data, additional weather data and pollution data. Weather data was also used in I-tree Eco and is available globally from the National Climatic Data Center (NCDC). On the other hand, the update meteorological data could be also taken from the website www.climatetemp.infor or www.wunderground.com.

2.2.3. Finishing data collection

Quality Assurance (QA) Plan was designed specifically for i-Tree Eco data collection using either volunteer or professionally trained field crews. Although originally intended for sample inventories, it can be modified for complete inventories. It was important to implement QA procedures to ensure accurate data. By setting standards and monitoring fieldwork, one can prevent or at least detect and corrected errors and eliminated the repetition of most errors. Quality assurance procedures used in data collection should be documented for future project management reference, especially if planning to repeat in the future. Although Quality Assurance information and procedures were not included in the Eco reporting, it was an essential part of a research to ensure consistency of collected data and model results. After the initial training period, periodic inspections should be made of every crew's fieldwork. Inspections were the most important mechanism for assuring quality data. The number of errors detected might influence the frequency of inspections.

2.3. Assessment of trees benefits

2.3.1. Carbon storage and sequestration

Whole tree carbon storage was calculated for each tree using forest-derived biomass equations and field measured tree data [12]. Biomass for each tree was calculated using allometric equations. Aboveground biomass were converted to whole tree biomass based on a root-to-shoot ratio of 0.26. Fresh weight biomass were multiplied by species conversion factors to yield dry weight biomass (0.48 for conifers and 0.56 for hardwoods). To address the difference between trees in more natural stand condition (e.g., forest) and urban trees, biomass results for urban trees were multiplied by 0.8 [13]. To estimate annual carbon sequestration, average annual diameter growth from appropriate genera, diameter class, and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1. Projected carbon estimates from year x+1 was subtracted from carbon estimates in year x to determine gross carbon sequestration.

2.3.2. Air pollution removal

Air pollution removal estimates were calculated for ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter less than 2.5 microns ($PM_{2.5}$). However, because of unavailable hourly concentration of these pollutants for at least 1 year, this study used the available hourly pollution data from the Itree – Eco model for $PM_{2.5}$ of Ho Chi Minh City in 2017. The hourly $PM_{2.5}$ removal (F, in $\mu g\ m^{-2}\ hr^{-1}$) was calculated as the product of deposition velocity of the pollutant to the leaf surface (*V*d, in $m\ hr^{-1}$) and concentration of $PM_{2.5}$ (C, in $\mu g\ m^{-3}$) [14]:

$$F = Vd \times C \quad (1)$$

Removal and resuspension rates for $PM_{2.5}$ varied with wind speed and leaf area [14]. The values of wind speed were taken from the data of Tan Son Nhat Weather Station in HCMC. For each wind speed, the median velocities of $PM_{2.5}$ was used to estimate the Vd for that wind speed per unit leaf area.

2.3.3. Economic benefits

According to the official dispatch 3479/VPCP-NN on pilot project of forest carbon credit trading in 2021, the economic equivalent of carbon sequestration was calculated by using the tree's carbon value multiplied by $5 per ton of carbon. For the removal of pollutants, the economic value obtained from $PM_{2.5}$ removal was calculated as 164,107 VND/kg $PM_{2.5}$ based on the default value of I-tree Eco model.

2.4. Scenario development

Based on the output of I-tree model, three scenarios were established following the purpose of analysis including environmental, economic aspects and environmental and economic combination to run the I-tree Eco model. Detailed scenario was presented in Table 1.

Table 1. *Scenario development*

Scenario	Aspect	Information
Base state		Present conditions of trees in the area of two universities and in the next 10 years
Scenario 1	Environment	Assumed that we replaced 100% of the total tree by the species that have the most ability of air pollutant removal in the next 10 years.
Scenario 2	Economic	Assumed that we replaced 100% of the total tree by the species that have the most economic benefit in the next 10 years.
Scenario 3	Environment and economic combination	Combine the information of scenario 1 and scenario 2

2.5. Model running and output data analysis

2.5.1. Model running

For the base state, the data of GPS, DBH, tree species, and total height then were entered into i-Tree Eco v6.1.40 for running the analysis and generated the initial results for the current year of study and after 10 years with the same species composition. Scenario 1, 2 and 3 were estimated based on the result of the base state with species composition varying with environmental, economic and combined benefits after 10 years.

2.5.2. Output data analysis

Outputs from the model provided all information of structure by species/stratum, population by species/stratum, species distribution by DBH class, benefits summary of trees by species/stratum, carbon storage of trees by species/stratum, annual carbon sequestration of trees by species/stratum, oxygen production of trees by stratum, pollution removal by trees and shrubs, and net annual benefits of all trees. These data were analyzed to achieve the objectives of this study by Excel.

3. Results and discussion

3.1. Tree characteristics of the universities

From the output results of I-tree Eco model, the urban forest of HCMIU had 247 trees with the tree cover of 1.4 percent. The three most common species are *Senegal mahogany* (36.8%), *Ta-khian* (25.1%), and *Yellow flametree* (13.0%) (Figure 1a). In HCMUT, there are 698 trees with the tree cover of 4.7 percent and three most common species are *Dipterocarpus spp.* (35.5%), *Ta-khian* (20.3%), and *Queen's crapemyrtle* (9.5%) (Figure 1b).

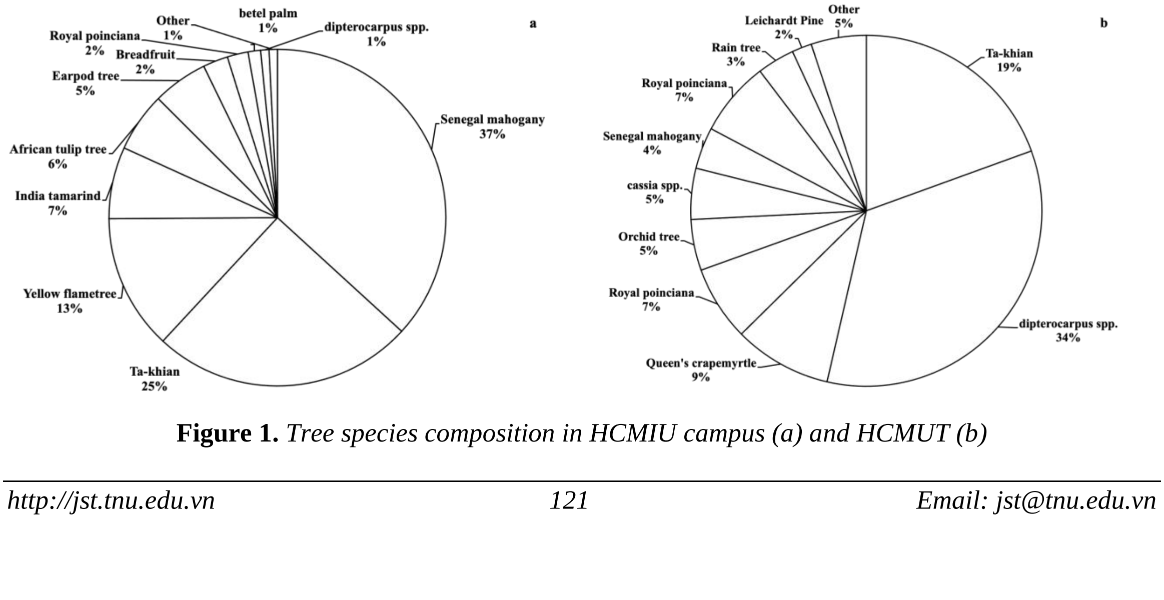

Figure 1. *Tree species composition in HCMIU campus (a) and HCMUT (b)*

The field data in average values from two collected universities were placed in Table 2 (HCMIU) and 3 (HCMUT) consisting of the average DBH (cm), total height (m) and tree count (numbers) of each tree species.

Table 2. *The average DBH (cm), total height (m), tree count (value) of each tree species in HCMIU*

Species Name	Average DBH (cm)	Average Total Height (m)	Tree Count	
			Value	%
African tulip tree	13.9 ± 3.4	9.3 ± 2.3	14	5.70
Betel palm	19.9 ± 1.8	13.3 ± 4.2	1	1.20
Breadfruit	30.7 ± 13.2	11.6 ± 3.2	6	2.40
Hairy-Leafed Apitong	17.0 ± 1.3	9.4 ± 0.7	2	0.80
Eagle rock blackberry	15.9 ± 0	10.6 ± 0	1	0.40
Earpod tree	21.7 ± 14.4	12.1 ± 8.0	13	5.30
India tamarind	27.2 ± 5.3	14.9 ± 3.1	17	6.90
Queen's Crape Myrtle	32.4 ± 0	10.8 ± 0	1	0.40
Royal poinciana	29.1 ± 10.3	16.1 ± 5.7	5	2.00
Senegal mahogany	35.6 ± 18.1	20.0 ± 9.7	91	36.80
Ta-khian	21.6 ± 9.6	12.0 ± 5.3	62	25.10
Yellow flametree	21.5 ± 5.3	12.4 ± 3.4	32	13.00
	Total		**247**	**100.00**

Table 3. *The average DBH (cm), total height (m), tree count (value) of each tree species in HCMUT*

Species Name	Average DBH (cm)	Average Total Height (m)	Tree Count	
			Value	%
Bauhinia spp	26.1 ± 0	11.0 ± 0	1	0.1
Breadfruit	42.6 ± 0	23.7 ± 0	1	0.1
Bucayo	29.6 ± 13.3	16.5 ± 7.4	21	3.0
Canafistula	19.7 ± 3.2	9 ± 0	2	0.3
Golden Shower	26.8 ± 11.1	14.9 ± 6.1	34	4.9
Hairy-Leafed Apitong	16.5 ± 1.1	55.8 ± 0.8	4	0.6
Dipterocarpus spp	20.5 ± 6.	11.4 ± 3.4	248	35.5
Freshwater Mangrove	22.2 ± 3.7	12.3 ± 2.1	5	0.7
Ginger-thomas	10.5 ± 0.6	5.9 ± 0.6	6	0.9
Japanese beech	28.9 ± 5.0	16.0 ± 2.8	5	0.7
Leichardt Pine	11.4 ± 3.4	6.4 ± 1.9	13	1.9
Livistona spp	44.4 ± 7.8	4.5 ± 0.5	2	0.3
Madagascar almond	33.4 ± 0	18.6 ± 0	1	0.1
Norfolk island pine	18.7 ± 0	10.4 ± 0	1	0.1
Orchid tree	25.8 ± 6.2	10.7 ± 2.6	34	4.9
Pine spp	26.4 ± 1.8	15.5 ± 0.9	4	0.6
Queen's crape Myrtle	17.6 ± 3.6	9.8 ± 2.0	66	9.5
Raintree	23.5 ± 5.4	13.1 ± 10.7	25	3.6
Royal poinciana	22.5 ± 6.6	9.3 ± 7.9	50	7.2
Senegal mahogany	34.7 ± 10.5	14.2 ± 2.6	28	4.0
Ta-khian	16.7 ± 6.	8.6 ± 3.8	142	20.3
Manila Palm	38.2 ± 6.9	21.2 ± 3.8	5	0.7
	Total		**698**	**100.0**

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. The diversity of tree species among those two universities is slightly different (Figure 2a and 2b). For example, about 41% and 36% of trees species in HCMIU and HCMUT are species native to Asia, respectively.

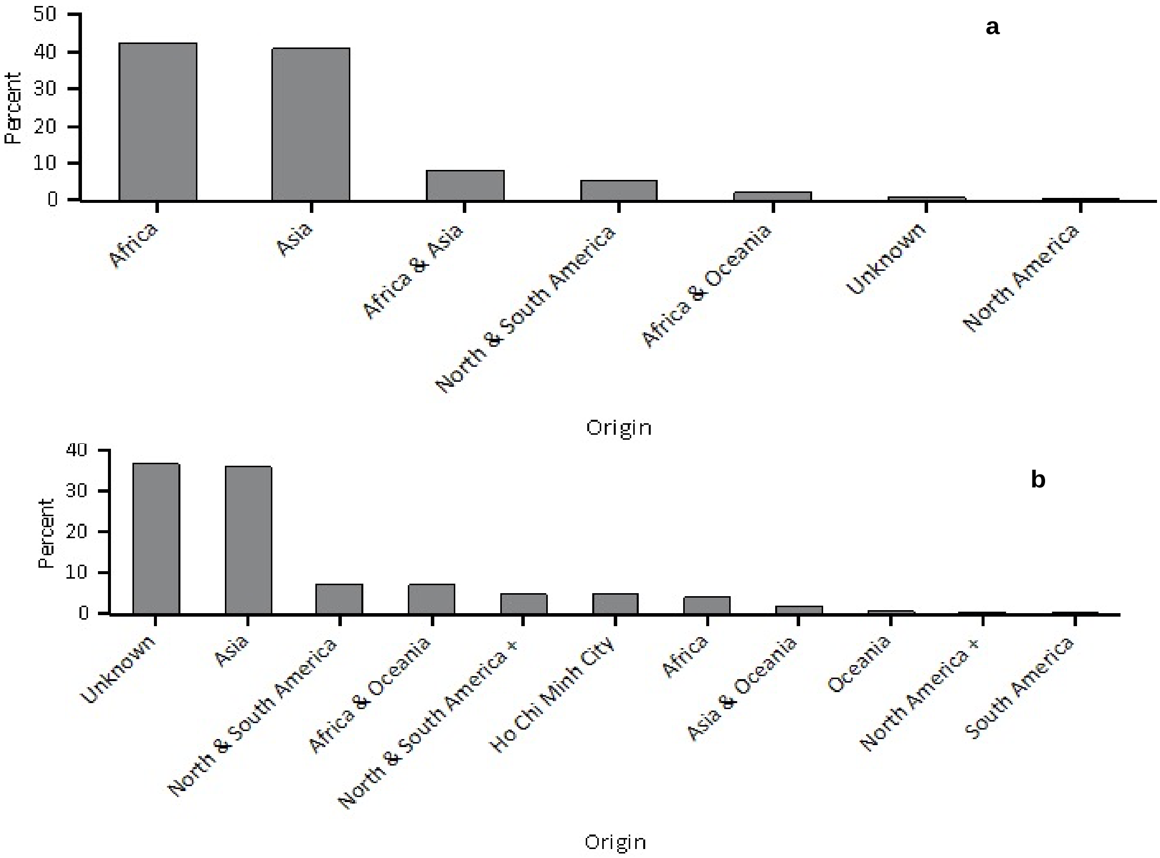

Figure 2. *Tree species collected in HCMIU (a) and HCMUT (b)*

The results also indicate that the tree species composition in HCMUT is higher than those of HCMIU. This can be explained by the larger number of areas for tree and higher overall tree density in HCMUT.

3.2. Tree cover and leaf area

Trees cover about 4.7% of HCMUT area and provide about 74,625 m^2 of leaf area. Total leaf area in HCMUT is higher than those in HCMIU whose trees cover about 1.4% and provide 46,094 m^2 of leaf area. As also explained above, the study area of HCMIU is quite smaller than those of HCMUT, leading the lower numbers of urban trees as well as the tree cover percentage. In HCMIU urban plants, the most dominant species in terms of leaf area are *Senegal mahogany*, *Ta-khian*, and *Yellow flametree* while in HCMUT urban plants are *Senegal mahogany*, *Ta-khian*, and *Dipterocarpus spp*. Table 4 listed ten species with the greatest importance values. Importance values (IV) are calculated as the sum of percent population and percent leaf area. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure.

3.3. Air pollution removal by urban trees and benefits

Due to unavailable hourly data in a year for levels of ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2) from the monitoring station of HCMC, this study estimates the $PM_{2.5}$ removal by tree only using field data, available pollution concentration data and available weather data. $PM_{2.5}$ is emphasized as an important parameter to assess the air quality in HCMC as this parameter mainly representative for Air Quality Index (AQI) in the big cities and causes numerous health effects for human. In HCMIU, it is estimated that trees remove about 10 kg of $PM_{2.5}$ per year with an associated economic value of 1.51 million VND. HCMUT has higher amount of $PM_{2.5}$ removal, about 14 kg and 2.16 million VND per year. Table 5 (HCMIU) and 6 (HCMUT) presented the results of removal of $PM_{2.5}$ for the tree species having the on-site number equal or higher than 5 in each university.

Table 4. *Most important species in HCMIU and HCMUT with percent population, percent leaf area and IV*

Species Name	Percent Population		Percent Leaf Area		IV	
	HCMIU	HCMUT	HCMIU	HCMUT	HCMIU	HCMUT
Dipterocarpus spp	0.8	35.5	0.2	43.8	1	79.5
Ta-khian	25.1	20.3	24.6	11	49.7	31.3
Senegal mahogany	36.8	4	54.6	10	91.4	14
Queen's crapemyrtle	-	9.4	-	3.3	-	12.7
Cassia spp	-	4.9	-	7.2	-	12.1
Royal poinciana	2	7.2	1.3	4.2	3.3	11.4
Rain tree	-	3.6	-	5.1	-	8.7
Orchid tree	-	4.9	-	2.9	-	7.8
Bucayo	-	3	-	3.9	-	6.9
Japanese beech	-	0.7	-	3.5	-	4.2
Yellow flametree	13	-	5.2	-	18.1	-
India tamarind	6.9	-	4.4	-	11.3	-
Earpod tree	5.3	-	4.3	-	9.6	-
African tulip tree	5.7	-	1.5	-	7.2	-
Breadfruit	2.4	-	3.1	-	5.5	-
Betel palm	1.2	-	0.2	-	1.5	-

Table 5. *The $PM_{2.5}$ removal efficiency (kg/yr) and value (VND/yr) in total and by tree species in HCMIU*

Species Name	$PM_{2.5}$ (kg/yr)	Removal value (VND/yr)	$PM_{2.5}$ (kg/yr/tree)	Removal value (VND/yr/tree)
African tulip tree	0.14	22884.29	0.01	1634.6
Betel palm	0.02	3723.89	-	-
Breadfruit	0.29	46719.58	0.05	7786.6
Hairy-Leafed Apitong	0.02	2795.19	-	-
Eagle rock blackberry	0.03	4099.93	-	-
Earpod tree	0.39	64766.26	0.03	4982
India tamarind	0.41	66559.35	0.02	3915.3
Queen's Crape Myrtle	0.03	4087.41	-	-
Royal poinciana	0.12	19573.91	0.03	3914.8
Senegal mahogany	5.08	823701.17	0.06	9051.7
Ta-khian	2.28	371733.24	0.04	5995.7
Yellow flametree	0.47	77953.76	0.01	2436.1
Total	**9.27**	**1508597.98**	**-**	**-**

Table 6. *The $PM_{2.5}$ removal efficiency (kg/yr) and value (VND/yr) in total and by tree species in HCMUT*

Species Name	$PM_{2.5}$ (kg/yr)	Removal value (VND/yr)	$PM_{2.5}$ (kg/yr/tree)	Removal value (VND/yr/tree)
Bauhinia spp	0.01	2,031.73	-	-
Breadfruit	0.07	11,178.56	-	-
Bucayo	0.52	84947.5	0.03	4045.1
Canafistula	0.01	2031.7	-	-
Golden Shower	0.95	155962	0.03	4587.1
Hairy-Leafed Apitong	0.04	6130.65	-	-

Species Name	$PM_{2.5}$ (kg/yr)	Removal value (VND/yr)	$PM_{2.5}$ (kg/yr/tree)	Removal value (VND/yr/tree)
Dipterocarpus spp	5.76	944079.3	0.02	3806.8
Freshwater Mangrove	0.15	24159.61	0.03	4831.9
Ginger-thomas	0.02	3406.64	0.00	567.8
Japanese beech	0.47	76206.76	0.09	15241.4
Leichardt Pine	0.09	13874.78	0.01	1067.3
Livistona spp	0.02	3418.21	-	-
Madagascar almond	0.04	5,997.44	-	-
Norfolk island pine	0.01	1,403.26	-	-
Orchid tree	0.39	63172.93	0.01	1858
Pine spp	0.11	19004.93	-	-
Queen's crape Myrtle	0.45	71352.73	0.01	1081.1
Raintree	0.67	110816	0.03	4432.6
Royal poinciana	0.56	91346.13	0.01	1826.9
Senegal mahogany	1.32	216474.1	0.05	7731.2
Ta-khian	1.44	236791.9	0.01	1667.5
Manila Palm	0.07	11122.16	0.01	2224.4
Total	**13.14**	**2,156,482.31**	**-**	**-**

3.4. Carbon storage, sequestration, and benefits

Trees in HCMIU are estimated to store 64 tons of carbon (equivalent to 6.63 million VND). In which, *Senegal mahogany* species stores and sequesters the most carbon (approximately 70.6% of the total carbon stored and 55.6% of all sequestered carbon). On the contrary, the urban plants in HCMUT are expected to store 92.7 tons of carbon (about 9.6 million VND). The *Dipterocarpus spp.* species stores approximately 38.9% of the total carbon and sequesters the most carbon as 44.3% of all sequestered carbon.

Table 7 (HCMIU) and 8 (HCMUT) presented the results of carbon storage (ton) and benefits (VND) in total and for tree species in each university.

Table 7. *Carbon storage, CO_2 equivalent (ton) and benefits (VND) in total and by tree species in HCMIU*

Species Name	Trees Number	Carbon Storage		CO_2 equivalent (ton)	Removal benefit (VND)
		Ton	%		
Breadfruit	6	1.03	1.6	3.8	106,483.35
Betel palm	3	0.46	0.7	1.7	47,889.18
Royal poinciana	5	0.95	1.5	3.5	98,531.25
Dipterocarpus spp	2	0.08	0.1	0.3	8,160.60
Earpod tree	13	2.35	3.7	8.6	243,979.06
Ta-khian	62	8.57	13.4	31.4	888,183.32
Senegal mahogany	91	45.14	70.6	165.6	4,676,285.86
Lagerstroemia spp	1	0.20	0.3	0.7	20,906.45
Yellow flametree	32	2.06	3.2	7.5	212,966.99
Eagle rock blackberry	1	0.14	0.2	0.5	14,695.93
African tulip tree	14	0.12	0.2	0.5	12,938.78
India tamarind	17	2.84	4.4	10.4	294,657.22
Total	**247**	**63.95**	**100.0**	**234.5**	**6,625,677.99**

Table 8. *Carbon storage, CO_2 equivalent (ton) and benefits (VND) in total and by tree species in HCMUT*

Species Name	Trees Number	Carbon Storage		CO_2 equivalent (ton)	Removal benefit (VND)
		Ton	%		
Rain tree	25	5.41	5.8	19.8	560,035.60
Breadfruit	1	0.38	0.4	1.4	39,454.24
Norfolk island pine	1	0.07	0.1	0.3	7,622.85

Species Name	Trees Number	Carbon Storage		CO_2 equivalent (ton)	Removal benefit (VND)
		Ton	%		
Bauhinia spp	1	0.21	0.2	0.8	21,779.43
Freshwater Mangrove	5	0.63	0.7	2.3	65,221.89
Orchid tree	34	5.48	5.9	20.1	567,888.62
Canafistula	2	0.18	0.2	0.7	18,755.60
Cassia spp	34	13.16	14.2	48.3	1,363,435.38
Royal poinciana	50	4.65	5.0	17.1	482,121.64
Dipterocarpus spp	248	36.04	38.9	132.4	3,733,732.05
Dipterocarpus caudatus	4	0.12	0.1	0.4	12,626.53
Bucayo	21	2.14	2.3	7.8	221,355.35
Japanese beech	5	1.15	1.2	4.2	119,456.96
Ta-khian	142	5.23	5.6	19.2	542,108.96
Senegal mahogany	28	9.91	10.7	36.4	1,027,230.79
Queen's crapemyrtle	66	2.94	3.2	10.8	304,255.09
Livistona spp	2	0.53	0.6	2.0	55,172.78
Leichardt Pine	13	0.16	0.2	0.6	16,559.98
Pine spp	4	1.22	1.3	4.5	126,490.63
Madagascar almond	1	0.39	0.4	1.4	40,854.17
Ginger-thomas	6	0.05	0.1	0.2	5,644.64
Veitchia spp	5	2.62	2.8	9.6	271,108.19
Total	**698**	**92.7**	**100.0**	**340.1**	**9,602,911.34**

3.5. Benefits from different scenarios

Based on the numbers of $PM_{2.5}$ removal, gross carbon sequestration and benefits, the species with highest capabilities and values of these aspects were selected to be replaced 100% of trees in HCMIU and HCMUT to estimate the total benefits from these changes. *Senegal mahogany* species were selected in HCMIU and *Senegal mahogany* and *Cassia* species were selected in HCMUT for estimating the benefits from different scenarios. Using the forecast function of the I-tree Eco, the annual benefits of $PM_{2.5}$ removal, gross carbon sequestration and total benefits were calculated after 10 years. Scenario A is a combined scenario of scenarios 1, 2 and 3 described in Table 1 because Senegal mahogany species is the species with the greatest ability to remove $PM_{2.5}$, absorb carbon and bring the highest economic benefits in HCMIU. Similarly, at HCMUT, scenario B is a combined scenario of scenarios 1, 2 and 3 described in Table 1 because *Senegal mahogany* species is the largest $PM_{2.5}$ remover, *Cassia* species is a largest carbon absorber and these are also the two species that bring the highest economic benefits. Based on that, the benefits of replacing all species to *Senegal mahogany* species in HCMIU (Scenario A) and *Senegal mahogany* and *Cassia* species in HCMUT after 10 years (Scenario A and Scenario B, respectively) were also estimated (Figure 3).

As mentioned in the estimating scenarios, the mortality rate of trees set by the I-tree Eco model based on the physiological properties of each species was in the range of 2.02 – 4.68% for HCMIU and 1.42 – 3.98% for HCMUT. In the current year, the *Senegal mahogany* species in HCMIU could remove about 0.06 kg/yr/tree for $PM_{2.5}$; the gross carbon sequestration was 20.02 kg/year/tree with the pollution removal benefit of about 905 VND/yr/tree. For base state, when the plant was kept at the same current situation on HCMIU campus, the $PM_{2.5}$ removal amount was estimated as 93.3 kg, the gross carbon sequestration was about 32 ton and therefore, the pollutant removal benefits was in total as 15.1 million VND for the next 10 years. However, if the *Senegal mahogany* species was chosen to be replaced onsite, the $PM_{2.5}$ removal was enhanced up to 139.6 kg, the gross carbon sequestration increased to 46.5 ton. For economic value, the pollutant removal benefit by *Senegal mahogany* was about 21.1 million VND for the next 10 years. In the case of HCMUT for the current state, the *Senegal mahogany* and *Cassia* spp were efficient to be replaced by the studied plants due to the high removal of $PM_{2.5}$ and gross carbon sequestration led to the potential pollutant removal benefits. For the base state in the next 10 years, the $PM_{2.5}$ removal and gross carbon sequestration was about 135.5 kg and 67.2 ton, respectively, with the estimated removal benefits being 22 milllion VND. When the scenarios were applied as species changing, the removal of $PM_{2.5}$ increased to 326 kg for *Senegal mahogany* and 196 kg for *Cassia* spp. The gross carbon sequestration also was obeyed this results as 120.5 ton for *Senegal mahogany* and 151 ton for *Cassia* spp. Finally, the pollutant removal benefit was enchanced up to 50.3 and 30 millions VND in the case of *Senegal mahogany* and *Cassia* spp, respectively.

In the next 10 years, if all species in HCMUT and HCMIU are replaced by *Senegal mahogany* and *Cassia* species, both environmental and economic benefits of $PM_{2.5}$ removal and carbon sequestration will increase more than 40% compared to the existing species composition of the base state. For the environmental benefits, the capacity of $PM_{2.5}$ removal and carbon sequestration in HCMUT in Scenario A will raise 141% and 79% while in Scenario B will be 44% and 125%, respectively. In terms of the economic benefits, the total values of $PM_{2.5}$ removal and carbon sequestration of Scenario A in HCMUT will grow 118% while of Scenario B will be about two times lower than those of Scenario A, about 45 million VND.

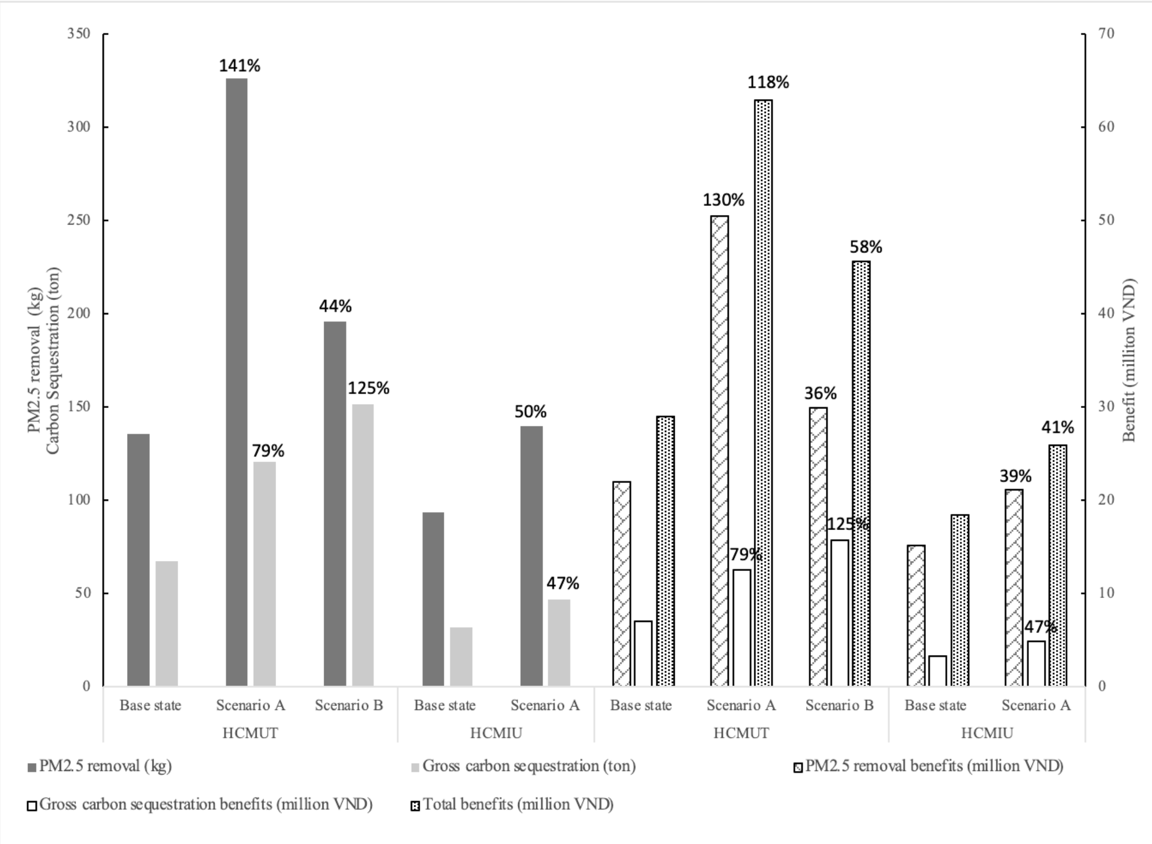

Figure 3. *Benefits of replacing all species to Senegal mahogany species (Scenario A) and Cassia species (Scenario B) in HCMUT and HCMIU after 10 years*

In summary, these findings contribute to the decision of governmental organizations and urban architecture specialists to select which species should be planted in the universities in particular and in the urban areas in general to improve the air quality as well as to bring more economic benefits in the future.

4. Conclusion

Understanding the structure, function and value of trees in two different universities in Ho Chi Minh City can promote management decisions that will improve human health and environmental quality. Data from 247 trees in HCMIU and 698 trees in HCMUT were analyzed using the I-tree Eco model developed by the U.S. Forest Service, Northern Research Station. From the results of the research, in HCMIU, three most common species are *Senegal mahogany* (36.8%), *Ta-khian* (25.1%), and *Yellow flametree* (13.0%) while HCMUT has three most common species, namely *Dipterocarpus spp* (35.5%), *Ta-khian* (20.3%), and *Queen's crapemyrtle* (9.5%). In terms of benefits of air pollutants removal, trees in HCMIU remove approximately 10 kg of $PM_{2.5}$, with an associated economic value of 1.51 million VND while trees in HCMUT remove 14 kg of $PM_{2.5}$, equivalent to an economic value of 2.16 million VND. For the benefits of carbon storage and sequestration, trees in HCMIU are estimated to store 64 tons of carbon (6.63 million VND). Conversely, the urban plants in HCMUT are expected to store 92.7 tons of carbon (about 9.55 million VND). Among multiple species, *Senegal mahogany* species in HCMIU and *Senegal mahogany* and *Cassia* species in HCMUT were identified as the species that produce the highest ability on $PM_{2.5}$ removal, gross carbon sequestration and annual benefits. First, for the environmental benefits, the capacity of $PM_{2.5}$ removal and carbon sequestration in HCMUT in Scenario A will rise 141% and 79% while in Scenario B will be 44% and 125%, respectively. In HCMIU, the capacities of $PM_{2.5}$ removal and carbon sequestration are lower, about 50% and 47%, respectively. Second, for the economic benefits, the total values of $PM_{2.5}$ removal and carbon sequestration of Scenario A in HCMUT will grow 118% while Scenario B will be about two times lower than those of Scenario A, about 45 million VND. The values of $PM_{2.5}$ removal and carbon sequestration of Scenario A in HCMIU are lower than those in HCMUT.

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