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Assessment of Carbon Dioxide Reduction Efficiency Using the Regional Carbon Neutral Model—A Case Study in University Campus, Taiwan

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ABSTRACT

A regional carbon neutral model was built to assess the balance of carbon dioxide (CO_2) *absorption by plants and emission by power usage in Tajen University, in the south of Taiwan, in order to test a carbon neutral model on a small-scale carbon neutral effect and its correlation to a large-scale forest carbon neutral effect. The number of plants was measured to estimate the* CO_2 *fixation volume on the Tajen University campus. The results showed that the total* CO_2 *absorption volume by plants was* 34,800 *tons during a* 40-*year plant life period on the campus. This absorption capacity was over the baseline of the green building standard in Taiwan, which is* 31,800 *tons. The plants on the Tajen University campus could absorb approximately* 870 *tons of* CO_2 *per year. However, this was lower than the estimated yearly* CO_2 *emission volume of* 6721 *tons which was emitted from power and diesel fuel usage in the campus. In order to reach a balance, it will be necessary to plant more trees and reduce energy usage on the campus in order to increase* CO_2 *absorption, and it will additionally be necessary to implement energy conservation policies to reach the goal of regional carbon neutrality.*

Keywords: *Greenhouse Gas, Plant, Carbon Dioxide, Carbon Neutral*

1. Introduction

In recent years, dramatic environmental changes have caused extraordinary climate changes around the globe. This has made countries all over the world focus on greenhouse effect issues [1-3]. It is an important problem that can't be ignored because the greenhouse effect causes global warming [4,5]. In the past century, research and literature has concluded that carbon dioxide (CO_2) concentration increased by 28% following the industrial revolution [6]. The global average temperature has increased by 0.3˚C to 0.6˚C, and the sea level rose 10 to 15 cm in the past 100 years. If greenhouse gas (GHG) emissions continue to increase at the present rate, it is predicted that the average global temperature will increase by about 1˚C by the year 2025, and by 3˚C at the end of the century [7]. The increase of atmospheric GHG concentration results to a large extent from human activities [8,9]. Scientists predict if no effective protection policies for the environment are put into place, the global temperature will increase by 1˚C to 3.5˚C, and the sea level will increase by 15 to 95 cm. This will make many countries uninhabitable by 2100 [10]. The second assessment report of Intergovernmental Panel on Climate Change (IPCC) stated that the CO_2 concentration in the atmosphere rose from 280 to 358 ppm in 1994 [11]. The World Meteorology Organization (WMO) greenhouse gas annual report in 2007 also pointed out that the CO_2 concentration had already risen to 383 ppm [12]. To avert global warming, the Kyoto Protocol mentioned that plants are the major absorbers of CO_2 [13]. Therefore, forestation has become an important subject for all countries [14]. Plants can purify the air, beautify the environment, and absorb the CO_2 in the atmosphere through photosynthesis, transforming the CO_2 into organic matter in order to store it in the plant body [15,16]. Thus, plants have multiple helpful environmental functions. Plants have made great contributions to reducing the greenhouse effect [17].

In this research, a regional carbon neutral model was built to assess the balance of CO_2 absorption by plants and emission by power use at the Tajen University campus, located in southern Taiwan. The goal of this research was to test the carbon neutral model on a small-scale carbon neutral effect and its correlation to a large-scale forest carbon neutral effect.

2. Materials and Method

2.1. Green Plants on the Campus

Plants are the major CO_2 absorption subjects in this study. To understand the CO_2 reduction effect of plants on the campus, we examined the plants and the background data regarding the campus. In this research, the campus was divided into nine sections marked A to I for the purpose of counting the categories and numbers of trees in each section which is shown in **Figure 1**. The trunk diameter of each tree was measured at the 1.3 m height of the tree. A tree was categorized as an old tree when the trunk of the tree was over 30 cm, or the tree height was over 10 m. The shade of an arbor was estimated as 25 m^2, but the shade of an old tree was measured by the actual projected area of the tree crown. The shade of trees influences the CO_2 fixation volume, as described in the following section. The tree heights, the intervals between trees, and the projected area of the trees were also recorded. Initially, the school's background data would influence the calculated results of this research, so the campus's environmental information had to be investigated. The school background investigation items included the building base areas, athletic fields, parking areas, and green areas, among other relevant components.

2.2. Carbon Dioxide Fixation Volume by Plants on the Campus

In this research, the estimation CO_2 fixation volume from plants followed the Green Building Handbook of Taiwan (2009 edition). The CO_2 absorption weight for arbors, bushes, and grass areas were 900, 300 and 20 kg/m^2, respectively, as shown in **Table 1**. This means the CO_2 absorption effect of arbors was 3 times that of bushes and was 45 times that of grass areas. However, the complex planted areas including the arbors, bushes, and grasses were the most effective for CO_2 fixation, with 1200 kg/m^2. The total CO_2 fixation volume calculation formula is displayed in Equations (1)-(3). The shaded areas for each tree were estimated as 25 m^2, and the shade of old trees was the actual projected tree crown areas, as mentioned in the prior section.

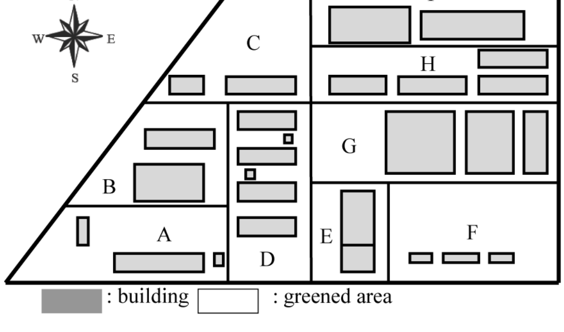

Figure 1. The investigation regions in Tajen University.

$$\mathrm{TCO_2} = \left(\sum (G_i \times A_i)\right) \times \alpha \quad (1)$$

$$\alpha = 0.8 + 0.5 \times ra \quad (2)$$

$$ra = \left(20 \times \sum_{i=1}^{n'} Nt'_i + \sum_{i=1}^{nb'} Nb'_i\right) \Big/ \left(20 \times \sum_{i=1}^{n} Nt_i + \sum_{i=1}^{nb} Nb_i\right) \quad (3)$$

where the TCO_2 is the total CO_2 absorption volume of green areas (kg); A_i is the shade area of arbor (m^2), and G_i is the CO_2 fixation volume in unit area for the plant (kg/m^2). The n and Nt are the kinds and numbers of tree, respectively. The n' and Nt' are the kinds and numbers of the original trees in Taiwan, respectively. The nb and Nb are the kinds and numbers of bushes, respectively. The nb' and Nb' are the kinds and numbers of original bushes in Taiwan, respectively.

The minimum CO_2 fixation volume in a region should be over the baseline of CO_2 fixation volume indicated in the Green Building Handbook. The baseline was calculated by Equations (4) and (5).

$$\mathrm{TCO_{2C}} = 1.5 \times (0.5 \times A' \times \beta) \quad (4)$$

$$A' = (A_0 - A_P) \times (1 - r) \quad (5)$$

where TCO_{2C} is the baseline of CO_2 fixation volume (kg) from the Green Building Handbook. A_0 is the base areas of the investigation region (m^2). A_P is the area which could not be green, such as the sports fields and track field (m^2). β is the base CO_2 fixation volume in a unit area with 500 kg/m^2 and r is the building ratio with 0.4.

Table 1. The CO_2 fixation volume in unit area for plant.

Category	Species	G_i (kg/m^2)
Complex ecology	arbor, bush, lawn[a]	1200
	broadleaf arbor	900
Arbor	conifer arbor	600
	palms	400
Bush[b]		300
Vines		100
Lawn, grass, aquatic plant		20

a. The interval of trees lower than 3.5 m; b. At least 4 trees in square meter area.

2.3. Regional Carbon Neutral Analysis

Plants were the major absorption source of CO_2 on the campus, and the major emission CO_2 source was power usage. A regional carbon neutral model was built in this research to assess the balance of CO_2 absorption by plants and emission by power use at Tajen University. The model structure is shown in **Figure 2**, which is shown according to the data base of plants on the campus discussed in the prior section and the power usage data used to assess CO_2 absorption and emission volume.

At Tajen University, power and diesel fuel were found to be the major CO_2 emission sources. The power usage and diesel fuel volume were measured for the purpose of calculating the CO_2 emission capacity. The CO_2 emission factor for power was 0.638 kg-CO_2/degree and 2.73 kg-CO_2/L for diesel fuel. The total CO_2 emission volume by power and diesel fuel in the campus could be calculated by Equation (6),

$$\mathrm{RCO}_2 = E_P \times k_P + E_d \times k_d \tag{6}$$

where RCO_2 is the total CO_2 emission capacity (kg); E_p and E_d are the power and diesel fuel use volume (degree or L), and k_p, k_d are the CO_2 emission factors for power and diesel fuel, respectively (no dimension).

The CO_2 concentration on the campus was measured with a CO_2 detector. The detection locations were marked by a Global Positioning System (GPS), and the CO_2 concentration distribution contours are shown in order to indicate the CO_2 differences on the campus.

2.4. Carbon Dioxide Concentration Detected on the Campus

There were 62 sampling points for the purpose of detecting the CO_2 concentration, which included 34 points inside the campus and 28 points at the boundary of the school. The gap for each sampling point was 50 m. The detection locations were marked by a Global Positioning System (GPS). The CO_2 concentration on the campus was measured with a CO_2 detector (KD Engineering, USA) using a Non-dispersive Infrared (NDIR) method.

The detection time for each sample was 60 seconds, and the detection range for CO_2 concentration was 0 to 10,000 ppm. The CO_2 concentration distribution contours could display the CO_2 differences on the campus.

3. Results and Discussion

3.1. The Plants on the Campus

As was mentioned earlier, the campus was divided into nine sections marked A to I for the purpose of counting the categories and numbers of trees in each section, as shown in **Table 2**. The most varied of arbors was in region A with 47 different varieties of plants, then the region I with 35. Region I had the most varied of bushes with 17, then the region A with 15. The greatest number of arbors was in region I (331). The next greatest num-

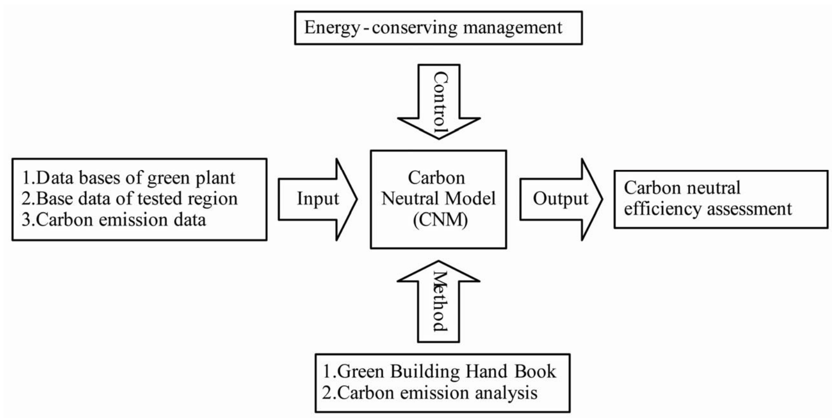

Figure 2. Carbon neutral model structure.

Table 2. The categories and numbers of plants in Tajen University campus.

Tree		Region									
		A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*Total*
Arbor	category	47	10	24	29	13	29	25	28	35	88*
	number	219	82	26	246	129	141	109	50	331	1333
Bush	category	15	11	3	9	11	4	2	2	17	46*
	area (m^2)	46	125	96	331	154	36	204	305	95	1392

a. There were some same kinds of plants in different regions, the total number was the summation of difference kinds plant in all regions.

bers were in regions D and A, with 246 and 219, respectively. The total number of arbors on the campus was 1333, including 88 different varieties. Among all of the trees, the most common arbors were the *Alstonia scholaris*, *Juniperus chinensis* and *Terminalia boivinii*. The most common bushes were the *Ficus microcarpa*, *Ixora williamsii* and *Codiaeum varirgatum*. The distribution of each kind of plant is displayed in **Figure 3**. The original trees and trees unique to Taiwan were about 23% and 4%, respectively.

3.2. Green Covering Rate

The green covering rate can indicate the regional green situation. The largest green area on the Tajen University campus was lawn, with an area of 33,267 m^2; next was the area of arbors, 28,904 m^2, which included broadleaf arbor (14,848 m^2), conifer arbor (12,581 m^2) and palms (1475 m^2). The complex ecological area was 10,200 m^2, and the bush area was 1392 m^2, vines area was 230 m^2. The total green area was 73,993 m^2 and the total base area of Tajen University campus was 154,693 m^2. The green covering rate is calculated as the ratio of green area to the base areas which was 47.8% for Tajen University. On the Tajen University campus, the green area was 3.2 times the required green building standard. It was above the standard of the Green Building Handbook of Taiwan, which is 15%.

3.3. Carbon Dioxide Neutral Analysis on the Campus

According to Equations (1-3), the total CO_2 absorption volume was 34,800 tons by plants during a 40-year period on the Tajen University campus. The absorption capacity was above the baseline of the green building standard in Taiwan, which is 31,800 tons. The lawn area was 45.0% of the total green area, but the CO_2 absorption volume by the lawn was only 2.0%. **Figure 4** presents the CO_2 absorption of different kinds of plants on the campus. The most efficient CO_2 absorber was the complex ecology area, which consisted of 13.8% of the total green area, but the CO_2 absorption efficiency was 33.0%. The broadleaf and conifer areas absorbed 40.0% and 22.8%of the CO_2, respectively.

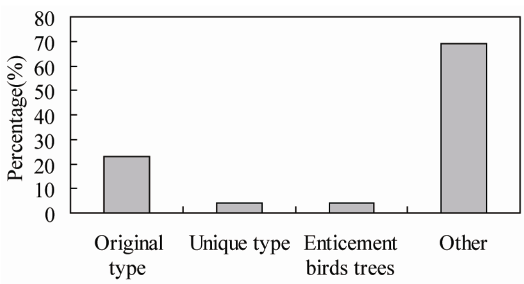

Figure 3. Percentages of different kinds of plants in Tajen University.

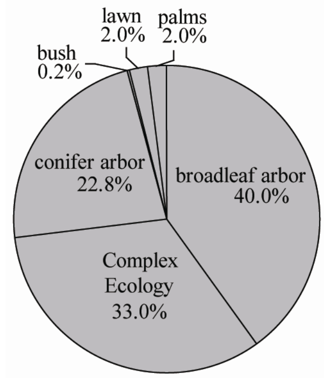

Figure 4. CO_2 absorption of different kinds of plants in Tajen Universit.

The average power and diesel fuel use on the campus from 2006 to 2009 was 9.88×10^6 degrees and 1.53×10^5 liters per year, respectively. According to the Bureau of Energy Ministry of Economic Affairs Taiwan (BEMEAT) power emission report, the CO_2 emission factor of power was 0.638 kg-CO_2/degree and 2.73 kg-CO_2/L for diesel fuel. The average CO_2 released by volume was 6,721 tons per year on the campus, which included 93.8% power use and 6.2% for diesel fuel. However, the total CO_2 fixation volume by plants was 870 tons per year.

The CO_2 absorption capacity was 12.9% of the emission volume. Green plants could absorb about 12.9% of the CO_2 that was released on the campus.

3.4. Carbon Dioxide Distribution on the Campus

The CO_2 concentration in the air of Tajen University from Aug. 2009 to Jan. 2010 was 314 to 534 ppm. The average CO_2 concentration during this period was 387 ppm, almost the same as the WMO report from 2008, which was 385.2 ppm. The CO_2 concentration distribution is shown in **Figure 5**. The higher CO_2 concentration areas were concentrated in the parking lots and the classrooms. Region A near the road and region H were both parking lots, so CO_2 concentrations were higher there than was the case in other areas. The CO_2 concentration was lower in more green areas such as regions C and F because trees can absorb CO_2. The more green areas appeared to have lower temperatures than other areas.

4. Conclusions

In this research, a carbon neutral model was made to as-

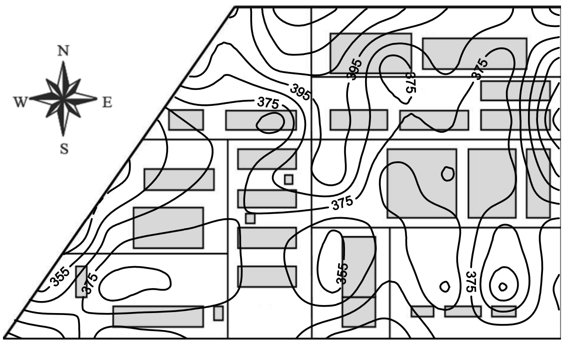

Figure 5. Average CO_2 concentration contour in Tajen University from Aug. 2009 to Jan. 2010.

sess CO_2 balance on the campus of Tajen University. Available plants were the major cause of CO_2 absorption. There were 88 kinds of arbors, with a total of 1333 and 46 kinds of bushes, with a total area of 1392 m^2. The total CO_2 absorption volume in the 40-year lifecycle of trees at Tajen University was about 34,800 tons. This was higher than the baseline of the green building standard in Taiwan (31,800 tons). Therefore, the plants on the Tajen University campus could absorb about 870 tons of CO_2 per year. However, the CO_2 absorption capacity by plants was only 12.9% of the emission volume resulting from power and diesel fuel use in the campus, which is far lower than the yearly CO_2 emission volume. In order to reach a balance of CO_2 capacity, more trees need to be planted and power and diesel fuel use needs to be lowered. Additionally, energy conservation policies need to be executed in order to achieve a goal of regional carbon neutrality.

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