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A Minimum-Cost Optimization of Greenhouse Gas Neutralization for *Cerrado*, the Brazilian's Biome

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Abstract. Global warming and climate change is a fact that is distressful to all population of the world. A solution being proposed by ecosystem's experts is the carbon footprint neutralization. Hence, the aim of this paper is to propose a design method to minimize the plantation costs of *Cerrado*, the Brazilian's Biome native flora. First, the greenhouse gas emissions inventory has to be established using the GHG (Greenhouse Gas) protocol. After determining the result of GHG emissions inventory, the gas neutralization has to be computed using the branch-and-bound optimization technique.

Keywords: Sustainable Economy, Sustainable Development, Optimization, Carbon Footprint, Cerrado, Brazilian's biome

1. Introduction

Climate change and global warming are currently major global concerns. The greenhouse effect is a physical phenomenon that naturally happens, caused by the presence of gases in the atmosphere, which is mainly composed of oxygen (21%) and nitrogen (78%). The main greenhouse gases are water vapor, carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20) [1].

The largest sources of GHG emissions include burning of fossil fuels and deforestation by releasing CO2 into the atmosphere. Hence, global warming has increased in recent decades due to the increase of GHG emissions by civilization. This represents a risk to life on Earth. That is, anthropogenic activities cause the emissions of Greenhouse Gases (GHG). This is directly related to the process of urbanization and the increase of energy consumption. As a consequence, awareness of world population has raised and now it demands a reaction for quality of life improvement.

Hence, the methodology of carbon offsetting process has arrived to satisfy that demand by decreasing the carbon rates in the atmosphere. One solution is the neutralization of carbon gas emission and computational models are required to a more efficient and reliable approach.

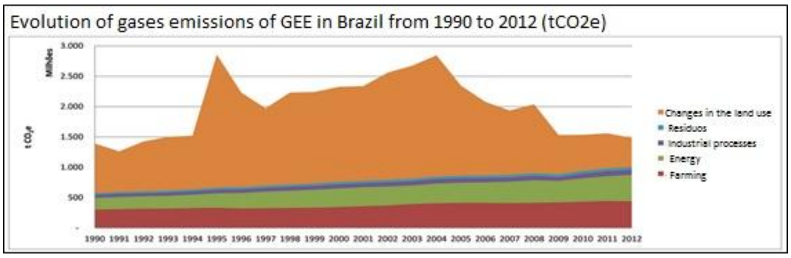

Fig. 1: Evolution of Gross Gas Emissions in Brazil.

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The evolution of emissions analyzed by the System of Estimates of Greenhouse Gas Emissions (SEEG) in Brazil for the last 22 years was not linear (see Figure 1). Due to the ups and downs recorded by the sector of Changes of Use of Land and Forests, computed relative to deforestation, the Brazilian totals varied greatly, reaching its peak in 2004 with 2.9 billion tCO2e (tons of carbon dioxide equivalent). Since then, the totals have been decreasing, mainly because of the significant drop in Amazon's rain forest deforestation [1].

Regarding these issues, a computational model was developed to plan the neutralization cost of carbon gas emissions for the Brazilian's Cerrado Biome, which has a large number of species of native trees in the database of plant species. The goal is to minimize costs by taking into account the regulatory restrictions. The optimization technique explored in this work is called Branch-and-Bound (B&B), based on the idea of developing an intelligent enumeration of candidate points to optimal solution [2].

This paper is organized as follows. The next section introduces general concepts about the carbon neutralization process adopted in this work, such as: Cerrado – the Brazilian's Biome; GHG Protocol, which is the emissions inventory; and how the neutralization computation is done. Section 3 presents the B&B technique and the mathematical model to minimize the costs of planning the carbon capture process. The section 4 presents the results obtained by applying the technique B&B with real data. Finally, in section 5 conclusions and future works are presented.

2. Background

The concept of carbon sequestration was enclosed in the Kyoto Conference [3], in 1997, which aimed to contain and reverse the buildup of greenhouse gases in the atmosphere resulting from human activities. One way to reverse this situation is carbon sequestration in forests. In principle, sequestration (fixing) carbon, apply the conservation of forest areas at risk of being destroyed, the restoration of degraded forests and the establishment of new forest plantations, as well as, the implementation of agroforestry systems with native or exotic species. The ecosystems can accumulate in its biomass, the carbon removed from the atmosphere during the process of photosynthesis. Plants absorb carbon dioxide and water using sunlight and energy, converting carbon dioxide into glucose. Oxygen (O2) is released during the production of biomass [4].

The Kyoto Protocol seeks to reverse the damage caused by global warming, generating guidelines, especially for the governments of industrialized countries, aiming to reduce their GHG emissions, and thus collaborating through regulating greenhouse. The environmental compensation measures have mobilized people and institutions in this cause. These measures consist in making attitudes that will reduce the emission of gases, or even, remove part of these gases from the atmosphere, by the relief of greenhouse effect on the planet.

One of the most used forms of environmental compensation is through the neutralization of carbon emissions by individuals, businesses, industries, government agencies and/or events with the planting of native trees, which in turn, incorporate CO2, removing it from the atmosphere.

The process of environmental compensation through the neutralization of carbon emissions by planting native seedlings is basically composed of three stages [5]:

- Inventory of CO2 emissions
- Calculation of neutralization
- Planting and maintaining native plants

2.1. Cerrado Biome

According to the Brazilian Ministry of the Environment (2013), the Cerrado is the second largest biome in South America, occupying an area of 2,036,448 km², about 22% of the brazilian national territory. Its continuous area focuses on the states of Goiás, Tocantins, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Bahia, Maranhão, Piauí, Rondônia, Paraná, São Paulo and the Federal District, and the enclaves in Amapá, Roraima and Amazonas. At this territorial space lies the headwaters of three major river basins of South America (Amazon/Tocantins, São Francisco, and Prata), which results in a high potential aquifer and promotes biodiversity.

In this region, the most important GHG emissions are CO2, resulting from the conversion of forests to agricultural or cropping areas.

2.2. Carbon Compensation

The environmental compensation can be understood as a mechanism of accountability for entrepreneurs and government causing significant environmental impact for the damage they cause to the environment. One way to mitigate the causes generated by businesses is promoting reforestation of degraded areas.

Many activities done by entrepreneurs and government have a negative effect on the environment. However, entrepreneurs and government must compensate this negative impact on the environment. One way to achieve this is throughout afforestation or reforestation, which in recent times has been essential to the preservation of the different biomes and crucial for the maintenance of biological equilibrium.

2.3. GHG Protocol

The GHG (Greenhouse Gas) Protocol, which was launched in 1998, and revised in 2004, is today the most important tool worldwide used by companies and governments to understand, to quantify, and to manage their emissions. According to the specifications of the Brazilian GHG Protocol Program, the methodology is compatible with the standards of the International Organization for Standardization (ISO), and the methodologies for quantifying the Intergovernmental Panel on Climate Change (IPCC). The application of Brazilian GHG Protocol Program since 2008 has been adapted to the Brazilian's context mode.

The information generated by the protocol has been applied to reports and questionnaires of initiatives such as Carbon Disclosure Project, Bovespa Index of Corporate Sustainability (ISE) and Global Reporting Initiative (GRI).

There are several benefits to the organizations participating in the program, which are:

- Competitive advantage - calculate, participate in benchmarks and manage GHG emissions can ensure the sustainability of business and improving efficiencies;
- Improved relations with stakeholders (stakeholders) - The development of a corporate/institutional GHG inventory, based on international standards and criterias, enables the company to publish reliable information according to the criteria of the Carbon Disclosure Project, the Bovespa Corporate Sustainability Index (ISE), the Global Reporting Initiative (GRI), and others of interest to funders, consumers and other audiences;
- Historical Data Logging - the establishment of a historical record of GHG emissions allows organizations to adopt voluntary measures to improve its processes, which may be considered under the legislation or programmatic regulations eventually adopted in the future;
- Conditions to participate in carbon markets - Companies that publish their inventories of GHG emissions can identify opportunities to reduce emissions and thereby carry out projects eligible for obtaining marketable credits in the carbon market.

The ultimate goal of the program is to promote, through engagement of technical, institutional capacities, and corporate culture of voluntary character for identification, the calculation and preparation of inventories of GHG emissions.

2.4. Emissions Inventory

The inventory of GHG emissions should be done using the GHG Protocol. The GHG Protocol brings all the methodology internationally accepted. The Brazilian program - GHG Protocol, was conducted by the Center for Sustainability Studies of the Getulio Vargas Foundation (GVces), which had a partnership with the Brazilian Ministry of Environment, the World Resources Institute (WRI), and the World Business Council for Sustainable Development (WBCSD). Widely used by governments and businesses around the world, the GHG Protocol is a methodology that guides the control and recording of emissions, allowing understand and quantify generators of GHG, ensuring reliable information.

In practice, the GHG Protocol provides an accounting framework for the measurement of all the GHGs and converting these pollutants into CO2 equivalent (CO2e), At the end, we have the total CO2e in GHG emissions of the organization.

2.5. Neutralization Computation

The neutralization of CO2e emitted, is nothing more than the removal of that CO2 from the atmosphere and converting it into biomass by photosynthesis reaction. The reaction allows the growth of trees and the accumulation of biomass by absorbing CO2 and releasing oxygen (O2) in the atmosphere, setting the carbon (C) in the trunks, branches, leaves and roots.

The carbon sequestration through forestry activities is based on two aspects. First, the carbon dioxide is an atmospheric gas that circulates worldwide. Then, the efforts for the removal of GHGs will have equal effect, whether applied alongside potential polluters or the other side of the world. Second, forests remove carbon dioxide from the atmosphere through photosynthesis, converting organic compounds used in their growth and in plant metabolism.

At the end, it was stipulated the number of native tree species to be planted, resulting the neutralization of the CO2 emitted for a period of one year.

Currently, the determination of the number of native tree species to be planted to neutralize the emission of CO2 is done in a very simple way, as follows: N= $\lceil (\mathbf{Q} \times \mathbf{43}) \rceil$, where N is the number of trees to be planted in the ceiling function of Q (quantity of carbon to tCO2e estimated in inventory) which is 43 times the amount of native trees required (considered a very conservative manner). The total is the amount of native trees necessary (considered a very conservative) to neutralize 1 tCO2 in a period of 1 year in accordance with EMBRAPA and [6].

3. Methods

The mathematical model used in the proposed problem and its subsequent solution was via the Branch-and-Bound (B&B) method. This technique was performed in order to relate: the involved variables, imposed constraints (limitations) and the objective function (which will be desired to optimize - to this problem is to minimize the total price cost of planting) [7]. In this particular case, the problem was modeled as a problem of integer linear programming [8]. One of the issues to be analyzed in this work, is whether the dimensionality of the models generated are able to run the method B&B until the end (ensuring the optimal solution to the problem) or with time limit (obtaining an approximation, but guarantying the maximum distance from the optimum solution).

For the creation of the mathematical model to be solved, it was necessary to follow the rules for reforestation. SMA (Secretaria do Meio Ambiente de São Paulo) Resolution 58, 30/12/2006, determines the direction for the heterogeneous reforestation of degraded areas and related measures. According to this resolution, there are specifications (constraints) to be considered, which are:

1 - Regarding the number of species to be used when planting:

a. must be used, at least, 20% of native species native from regional vegetation;

b. must be used, at least 5% of native species from the regional vegetation, framed in any of the categories of threat (vulnerable in danger, critically endangered or presumed extinct);

c. in total area of plantations, the species chosen should address both ecological groups: pioneers (pioneer and early secondary) and non-pioneers (late secondary and climax), considering a minimum threshold of 40% for any of the groups, except for the forested savanna (Cerrado).

2 - In relation to the number of individuals species to be used in situations of planting:

a. The total number of individuals species belonging to the same ecological group (pioneer and not pioneer) cannot exceed 60% of the total number of individuals species in the planting;

b. No pioneer species may exceed the maximum limit of 20% of the total individual species planting;

c. Any kind of not pioneer may exceed the maximum limit of 10% of individual species from the total planting;

d. Ten per cent (10 %) of planted species, at maximum, may be less than twelve (12) individual species per project.

All these specifications have been used in the mathematical model as parameters and restrictions, to be chosen the best tree seedling with lowest price cost. The mathematical formulation for the resolution of the problem in accordance with the specified criteria is followed.

i = {Chimbuva, Gabiroba,...} → Popular Name

i =1... n is the quantity of species.

j = {zoochoric, anemocoric} → Dispersion.

j= 1...m is the quantity of dispersions

z = {pioneer, non-pioneer} → Ecological Group.

z = 1...p is the quantity of ecological groups

k = {In danger, not endangered} → Category of threat

k =1...q is the quantity of threat category

C_i = is the price cost of tree/tree seedling i

X_{ijzk}= quantity of tree/tree seedling i, considering dispersion j, of ecological group z e of threat category k.

N = is the minimum number of trees/trees seedling to be planted as specified in section II.E.

Minimize $\sum_{i=1}^{n} C_i X_{ijzk}$

Subject to Table 1.

Table 1: Criteria defined by SMA.

$\sum_{i=1}^{n} X_{i1zk} \geq \sum_{i=1}^{n} X_{ijzk} * 0.2$	(1) Minimum 20% of zoochoric species.
$\sum_{i=1}^{n} X_{ijz1} \geq \sum_{i=1}^{n} X_{ijzk} * 0.05$	(2) Minimum of 5% of the threatened species category.
$\sum_{i=1}^{n} X_{ijzk} \geq N$	(3) The number of trees to be used is at least N.
$\sum_{i=1}^{n} X_{ij1k} \geq \sum_{i=1}^{n} X_{ijzk} * 0.4$	(4) Number of pioneer trees at least 40% of the total.
$\sum_{i=1}^{n} X_{ij2k} \geq \sum_{i=1}^{n} X_{ijzk} * 0.4$	(5) Number of non-pioneer trees at least 40% of the total.
$\sum_{i=1}^{n} X_{ij1k} \leq \sum_{i=1}^{n} X_{ijzk} * 0.6$	(6) Number of pioneer trees not greater than 60% of the total.
$\sum_{i=1}^{n} X_{ij2k} \leq \sum_{i=1}^{n} X_{ijzk} * 0.6$	(7) Number of non-pioneer trees not greater than 60% of the total.
$X_{ij1k} \leq \sum_{i=1}^{n} X_{ijzk} * 0.2$	(8) Quantity of each pioneer tree does not exceed 20% of the total.
$X_{ij2k} \leq \sum_{i=1}^{n} X_{ijzk} * 0.1$	(9) Quantity of each non-pioneer tree does not exceed 10% of the total
$X_{ijzk} \in Z^+$	(10) All variables are integer positive.

4. Results

The starting point of the process is determining the emissions inventory of GHG emitted, through the calculation of the amount of tons from CO2 equivalent (tCO2e) produced.

The data collected about Cerrado trees, shown in Table 2, were obtained in http://www.clickmudas.com.br site, credit by the BIF (Brazilian Institute of Forestry). The website presents the necessary information to the proposed model, such as the native trees names of the Brazilian Cerrado and their respective prices.

Table 2: The 6 types of plants considered

Tree Type	Specie	Popular Name	Dispersion	Ecological Group	Threat *	Unit Cost $US
1	Enterolobium timbouva	Chimbuva	Zoochoric	Pioneer	Ne	1.20
2	Calophyllum brasiliensis	Guanandi	Zoochoric	Non-Pioneer	Id	2.50
3	Cedrela fissilis	Cedro Rosa	Anemocoric	Non-Pioneer	Ne	5.00
4	Cordia ecalyculata	Café de Bugre	Zoochoric	Non-Pioneer	Id	5.00
5	Peltophorum dubium	Canafístula	Zoochoric	Pioneer	Id	12.50
6	Anadenanthera	Angico Branco	Anemocoric	Late secondary	Ne	5.00

*Id – in danger, Ne – not endangered

Following, we have the resolution of the computational model proposed in Section III, taking into account the 6 types of plants presented in Table 2. If desired neutralization is 200 tCO2e over 1 year, we must use at least 8600 trees, N = seedlings/tree has:

N= $\lceil (Q \times 43) \rceil$

N= $\lceil (200 \times 43) \rceil$ **= 8600 trees**

Below, is the formulation of the proposed method with data presented on Table 2 and considering the specifications described on Section III.

MINIMIZE 1.2X1112 + 2.5X2121 + 5X3221 + 5X4121 + 12.5X5111 + 5X6222

Subject to

X1112 + X2121 + X4121 + X5111 - 0.2X1112 - 0.2X2121 - 0.2X3221 - 0.2X4121 - 0.2X5111 - 0.2X6222 >= 0

X2121 + X3221 + X4121 + X5111 - 0.05X1112 - 0.05X2121 - 0.05X3221 - 0.05X4121 - 0.05X5111 - 0.05X6222 >= 0

X1112 + X2121 + X3221 + X4121 + X5111 + X6222 - 8600 >= 0

X1112 + X5111 - 0.4X1112 - 0.4X2121 - 0.4X3221 - 0.4X4121 - 0.4X5111 - 0.4X6222 >= 0

X2121 + X3221 + X4121 + X6222 - 0.4X1112 - 0.4X2121 - 0.4X3221 - 0.4X4121 - 0.4X5111 - 0.4X6222 >= 0

X1112 + X5111 - 0.6X1112 - 0.6X2121 - 0.6X3221 - 0.6X4121 - 0.6X5111 - 0.6X6222 <= 0

X2121 + X3221 + X4121 + X6222 - 0.6X1112 - 0.6X2121 - 0.6X3221 - 0.6X4121 - 0.6X5111 - 0.6X6222 <= 0

X1112 - 0.2X1112 - 0.2X2121 - 0.2X3221 - 0.2X4121 - 0.2X5111 - 0.2X6222 <= 0

X5111 - 0.2X1112 - 0.2X2121 - 0.2X3221 - 0.2X4121 - 0.2X5111 - 0.2X6222 <= 0

X2121 - 0.1X1112 - 0.1X2121 - 0.1X3221 - 0.1X4121 - 0.1X5111 - 0.1X6222 <= 0

X3221 - 0.1X1112 - 0.1X2121 - 0.1X3221 - 0.1X4121 - 0.1X5111 - 0.1X6222 <= 0

X4121 - 0.1X1112 - 0.1X2121 - 0.1X3221 - 0.1X4121 - 0.1X5111 - 0.1X6222 <= 0

X6222 - 0.1X1112 - 0.1X2121 - 0.1X3221 - 0.1X4121 - 0.1X5111 - 0.1X6222 <= 0

Integer X1112 X2121 X3221 X4121 X5111 X6222

PROBLEM SOLUTION

Total Cost = $48,267.50

1 X1112	=	2150	<== Number of trees from type 1
2 X2121	=	1075	<== Number of trees from type 2
3 X3221	=	1075	<== Number of trees from type 3
4 X4121	=	1075	<== Number of trees from type 4
5 X5111	=	2150	<== Number of trees from type 5
6 X6222	=	1075	<== Number of trees from type 6
Total	**=**	**8600**	**<== Total Number of Trees**

The model solution was obtained through a coded in C language and making use of GLPK API program that makes the B&B method on a machine with Intel Core I5 M450 2.4GHz processor and 4 GB of RAM DDR3.

Given the solution to the model proposed by method B&B with the presented data (which took 0.1 ms of execution time on the machine specified), we should use 2150 trees of type 1, 1075 trees of type 2, 1075 trees of type 3, 1074 trees of type 4, 2150 trees of type 5 and 1075 trees of type 6, totalizing 8600 trees to be planted at a minimum price cost of $48,267.50. The number of trees to be planted, proposed by the solved model, was the same as the calculated by simplistic method described in section II.E. However, this method obeys the SMA Resolution 58, 30-12-2006, regarding the issues and limitations of use of each species and tree type, which is completely ignored by simplistic method. Thus, the method proposed here, presents a more realistic solution, conforming the relevant legislation and giving the final amount cost (minimum) of reforestation for carbon neutralization taking into account the value of different types of trees/seedlings.

5. Conclusions

This work aimed to develop a computational tool conducive to determine which native trees of Brazil Cerrado biome must be used on a plantation in order to neutralize a given amount of carbon (GHG in tCO2e) expending a minimum cost and respecting the constraints of regulations imposed by the Brazilian's government.

The purpose of this work is to minimize the price costs with reforestation activities in the forestry area, especially for companies that release CO_2 into the atmosphere through their production activities, and need to neutralize it.

Making use of the computational method presented here, companies can plan the reforestation to neutralize GHGs, by determining the needs for compensation by means of transparency, agility, with a minimum price cost.

6. Acknowledgment

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