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AN INDIGENOUS APPLICATION FOR ESTIMATING CARBON FOOTPRINT OF ACADEMIA LIBRARY SYSTEMS BASED ON LIFE CYCLE ASSESSMENT

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Abstract

Global Warming is one of the pressing problems of the current century and can have disastrous effects in disturbing the ecological balance and climate stability on the planet Earth, if not addressed pro-actively by all nations across the world. A carbon footprint is a measure of the impact human activities have on the environment in terms of the amount of green house gases produced, measured in units of carbon dioxide. It is meant to be useful for individuals and organizations to conceptualize their personal (or organizational) impact in contributing to global warming. The current work highlights a cradle-to-grave approach based on a thorough Life Cycle Assessment (LCA) of all the components of a library system that involve energy usage, varying from the energy required to sustain labor, transportation of that labor, electrical energy consumption involved with the library hall/building, embodied energy of both books and supplies and all the infrastructure associated with the premises. A web-based user-friendly application that can calculate the carbon footprint of a library system in California during the 2007 - 2008 year to a sufficient degree of accuracy based on user inputs has been developed and its electronic version is now available online at the following URL http://librarylca.berkeley.edu.

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1. INTRODUCTION

This section discusses some of the key ideas and concepts that underline the bulk of the study and analysis carried out through this work.

1.1 Global Warming and Kyoto Protocol

There is no debate on the issue that climate change has quickly become a topic of important concern for nations around the world. Global Warming is an intensely challenging climate problem that confronts the whole of the planet Earth. Its scope is not limited to any particular geographical region alone; it is expected to lead to a global temperature increase of 2.5 degrees Celsius by the year 2100 [1]. This can severely disrupt the ecological balance of the planet in several ways. Sea-level rise will lead to increased coastal flooding through direct inundation and an increase in the base for storm surges, allowing flooding of larger areas and higher elevations. Further melting of the Arctic Ice Caps (at the current rate) could be sufficient to turn off the ocean currents that drive the Gulf Stream, which keeps Britain up to 6°C warmer than it would otherwise be. Other effects of global warming include changes in agricultural yields, trade routes, glacier retreat, species extinctions and increases in the ranges of disease vectors. In short, the ecological effects of Global Warming can be threatening to the existence of life on the planet in the near future.

An international protocol with the objective of reducing greenhouse gases called the Kyoto Protocol was ratified and signed by 41 participating countries across the globe. As of April 2008, a total of 178 countries and other governmental entities have ratified the agreement. It is an agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared

to the year 1990. The goal is to lower overall emissions of six greenhouse gases – carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons; averaged over the period of 2008-2012.

Since the last decades of the 20th century, increased awareness of the scientific findings surrounding global warming has resulted in political and economic debate. Poor regions, particularly Africa, appear at greatest risk from the projected effects of global warming, while their emissions have been small compared to the developed world. At the same time, developing country exemptions like that of China and India from provisions of the Kyoto Protocol have been criticized by the United States and Australia, and used as part of a rationale for continued non-ratification by the U.S. However, California is finding its own ways to combat climate change, such as voluntary emissions reporting and reductions.

1.2 Carbon Footprint and Global Warming Potential of Greenhouse Gases

The carbon footprint is a measure of the exclusive global amount of carbon dioxide (CO2) and other greenhouse gases emitted by a human activity or accumulated over the full life cycle of a product or service. [2]

In this respect, it is apt to define the Global Warming Potential (GWP) of a gas 'x' as the potential to contribute to global warming change as measured on a per-molecule basis and defined approximately as in equation below:

$$GWP = \frac{\text{Time integrated radiative absorption due to 'x'}}{\text{Time integrated radiative absorption due to } CO_2}$$

The life cycle concept of the carbon footprint means that it is all encompassing and includes all possible causes that give rise to carbon emissions. In other words, all direct (on-site, internal) and indirect emissions (off - site, external, embodied, upstream and downstream) need to be taken into account. Normally, a carbon footprint is expressed as a CO_2 equivalent (usually in kilograms or tonnes), which accounts for the same global warming effects of different greenhouse gases. Carbon footprints can be calculated using a Life Cycle Assessment (LCA) method, or can be restricted to the immediately attributable emissions from energy use of fossil fuels.

The goal of LCA is to compare the full range of environmental damages assignable to products and services, to be able to choose the least burdensome one. The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence. The sum of all those steps or phases is the life cycle of the product. The concept also can be used to optimize the environmental performance of a single product (eco-design) or to optimize the environmental performance of an office setting. Common categories of assessed damages are global warming (greenhouse gases), acidification, smog, ozone layer depletion, eutrophication, eco-toxicological and human-toxicological pollutants, desertification, land use as well as depletion of minerals and fossil fuels.

This forms the conceptual basis of the carbon footprint estimation based on a comprehensive LCA analysis carried out in this work on all encompassing aspects of the academia library systems ranging from the energy required to sustain labor, transportation of that labor, electrical energy consumption involved with the library hall/building, embodied energy of both books and supplies and all the infrastructure associated with the premises.

1.3 Carbon Offsetting

Carbon Offsets can be used to compensate for the emissions produced by funding an equivalent carbon dioxide saving somewhere else. The Kyoto Protocol defines legally binding targets and timetables for cutting the greenhouse gas emissions of industrialized countries that ratified the Kyoto

Protocol. Accordingly, from an economic or market perspective, one has to distinguish between a mandatory market and a voluntary market.

In the larger compliance market, companies, governments or other entities buy carbon offsets in order to comply with caps on the total amount of carbon dioxide they are allowed to emit. In the much smaller voluntary market, individuals, companies, or governments purchase carbon offsets to mitigate their own greenhouse gas emissions from transportation, electricity use, and other sources.

Offsets are typically generated from emissions–reducing projects. The most common project type is renewable energy, such as wind farms, biomass energy, or hydroelectric dams. Other common project types include energy efficiency projects, the destruction of industrial pollutants or agricultural by-products, destruction of landfill methane, and forestry projects.

2. GOALS AND OBJECTIVES

2.1 General Need

Reduction in environmental impacts is the primary objective behind determining the carbon footprint of library systems. This impact assessment shall provide library systems with the know–how of how to reduce their footprint, making them leaner and greener. The metric formulation shall enable them to compare their footprint with other library systems from a user perspective. Just like industries need to be conscious of their environmental impacts, offices and institutions also need to know and understand that their functioning places a load on the environment and contributes especially to global warming. As stated before, there exists a voluntary market that is keen on offsetting their footprint by buying carbon credits that cancel their contribution to global warming. It is then left up to the discretion of the library systems to decide whether or not they want to offset their GWP contribution.

2.2 Specific Goals

The specific goals and objectives of the work have been clearly highlighted below:

1) *To make academia in general aware of the environmental impacts of their lab/office practices and purchases*: Academia in general is considered as a 'green' and clean place but there is a conceptual flaw underlying this assumption. Firstly, the layman perceives the environmental impacts as synonymous only with hazardous liquid and gaseous emissions and non–recyclable waste accumulation, and thus attributes these emissions mainly to industries. These are no doubt some of the most visible environmental impacts but a thorough life cycle assessment for a given product attributes each of the visible and non–visible impacts ranging from extraction, manufacturing, use, disposal and recycling (if any) phase to the given product. Hence visibly green products in their use phase may have had a large footprint associated with their not–so–visible manufacturing and extraction phase, for example.

2) *To provide an indigenous resource for calculating and offsetting the greenhouse gas emissions associated with energy use*: External reliance on carbon offsetting agencies for businesses and offices is not just professionally very costly, it may be limited in its approach to actually determine an accurate analysis for the environmental footprint of these offices or institutions. In that respect, this work aims at highlighting a comprehensive approach to carry out such an analysis based on a cradle-to-grave Economic Input Output Life Cycle Assessment (EIO-LCA) model of Carnegie Mellon University [3], and taking into account other sources (human factors) of energy use too.

3) *To provide a baseline for energy consumption improvements while promoting energy consumption reduction*: The carbon footprint of the library systems as determined in this work contains a thorough analysis of the pattern of energy usage and the environmental impact associated with the greenhouse gas emissions expressed in terms of GWP. This offers these institutions an insight to understand how to reduce their total GWP.

4) *To provide an open source web based application catering to the library environments in any academia in US, especially the California based UC system*: The purpose of building an open source web-based application is to make it available to as many library systems as possible. The database for the application is expected to be stored and saved on the Mechanical Engineering Department's Kepler Server a UC Berkeley. The detailed calculations in the database can also be provided if requested. The results of the database shall be used to strengthen the metric definition further and to provide a threshold for optimum performance by analyzing the existing performance results of different library systems in California.

5) *To perform a case study analysis on the Kresege Engineering Library at UC Berkeley*: The approach mentioned above for the LCA analysis of the library systems has been rigorously applied as a case study to the Kresege Engineering Library at UC Berkeley to start with, just to highlight the procedure for carrying out this analysis. The generalized application was built considering the Engineering Library as a representative model of most academia library systems.

To summarize, as global warming and energy consumption become common topics in California, and as people seek to offset their impacts with carbon trading, this project will provide the campus insight into lab and office contributions to global warming.

3. BACKGROUND AND MOTIVATION

3.1 Take on Sustainability – Audience Perspective

The authors' take on sustainability is:

"*Sustainability is a state of perpetuating the existence of future life by making pro-active decisions in the present involving optimizing resource needs, minimizing waste, reducing environmental and social impacts, and promoting business growth with an emphasis on long term stakeholder values; and all this without compromising profitability, service quality and competitiveness.*"

While this definition is all encompassing and includes social, environmental and business aspects of Sustainability, in this work we particularly emphasize on mitigation of environmental impacts of office practices in academia by concentrating on library systems in particular. The authors feel that this defined context shall be interesting for the audience because firstly the layman does not associate environmental impacts with office settings and consequently this work will act as an eye - opener and secondly although the LCA approach followed is rigorous; it is simply and lucidly presented for ease of comprehension by all and one.

3.2 Contextual Background

A lack of tools to measure environmental impacts means many businesses are struggling to meet government targets for the low carbon economy. In Europe, a survey by IT services firm LogicaCMG stated that more than four in five of the UK, French, German, Dutch, and Swedish companies needed technology that would help them improve their energy efficiency. Some 74% of them said they also needed a way to measure their impact on the environment. This growing political and business salience of 'environmental' impacts has sparked a "green gold rush", which has seen a dramatic expansion in the number of businesses offering both companies and individuals the chance to go "carbon neutral", offsetting their own energy use by buying carbon credits that cancel out their contribution to global warming. The burgeoning regulated market for carbon credits is expected to more than double in size to about $68.2bn by 2010, with the unregulated voluntary sector rising to $4bn in the same period.

Many online greenhouse gas calculators offer to determine the emissions associated with an individual, office or institution. First, they calculate the tons of carbons we use each year — our so-called "carbon footprint" — based on our input. They ask questions such as how one's home is heated (oil, gas, etc), how big the home is, and where one is physically located (local climate affects how much we heat or cool our home, for example). Based on analysis of the power sources in one's zip

code and state, they can calculate estimates of the carbon amounts one is using. One can of course fine-tune some of these estimates by providing them more information.

Much of this generalized approach to determine the carbon footprint and the corresponding offsets does not indeed match the specific concerns of various offices and institutions. To some extent, an ignorance of the tools and methodologies needed to carry out such an analysis leads to an overdependence on these several new carbon offsetting business that are thriving. Through this project, we thus intend to carry out such an analysis for an office setting in an academia (e.g. a University Library) and would want to generalize it to be applicable to similar academia environments, thus in turn laying the foundation for building an indigenous tool/application for Global Warming Potential (GWP) estimation, without the help of external business agencies.

4. METHODOLOGY

The general methodology consists in subdividing all essential aspects of GWP estimation of greenhouse gases (GHG) in a library system as follows:

(1) GWP of GHG attributable to the energy use of Labor: Researchers at Berkeley have estimated the average energy use of a given worker in US following a top-down approach where they attribute the total industrial energy use minus a particular sector's use to the entire working population of the country to get a bound on the energy use of labor [4]. This concept has been extended by them to greenhouse gas emissions as well through a similar analogy. Their results are used as a reference to estimate the GWP associated with the energy use of the working labor involved in a library system.

(2) GWP of GHG attributable to the Transportation emissions of the associated labor: The working labor in any given library is associated with daily commuting to and from its office. Some key assumptions involved are related to the percentage of CO_2 emitted in the total Greenhouse gas emission spectrum [5], the mileage of transportation mediums like car [6], bus [7], moped [8] etc. Occasionally, the library officials also make business trips to different parts of the country and abroad. The related emissions are also a part of the carbon footprint of the library system. The emissions for an airplane trip can be found by using online flight calculators, which generate emissions based on the distance travelled [9].

(3) GWP of GHG attributable to the Electricity consumption of Electronic equipments: Any library hosts several electronic equipments like scanners, printers, computers, monitors etc. Energy use is associated with the electricity consumption of these equipments. PG&E Berkeley campus values were used to estimate the cost of electricity ($/kWh) [10] and average CO_2 emissions associated with the production of 1kWh of electricity [11]. The general application shall of course use California values for UC campuses and average US values for in general any academia inside US.

(4) GWP of GHG attributable to the Embodied Energy of Infrastructure: This is where EIO-LCA analysis comes into the picture to evaluate the embodied energy of the entire infrastructure that the library supports from furniture to paint, carpeting and posters etc.

(5) GWP of GHG attributable to the Embodied Energy of Books: A major component of the library involves the use of books and journals. Their embodied energy is also calculated through the EIO-LCA model and suitable assumptions are made regarding the production (including transportation) costs of such books as different from their very high retail costs.

The implementation of the above methodology has been carried out both as a case study on Engineering Library and as a part of a generalized web-based application which accepts user based inputs to generate the corresponding results.

Having estimated the GWP contribution due to all these factors, we propose a metric that takes into the account the number of visitors in the library and the average amount of time that they spend in the library.

5. RESULTS

The following results are for the case study carried out in this work for the calculation of GWP of greenhouse gas emissions associated with the carbon footprint of the Kresege Engineering Library at UC Berkeley.

5.1 Labor

Figure 1 below shows the GWP due to GHG emission associated with the energy use of the labor for the case study on Engineering Library.

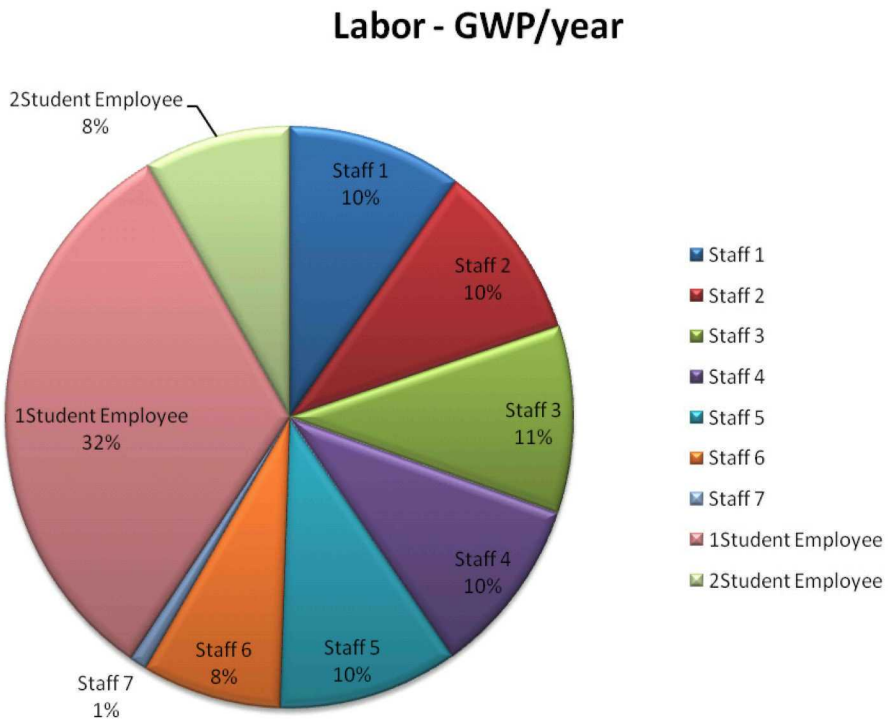

Fig.1 Pie chart of GWP/year distribution for Labor

The total GWP estimation due to the labor was evaluated to be **78.25 metric tonnes of CO2 equivalent per year**.

5.2 Transportation of Labor

Figure 2 below shows the GWP due to GHG emission associated with the daily commuting part of transportation for the case study on Engineering Library.

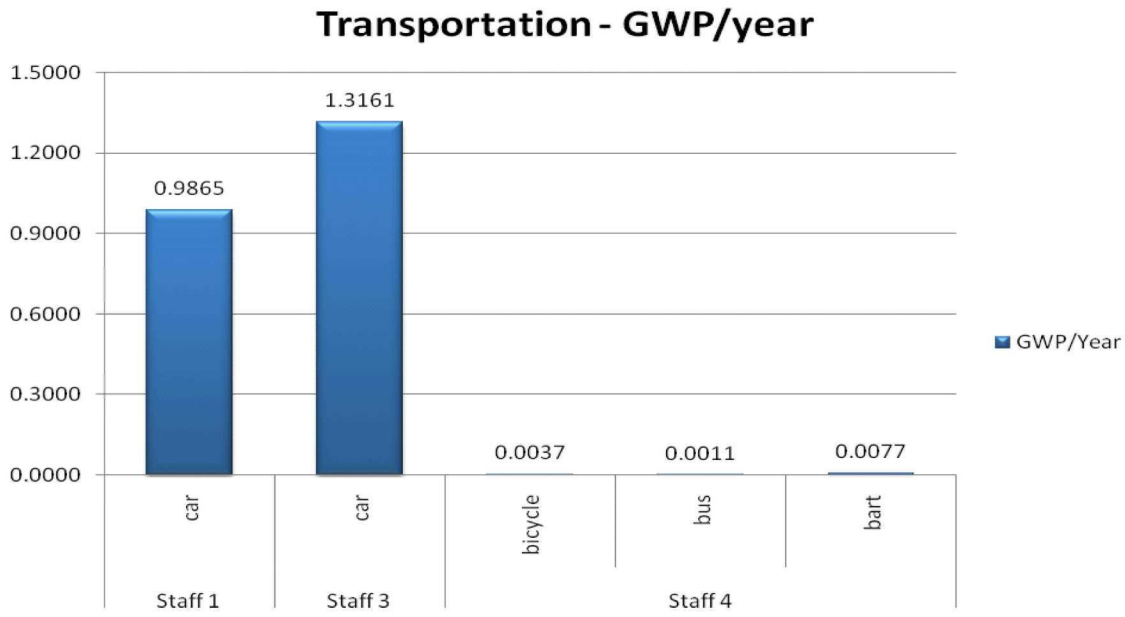

Fig.2 Bar graph of non-zero GWP/Year for Transportation

The total GWP estimation due to daily commuting was evaluated to be **2.32 metric tonnes of CO2 equivalent per year**.

Figure 3 below shows the GWP due to GHG emission associated with the business trips section of transportation for the case study on Engineering Library.

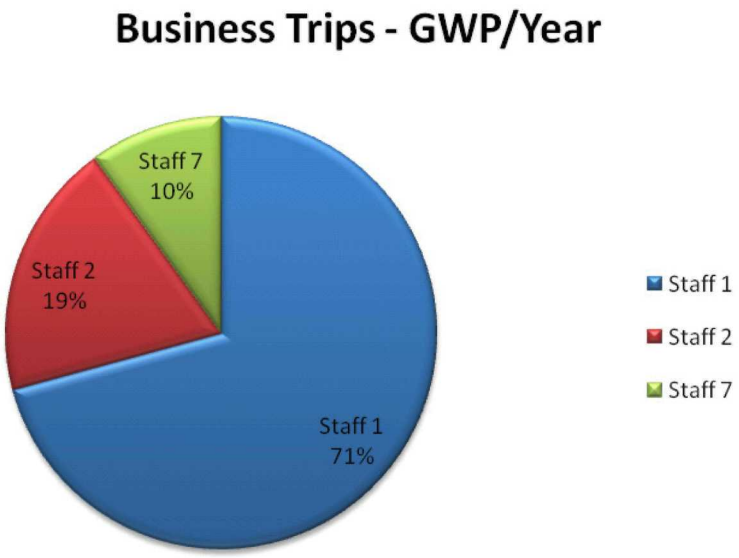

Fig.3 Pie chart of GWP/Year for staff business trips

The GWP estimation due to business trips was evaluated to be **1.35 metric tonnes of CO2 equivalent per year**.

Thus the total GWP estimation due to transportation was **3.67 metric tonnes of CO2 equivalent per year**.

5.3 Electricity Use of Electronic Components

Figure 4 below shows the annual power consumption among the various electronic/electric components for the case study on Engineering Library. Note that the GWP for the GHG emissions is simply equal to the electrical power consumption multiplied by the PG&E CO_2 equivalent emissions rate of 0.524 lbs/kWh [11].

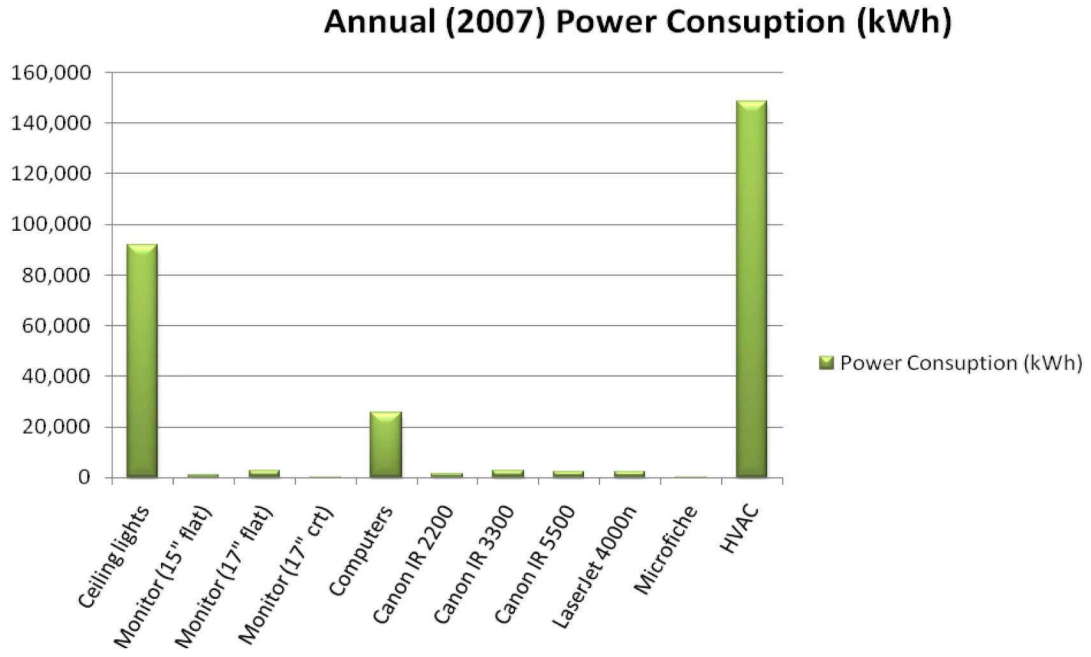

Fig.4 Bar graph of all power consumption for all the major electric items

The monthly total annual power consumption and cost estimation for the Bechtel Engineering Center was calculated as **568,933 kWh** and **$46,164.04** respectively. The electrical GWP/Year for the Engineering Library was evaluated to be **66.06 metric tonnes of CO2 equivalent per year**.

5.4 Embodied Energy of Infrastructure

Figure 5 below shows the GWP due to GHG emission associated with the embodied energy of the infrastructure for the case study on Engineering Library

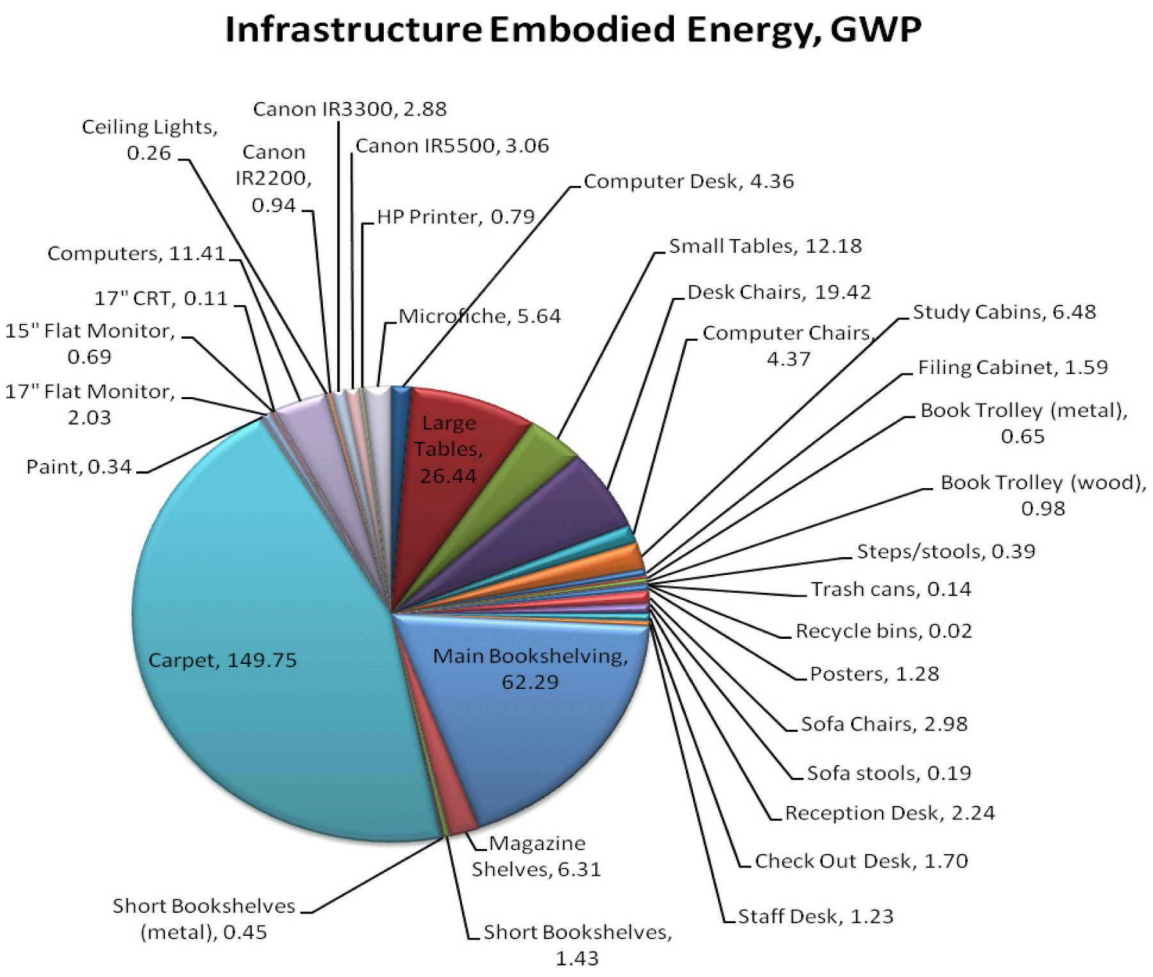

Fig.5 Pie chart of GWP for embodied energy of the infrastructure

The total GWP estimation due to the embodied energy of the infrastructure (including electronic devices) was evaluated to be **335.02 metric tonnes of CO2 equivalent**.

5.5 Embodied Energy of Books and Documents

Figure 6 below shows the GWP due to GHG emission associated with the energy use of books and supplies for the case study on Engineering Library.

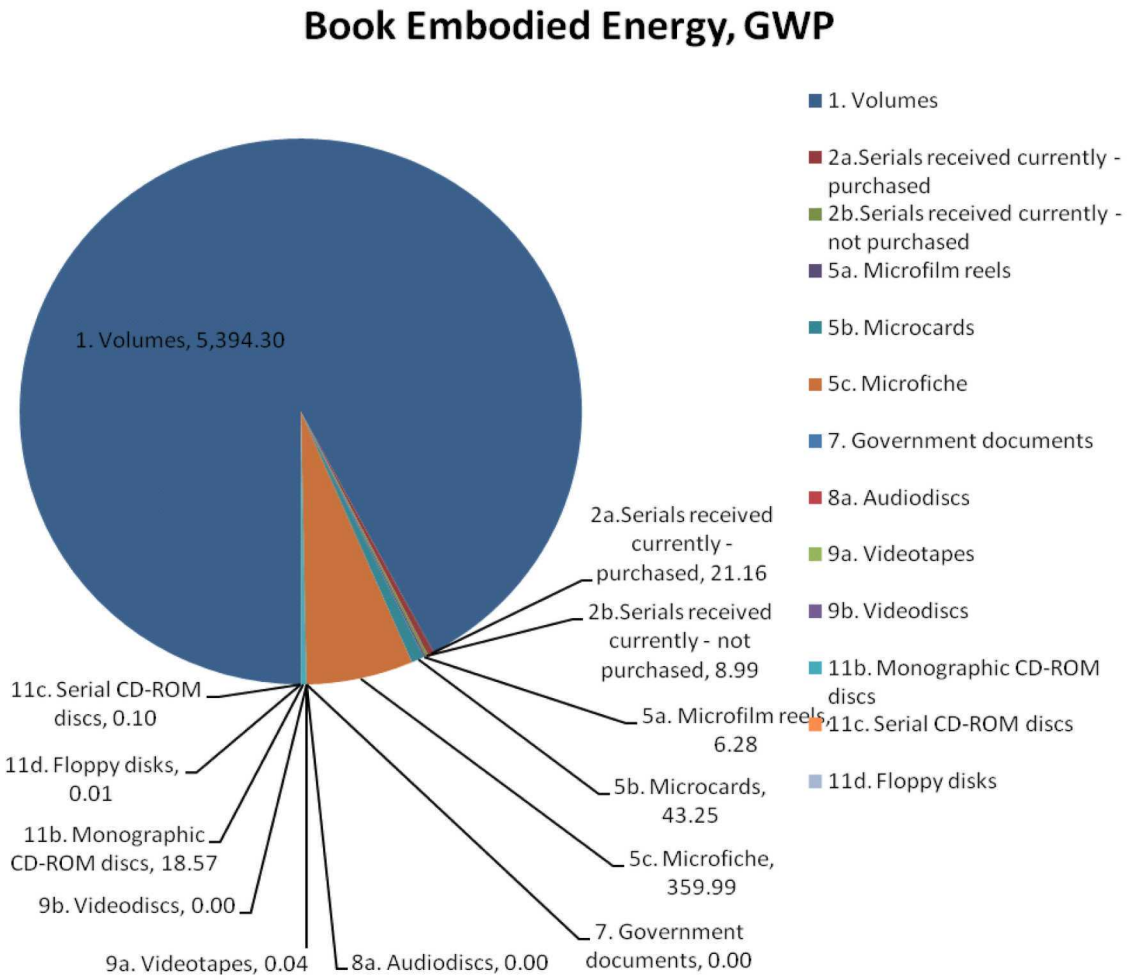

Fig.6 Pie chart of the GWP for the embodied energy of books and documents

The total GWP estimation due to books and documents was evaluated to be **5852.59 metric tonnes of CO2 equivalent per year**. Volumes have the major contribution with **5394.30 metric tonnes of CO2 equivalent per year.**

5.6 Web Application Development

The Web-Application, www.libraryLCA.berkeley.edu is shown in Figure 7, and is now currently being hosted on the Mechanical Engineering Department's Kepler Server at UC Berkeley. Attempts to simplify the questions, where only the basics necessary to do analysis were asked, still resulted in a fairly long and extensive form. Thus additional features, such as an employee labor and transportation calculator pop-up, will be added to make the computation of these figures easier for the user. In addition, details of how to permanently store user data in the best manner still needs to be negotiated for the Kepler Server.

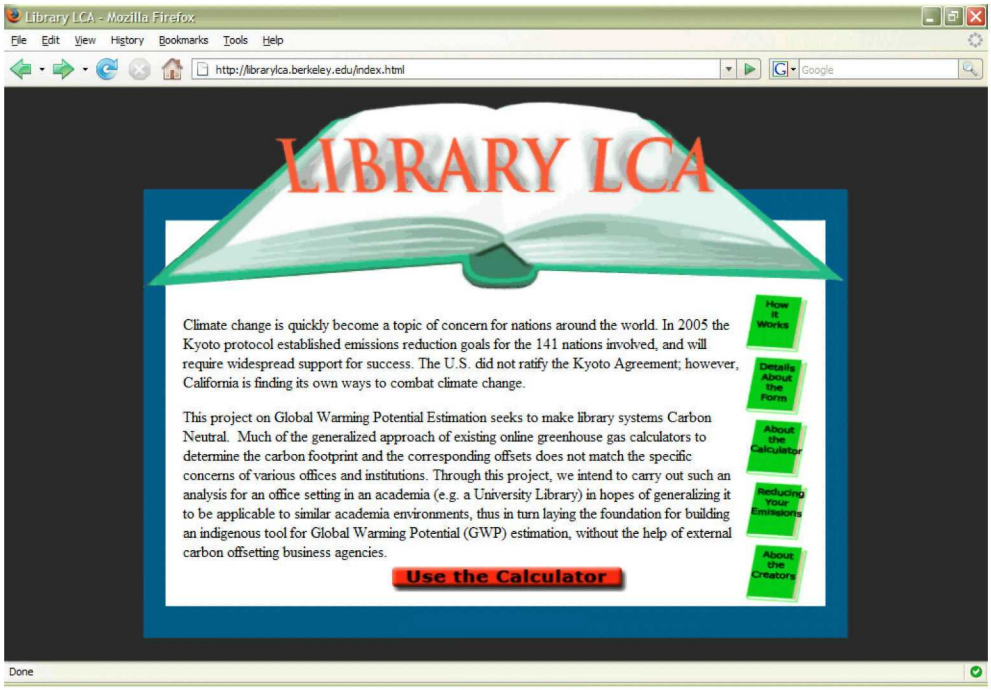

Fig.7 Library LCA Website

6. CONCLUSIONS

The tool created is an indigenously built resource for calculating and offsetting the greenhouse emissions associated with energy use. Through this analysis, the library is able to assess its environmental impact. By breaking down the different inputs of energy in the library in this application, the total emissions generated by the library facility in operation can effectively be estimated. It can be seen which factors contribute the most towards emissions and this generates a basis on which improvements can be made. It will thus enable the library to see where necessary changes can be made in order to reduce their energy consumptions, in turn reducing their carbon footprint. The tool is merely a basis for a much more detailed application, which can be adapted to suit any type of library establishment, within and outside US. The application is currently accessible online and is available for use by external users.

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