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Carbon Footprint Estimation of A Medium-Sized School in an Urban City

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ABSTRACT

National Academy For Learning (NAFL), Bengaluru has been actively working to make the school carbon-neutral under the NAFL Green initiative. The present investigation conform the effort and presents the trajectory for understanding and estimating the carbon footprint of the school, and suggests potential solutions. It uses the GHG Protocol's Corporate Standard, which categorizes emissions into three scopes based on their source. The study extensively explores each of the three scopes and emission offsets, and reports the carbon footprint of NAFL to be 107030kg CO2e. The major contributor to this is the third-party transportation facility, accounting for almost 75% of the emissions. The trees maintained by the school offset only 1.3% of the carbon dioxide emissions. This indicates that there still remains a huge scope for improvement in the carbon footprint, and so potential methods of reducing the footprint are suggested. Additionally, in order to allow for a similar estimation to be made by others, a python GUI programme is developed. The study concludes that the school needs to address its carbon footprint using the recommended solutions in this study. The study will also hopefully kindle similar studies that can collectively aid in a better understanding of the situation.

KEYWORDS:*Carbon footprint, GHG Protocol, CO2e, emissions and off-sets.*

I. INTRODUCTION

In today's world, there has been a growing concern about the issue of climate change, the primary cause of which points to anthropogenic emissions of greenhouse gases (GHGs) [1]. Many scientists, environmentalists, activists and politicians have spoken about this, highlighting their own research findings and opinions [2]. Numerous inter-country organizations like the United Nations and the G20 have convened extensive sessions in this regard. The G20 has published reports to assess the impact that each member country is creating due to its economic activities that affect the climate [3]. The United Nations adopted an environmental treaty called the United Nations Framework Convention on Climate Change (UNFCCC) as early as May 1992. In December 1997, 83 countries signed the Kyoto Protocol, which aimed to get industrialized countries to reduce and limit their greenhouse gas emissions [4]. More recently, in November 2016, the Paris Agreement with its 195 signatories came into force, which aimed to ensure that the global temperature remains below 2°C from the pre-industrialization era (from about AD1760) [5] .

These have become affirmative strides towards creating a society that is more cognizant about the plight of the environment and the often unbeknownst impact that seemingly trivial everyday tasks have on it.

It should not be surprising that almost all the countries are pouring millions, if not billions, of dollars to find and implement solutions that tackle this increase in the global temperature (more popularly called global warming). In 2017 alone, the economies of the world and its citizens spent a record high of roughly $612 billion on climate-related financing, a large chunk of which came from private actors [37]. This is testament to the fact that global warming is a serious phenomenon that has far reaching consequences for nature, and ultimately humanity. Studies have shown that the numbers of heat waves are on the rise, and with it, the number of deaths it has led to [38]. The increased heat not only melts so much Arctic ice that about two-thirds of the polar bear population is projected to die within the next thirty years [39] , but will also result in tens of millions of humans being displaced by the end of this century due to the rise in sea levels [40] . The less compacted ice and more mobile icebergs are posing an increased threat to ships that ferry close to the poles, the cross-Atlantic routes being especially vulnerable [41]. Though seemingly far-fetched, a study from the University of California, Berkeley has even identified a link between global warming and an increased risk of civil wars in Africa [42].

Due to the gravity of the situation, many individuals and organizations are enthusiastically attempting to reduce the impact they have on the Earth's temperature, and hence tackle climate change, by adopting more environment-friendly methods of production and lifestyle. Appreciating the relevance of the concept of carbon footprint has become increasingly pervasive through the decades, and will continue to be a subject that will witness conversations and debates to a great extent over the coming years. Carbon footprint gives us a yardstick to understand the degree of sustainability that exists in the activities we undertake, and assists in a multilateral and long term approach to everyday problems. It provides a measure of the impact of human activities on the environment in terms of the amount of greenhouse gases produced [8] . This will help provide a fair understanding of the impact that an individual, an organization, an industry or a country is having on the planet's climate due to its activities, by both directly and indirectly emitting GHGs into the atmosphere.

In the recent past, many students too have actively taken part in movements and strikes to spread awareness about climate change, and many schools, colleges and universities in various countries have adopted measures to reduce their carbon footprints. Some educational institutions have even adopted a 'zero carbon footprint' plan that ensures zero net CO_2e emissions by designing every aspect of the working of the organization (from its construction to its daily operations) to be carbon neutral. In 2019 for example, Colgate University in the state of New York, USA attained carbon neutrality by utilizing renewable resources such as solar and geothermal energies to generate electricity (hence eliminating a majority of their indirect emissions), achieving LEED certifications on several of their buildings, and purchasing carbon offsets [43].

These techniques implemented by educational institutions around the world can help broaden our horizons on viable avenues we can tread on to tackle climate change at the school level as well. It becomes vital, therefore, to first understand the climatic impact a school is having, and this study aims to estimate the carbon footprint of a school over the span of one year. The results of this study shall likely propagate and nurture the gravitas of climate change, and provide useful to other schools seeking to go green.

II. Methodology

This section constitutes the following topics: (3.1) description of the school being considered for this study, (3.2) the research methods adopted for this study, and (3.3) scope of the study and justifications for attributes being excluded.

Study area:

The city of Bengaluru is located in the Deccan plateau in Karnataka, at an average altitude of 920m above sea level. The population density is over 17,000 people per square kilometer, with about 12 million residents spread over an area of 710 square kilometers [29].

National Academy For Learning (NAFL) is a non-residential school of 900 students, 50 teachers and 50 other staff members. Established in 1994 by Dr. K.P. Gopalkrishna, it is part of the National Public group of schools as a co-educational, day boarding unit. It is located in a mostly residential neighborhood in west Bengaluru. The school campus has two academic buildings (with science and computer labs), a playing field with a basketball court, a sand pit with playground equipment, a sport-room outhouse, a security outhouse, and a storage outhouse. There are no canteens.

The data for this study has been collected for the academic year 2017-18, which is from June 2017 to March 2018. The summer vacation month of April and May witness minor albeit, negligible, activity from certain senior school students who have to attend classes for about a fortnight. The total number of working days in a typical year is 215 and each lasts an average of 7 hours and 30 minutes. Around 27 days in a year witness reduced activities due to the term exams that last shorter than a typical day for about 4 hours and 30 minutes. So do the entire first, third, fourth and the fifth Saturdays of a month, which add up to about 30 days for the year.

The Greenhouse Gas Protocol or the GHG Protocol (2015) of the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) lays down clear procedures for calculating emissions and guidelines for calculating offsets [9] . In accordance with the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), it establishes the auditing guidelines that take the following six GHGs into account: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF 6), and in addition to these, nitrogen trifluoride (NF3) [4] .

The unit of carbon dioxide equivalent (CO_2e) helps quantify the results. Due to the vast number of gases that cause global warming (i.e. GHGs), a single unit is necessary to measure the extent of damage these gases do to the climate. Carbon dioxide equivalents help assess the global warming potential of each gas - which measures its total warming impact on the planet over a hundred years, relative to the total warming impact on the planet done by carbon dioxide - on a single scale [6] . This proves effective while measuring the carbon footprint, which refers to the total amount of greenhouse gases, produced to directly and indirectly support human activities [7].

CO_2e emissions

According to the GHG Protocol Corporate Accounting and Reporting Standard, the data for emissions is collected under three categories called scopes.

Scope 1 - Direct GHG emissions

The direct emissions due to resources owned by the organisation are accounted for in this scope.

Scope 2 - Electricity indirect GHG emissions

The emission due to the consumption of electricity for the functioning of the organisation, which is produced at an electricity generation facility not controlled by the organisation, is accounted for in this scope.

Scope 3 - Other indirect GHG emissions

The emissions due to other activities in the value chain (excluding scope 1 and scope 2) using resources that are not owned or controlled by the organization are accounted for in this scope.

Contextualizing an urban school, scope 1 includes emissions from a fossil-fuel based backup generator, school-owned transportation services, use of liquefied petroleum gas (LPG) for cooking, and other fossil fuels burnt. Scope 2 includes the emissions from electricity purchased from the mains. Scope 3 includes emissions by any other activity not covered in the two preceding scopes that cause GHG emissions, such as independent transportation facilities hired by the school, chemical manufacturing companies for the yearly chemicals purchase for the school's laboratories, and utility goods purchased from various corporations for the maintenance of the school campus, amongst others.

Scope 1 direct emissions

Scope 1 encompasses the direct emissions from the consumption of diesel fuel for the diesel engine backup generator that National Academy For Learning utilises in situations of a power outage. As the school does not operate the school bus transportation facility for students, teachers or other faculty, this is not included under scope 1. The data regarding the generator and its fuel usage was provided by the school administration.

FG Wilson's FB125-2, a 125kVA rated diesel generator, is installed in the school.

Conversion factors necessary to calculate CO2e emissions were provided by Defra [49]:

Table 1 Relevant Defra data for scope 1 emissions

Mass of CO_2 emitted per dm^3 of diesel consumption / kg	2.65020
Mass of CO_2 emitted per dm^3 of diesel consumption from CH_4 / kg	0.00042
Mass of CO_2 emitted per dm^3 of diesel consumption from N_2O / kg	0.03717
Mass of CO_2e emitted per dm^3 of diesel consumption / kg	2.68779

The amount of fuel burnt and the above values can be used to quantify the scope 1 emissions.

Scope 2 indirect emissions

The transmission of electricity generated in India is handled by multiple local transmission corporations which oversee the distribution within their jurisdictions. Scaling this process to connect an entire region allows for excess power to be supplied to areas that lack infrastructure to generate electricity efficiently. These regional grids, namely the Northern, Eastern, Western, and North-Eastern were further interconnected in August 2006, leaving only the Southern grid unsynchronised with the rest of the grids. Since January 2013 however, this final grid too was integrated and synchronised to form a single unified grid for the country. This system allowed power distribution to become more efficient, as inter-region transmissions decreased the limitations of a local region system, especially at regional borders.

Each state in the country has established a public company that handles the purchase and distribution of electricity within the state, sourcing electricity from the state owned power generation infrastructure and purchasing electricity from other sources: independent power producers (IPPs), Central Generating Stations (CGS), and others.

The Karnataka Power Transmission Corporation Limited (KPTCL) is concerned with the transmission of electricity within the state of Karnataka. It has set up five electricity supply companies/corporations in the state, each managing the operations for an average of six districts. The Bangalore Electricity Supply Company Limited (BESCOM), under whose jurisdiction the city of Bengaluru (Bengaluru Urban district) falls, specifies the various sources of power generation in the country from which it has purchased power - and subsequently supplied to consumers in the city - in its annual report. To remain as accurate as possible, an extensive study of the annual report is done to estimate the amount of CO_2 emissions for every unit of electricity supplied by BESCOM, and can be found under appendix A.

0.8165 kg kWh^{-1} is the specific CO_2 emission value used to quantify scope 2 emissions for all organisations operating within the jurisdiction of BESCOM.

Scope 3 indirect emissions

Almost any activity will involve a certain amount of emissions which technically need to be accounted for under scope 3. However, many of these activities tend to be quite insignificant with respect to the total emissions of the organisation. Such activities are excluded from the estimation as they are economically or technically infeasible to conduct, and do not decrease the accuracy of the carbon footprint estimation by a significant margin.

In this regard, emissions from outsourced school bus transportation for students, field trips organized, events conducted, and solid waste disposal need to be taken into account.

National Academy For Learning outsources the school bus transportation facility to a private travel company in Bengaluru that runs a fleet of 11 diesel engine buses along their own unique routes throughout the city. All the buses operate along these routes twice a day (once in the morning and once in the late afternoon), but a few routes operate four times a day (twice in the morning, once at noon and once in the late afternoon), as the preschoolers have a different school timing. Data from Table 1 can be utilized to calculate the CO_2e emissions due to the buses' diesel consumption.

Some activities that may contribute sizably to the scope 3 emissions are difficult to audit in order to attain their CO_2e emissions.

The “annual concert” event by the school for the year 2017-18 was held in a memorial hall in Bengaluru. The amount of electricity consumed by the school at this event - which would be a good chunk of the indirect emissions - could not be obtained.

Similarly, the amount of waste generated by the school had never been measured, and it could not be done during the writing of this paper due to the school being shut down in accordance with the pandemic lockdown.

1) CO_2e offsets

Offsets are discrete GHG reductions to compensate for GHG emissions elsewhere. This would imply that any means by which schools are offsetting CO_2 through their operations need to be accounted for.

Trees sequester CO_2 from the atmosphere through the process of photosynthesis and convert it into biomass that makes up their leaves, stems, branches, and other parts. They however emit CO_2 into the atmosphere during the process of respiration. The net effect despite the CO_2 emission due to respiration is a carbon sink, which means more CO_2 is sequestered than emitted by trees **[19]**. The net CO_2 captured by the tree remains trapped until the tree dies and the CO_2 is released back into the atmosphere **[20]**. This implies that any CO_2 sequestration by trees will be offset in the short term. In the long term however, the death of plant material will re-release these trapped masses of CO_2into the atmosphere due to microorganism metabolisation of the dead matter **[36]**. Therefore, this section would restrict the longevity of the carbon footprint estimation to about 50-100 years, post which the death of plant material may need to be accounted for under scope 3 emissions.

Trees sequester CO_2 at different rates. The sequestration values utilised in this study have been taken from various research papers, while attempting to reduce the impact of potential factors that may affect these values, like climatic conditions, soil type, age of the tree, etc.

Many urban school campuses house trees within their campus, or the organisation that runs the school actively maintains trees outside the physical boundaries of the school campus. Therefore, CO_2 sequestration values for these trees need to be taken into account.

A carbon sequestration value is converted into CO_2 sequestration by multiplying the value with a constant *c* **[21]**:

$$c = 44/12$$

All CO_2 sequestration values have been reported in terms of kg m^{-2} $year^{-1}$. Some values have been converted from $\mu mol \cdot m^{-2}$ s^{-1} to kg m^{-2} $year^{-1}$ by using the equation:

Equation 1 Conversion to the common unit of kg m^{-2} $year^{-1}$

$$(x)\mu mol\, m^{-2}s^{-1} = \frac{\frac{(x)\times 44.01}{10^6}\times(60\times 60\times 24\times 365)}{10^3}\, kg\, m^{-2}year^{-1}$$

where:

x	Value to be converted
44.01/ 10⁶	Molar mass of CO_2 divided by factor to convert µmol to mol
(60x60x24x365)	Factor to convert seconds (s) into years
10³	Factor to convert grams (g) into kilograms (kg)

The CO_2 sequestration values for 20 varieties of trees are listed in Appendix B.

Depending on the canopy area covered by the trees and the duration for which the carbon footprint estimation is conducted, the approximate CO_2 sequestration can be calculated for a school campus.

Scope of the study

The organizational boundaries for a school campus in this study is set as follows: institution building(s), playing ground(s), other sport facilities, auditoriums, laboratories, lawns, hostel(s), canteen(s), road network within the physical boundaries of the campus and accompanying lighting systems, maintenance department(s), parking lot(s), and aesthetic structures and fixtures. Emissions and offsets caused by school events, such as a “sports day”, an “annual concert", and others, are included in the estimation within their respective scopes.

The carbon footprint estimation in this study will exclude the following:

1. Life cycle assessment (LCA) of products, which accounts for virtually every source of GHG emissions from the beginning to the end of every product's life. This allows for the greatest GHG reduction opportunities. However, this study is a preliminary attempt at estimating carbon footprint, and can be extended to account for all these indirect emissions under scope
2. Private methods of transportation, as this are accounted for in the individual's personal carbon footprint. The rationale behind this is that the individual chooses his/her mode of transportation by himself/herself, and this is not facilitated by the school. A school bus organized or outsourced by the school, however will be taken into the school's account as it has been facilitated by the school.
3. Food and water brought to the school, as this is accounted for in the individual's personal carbon footprint. The rationale behind this is that the individual chooses his/her meal by himself/herself, and this is not facilitated or regulated by the school. A school canteen however, will be taken into the school's account as it has been facilitated by the school.

Exclusion 1 has a separate GHG Protocol standard called The Product Life Cycle Accounting and Reporting Standard that governs its accounting. This standard provides guidelines to audit every product the school uses and includes CO2e emissions emitted during a product's entire life cycle - from raw material extraction to disposal/recycling .

Exclusions 2 and 3 ensure that double counting does not occur, and help attain a better understanding of the situation which will result in more viable and plausible solutions.

The carbon footprint estimation in this study employs calculation methods developed by Defra to calculate scope 1 emissions. However, these methods use values relevant to the United Kingdom, while this study is set in India. This may suggest that the accuracy of any calculation done using these values may be inaccurate. However, the data sourced from Defra for this study is unlikely to vary the results significantly, as the emission factor of a fuel is its fundamental property, and any changes despite this would be very insignificant while considering the scale of these calculations.

Furthermore, the carbon footprint estimation in this study does not utilise precise CO2 sequestration values for the trees actually present on the campus grounds or managed by the school administration that are accounted under CO2e offsets (section 3.2.2). This process requires an extensive study of the biological composition of each tree over an entire year, which is beyond the scope of this paper. Carbon dioxide sequestration values from other research papers have been used so as to appreciate the concept of the inclusion of CO2e offsets by trees in the carbon footprint estimation.

III. RESULTS

This section constitutes the following topics: (4.1) CO_2e emission results obtained, (4.2) CO_2e offset results obtained, (4.3) carbon footprint of National Academy For Learning for the year 2017-18, and (4.4) a general discussion of the obtained results and solutions to reduce the carbon footprint.

CO_2e Emissions

The CO_2e emissions are illustrated with their respective scopes in terms of CO_2e emission value and percentage of contribution. The total mass of CO_2e emitted during the academic year 2017-18 was 108055 kg. Figure 1 shows the mass value of the emissions for each of the three scopes, and a stacked bar for the total mass of emissions. Figure 2 shows the contribution of each scope to the total CO_2e emissions. The visualised data has been discussed under sections 4.1.1, 4.1.2 and 4.1.3.

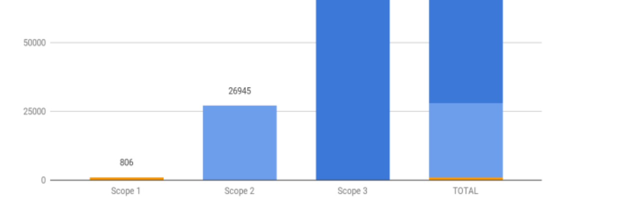

Figure 1 CO_2e emissions for the academic year 2017-18 in kg

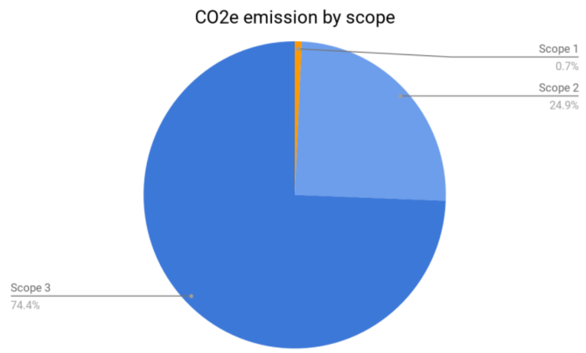

Figure 2 CO_2e emissions by scope for the academic year 2017-18

Scope 1 direct emissions
The amount of diesel consumed per month by the backup generator for the year 2017-18 was approximately 300 dm^3. This translates to about 806 kg CO_2e. This was the sole contributor to direct scope 1 emissions for the school. Overall, scope 1 contributed to about 0.7% of the total CO_2e emissions.

Scope 2 indirect emissions
The number of units of electricity consumed per month for the year 2017-18 was approximately 33000 kWh. This translates to about 26945 kg CO_2e. Electricity consumption from the grid accounted for 100% of scope 2 emissions. Overall, scope 2 contributed to about 24.9% of the total CO_2e emissions.

Scope 3 indirect emissions
The amount of fuel consumed per month by the school buses for the year 2017-18 was on average 30000 dm^3 of diesel. This translates to about 80634 kg of CO_2e. All of scope 3 emissions is constituted by this sole contributor. Overall, scope 3 contributed to about 74.3% of the total CO_2e emissions.

CO_2e Offsets
National Academy For Learning has a total of 70 trees: 30 silver oaks, 30 false ashokas, 3 coconuts, 2 badams, 1 guava, 4 unknown species. The masses of CO_2 sequestered by each tree are provided in Table 2.

Table 2; CO2 sequestration by National Academy For Learning

Common name of the tree	Number of trees	Total canopy area of all trees / m^2 (3 s.f.)	CO_2 sequestration for the year 2017-18 / kg (3 s.f.)
Silver Oak	30	300	230
False ashoka	30	30.0	346
Coconut	3	110	557
Badam	2	19.0	134
Guava	1	10.0	1.13
Unknown	4	-	87.0
TOTAL			1360

The total mass of CO_2e sequestered, therefore offset, by all the trees for the year 2017-18 was 1355 kg.

The Carbon Footprint of National Academy For Learning
The total CO_2e emissions are 108358 kg and total CO_2e offsets is 1355 kg. Figure 3 shows the offsets as a percentage of total emissions. The CO_2e offset is merely 1.3% of the total CO_2e emissions.

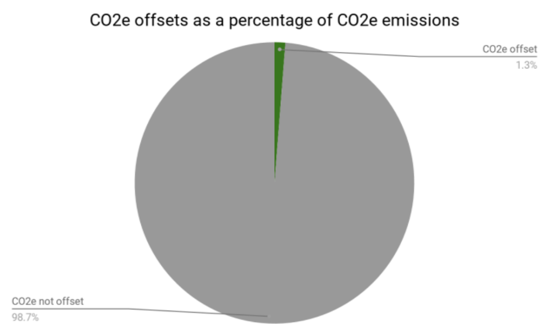

Figure 3 CO_2e offsets as a percentage of CO_2e emissions for the academic year 2017-18

By subtracting the CO_2e offset from the CO_2e emitted, the carbon footprint for National Academy For Learning for the year 2017-18 is estimated to be 107030 kg CO_2e. Scope 3 contributed the maximum. This scope is difficult to control due to its execution by third parties. Unfortunately, there is no historical data or similar studies to make a comparison with the results of this study.

Discussion and Solutions

Assessment of the school with the results of this study in hand will help in an effective approach to reduce the carbon footprint. By disbanding the data into the three scopes, corrective action can be taken methodically to tackle each scope, or a small aspect of each scope, at a time.

Though insignificant, scope 1 emissions may be a good way to start the carbon footprint reduction process. It is often the case that diesel run generators may be old, and may be emitting more carbon dioxide by burning fuel than they are supposed to. A fuel emission test must be conducted every six months or one year depending on the usage. Replacing the backup generator with one that utilises a cleaner fuel, like biodiesel and renewable diesel, will reduce the scope 1 emissions, as indicated by a life cycle assessment study **[48]**.

The school utilizes only the mains for its electricity needs. This has resulted in high scope 2 emission estimation. An audit on all the electric appliances used by the school will help identify the major power consuming components, and could potentially highlight old, inefficient light bulbs, and computer screens that remain turned on while not in use, amongst other problems. Addressing these will help reduce the consumption of electricity. Another solution to reducing the scope 2 emissions would be to install solar panels on the rooftops of the institutional buildings. These can then be connected to the mains supply switch board that connects to the rest of the school, and in the long term can minimize the utilization of the mains power supply to negligible amounts. The implementation of this project will be a slightly expensive affair in the short term, as not only should the solar panels be purchased and installed, but the continued usage of the mains power supply during and after the installation will add to the costs. It is certain that during and after the installation, the solar panels cannot be relied upon as the sole source of electricity. Due to its climatic conditions, the city of Bengaluru receives only about 200 days of sunshine a year, with some potential no-sunshine-days for many days at a stretch. During these times, either the mains power supply needs to be used, or another alternative source of renewable energy generation must be looked into.

A majority of the total emissions come from scope 3, vis a vis the outsourced transportation. As this is a private company, the school would not have enough control over the decisions made by the private transportation company. However, suggestions to use only the vehicles that pass the emissions test and those that run on cleaner fuels can be made. Students can be urged to bike or hike to school instead of using motorized transportation, and encouraging electric vehicles that charge their batteries using renewable resources would also help reduce these emissions.

While reducing the CO_2e emissions, a plausible addition to the process would be to increase CO_2e offsets. Planting trees such as teak and cluster fig that have high CO_2 sequestration values can help steadily reduce the net amount of CO_2 being emitted. This can be done within the physical boundaries of the school campus, or on any piece of land that the school organisation owns.
A very popular option amongst corporates today is to purchase carbon credits. These are tradable certificates that allow for the emission of some amount of CO_2e gases with the assurance that an equal amount will be offset elsewhere, thereby making the net emission zero. The CO_2e offset is done by companies and organisations like Cool Effect and COTAP investing the money in renewable projects and planting trees. These provide a temporary solution and need to be renewed after expiration.

It is essential that schools understand and estimate their carbon footprint as it not only brings the topic to the attention of the policy makers for the organisation, but also raises awareness about the seriousness of the issue amongst its students. As this may involve the excruciating effort that is required to get a reasonable estimate, the results of this research has been developed into a GUI python-powered carbon footprint estimator programme that aids schools (or any similar organisation) in the city of Bengaluru (Bengaluru Urban district), and the adjoining districts of Bengaluru Rural, Ramanagara, Kolar, Tumkuru, Chitradurga and Davanagere, to estimate their carbon footprints.

Figure 4 GUI programme screenshot 01

The programme is designed on the lines of this research paper. It requires the user to input the amount of fuels consumed throughout the year (scope 1 direct emission), the amount of electricity consumed throughout the year (scope 2 indirect emissions), and if applicable, outsourced transportation's fuel consumption throughout the year (scope 3 indirect emission).

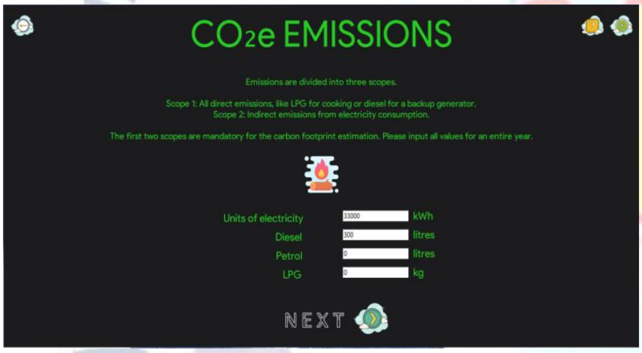

Figure 5 GUI programme screenshot 02

It then asks the user whether their organisation maintains plants, as this need to be accounted under offsets. Upon entering the name of the tree, it looks through the database (Appendix B) and adds the trees to a list.

Figure 6 GUI programme screenshot 03

After calculating the emissions for each of the scopes and offsets using the data from this research paper, the DEFRA (UK) and the CEA(India) **[50]**, it outputs the final carbon footprint estimation of the institution.

Figure 7 GUI programme screenshot 04

Once a school knows its carbon footprint, it can begin taking necessary actions to reduce or eliminate its carbon footprint.

Most importantly however, a striving effort has to be made in order to educate the public about global warming and their own carbon footprint. Changing human behaviour is a difficult task, but is not a feat that cannot be accomplished. Governments all over the world must lay greater emphasis on the issue of climate change, and a suitable way to do this is by including a sizable amount of scholastic material that will be taught to all students at school. This will allow the coming generations to be better prepared for the world they will be living in, and empower them to make better and more sustainable decisions to protect the planet.Conclusion

It is clear that global warming and climate change are phenomena that need greater attention from human beings, now, more than ever. Each entity and individual need to focus on developing solutions that reduce global warming, and an ideal way to start is by assessing the GHG emissions that lead to the phenomenon. This can be done by estimating the carbon footprint, which has been done on a medium sized urban school in this study. Literary reviews clearly show that there are many different ways to calculate the carbon footprint.

This study has chosen the method outlined by the GHG Protocol, which divides the CO_2e emissions into three scopes for a more methodical data collection. This approach also helps identify the problem areas, and aids in better solutions to fix the shortcomings. The study used data from the year 2017-2018. It falls short in quantifying all scope 3 emissions, which require conducting a life cycle analysis of all the products. Future studies need to take into account these factors as well, as the contribution from the goods and services purchased by the school towards CO_2e emissions is currently unknown.

The study strongly suggests that the transportation of students by the outsourced bus services is the major contributor to the emissions, comprising almost three quarters of it under scope 3. It also brings to light the extent to which CO_2e emissions are being offset, which is at a staggeringly low level of about 1%.

It is therefore essential that schools become more aware of their impact on the environment, and estimate their carbon footprint to realise the extent of the issue. Once this has been done, they must identify the areas where the carbon footprint can be reduced, and must opt for greener energy sources and sustainable forms of products they utilise regularly. The study aids schools in achieving this goal, and takes them one step closer towards a more sustainable and greener world.

References

[1] https://scholar.harvard.edu/files/xiwangli/files/li_tan_carbon_cleanproduction_2015.pdf

[2] https://www.theguardian.com/environment/climate-change

[3] https://www.climate-transparency.org/g20-climate-performance/g20report2018#1531904804037-423d5c88-a7a7

[4] https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en https://unfccc.int/process-and-meetings/the-kyoto-protocol/what-is-the-kyoto-protocol/kyoto-protocol-targets-for-the-first-commitment-period

[5] https://theconversation.com/what-is-a-pre-industrial-climate-and-why-does-it-matter-78601 https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[6] https://www.theguardian.com/environment/2011/apr/27/co2e-global-warming-potential

[7] https://timeforchange.org/what-is-a-carbon-footprint-definition

[8] http://wgbis.ces.iisc.ernet.in/energy/paper/carbon-footprint/319024_1_En_8_Chapter_OnlinePDF.pdf

[9] https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

[10] https://energy.economictimes.indiatimes.com/news/renewable/diu-smart-city-first-in-india-to-run-on-100-pc-renewable-energy-during-daytime-official/63889099#:~:text=New%20Delhi%3A%20The%20Diu%20Smart,till%20last%20year%2C%20it%20added.

[11] https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/global-renewable-energy-trends.html?id=gx:2el:3dc:4direnenergy:5awa:6di:09132018

[12] https://cag.gov.in/sites/default/files/audit_report_files/Report_No_3_of_2018_-_Public_Sector_Undertakings_Government_of_Karnataka.pdf

~~[13] https://www.bijlibachao.com/electricity-bill/what-are-watt-kilowatt-and-a-unit-of-electricity.html~~

[14] http://cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver14.pdf

[15] https://petrobazaar.com/furnace-oil-fo-specification-10148.html

[16] https://ghgprotocol.org/sites/default/files/Stationary_Combustion_Guidance_final_1.pdf

[17] https://www.indiaratings.co.in/PressRelease?pressReleaseID=25643&title=Ind-Ra-Downgrades-Raichur-Power%E2%80%99s-Senior-Project-Bank-Loans-to-%E2%80%98IND-BB%2B%E2%80%99%3B-Outlook-Negative

[18] https://www.sciencedirect.com/topics/engineering/gross-calorific-value#:~:text=Calorific%20value%20or%20heat%20of,kg%20for%20heavy%20fuel%20oil.

[19] https://www.abc.net.au/news/2017-11-18/plant-respiration-co2-findings-anu-canberra/9163858

[20] http://www.forestecologynetwork.org/climate_change/forest_sequestration.html

[21] https://www.ecomatcher.com/how-to-calculate-co2-sequestration/#:~:text=The%20weight%20of%20CO2%20in,the%20tree%20by%203.671.

[22] https://www.researchgate.net/publication/318471008_Carbon_Sequestration_Potential_of_Urban_Trees

[23] http://isasat.org/DAPOLI%20AARJ%20CTP/AARJ_1_1_3.pdf

[24] https://www.researchgate.net/publication/267263364_Estimation_of_carbon_sequestration_potential_in_coconut_plantations_under_different_agro-ecological_regions_and_land_suitability_classes

[25] https://www.researchgate.net/publication/273996169_Carbon_Dioxide_Absorption_of_Common_Trees_in_Chulalongkorn_University

[26] https://link.springer.com/article/10.1007/s10457-016-0023-z

[27] researchgate.net/profile/Soumyajit_Biswas/publication/261145574_Carbon_Sequestration_Rate_and_Aboveground_Biomass_Carbon_Potential_of_Four_Young_Species/links/00b7d533566ba2d96b000000.pdf

[28] https://www.usda.gov/media/blog/2015/03/17/power-one-tree-very-air-we-breathe

[29] https://worldpopulationreview.com/world-cities/bangalore-population

[30] https://bescom.karnataka.gov.in/storage/pdf-files/Finance%20and%20GST%20-%20Annual%20Report/16th%20Annual%20Report%20FY%202017-18.pdf

[31] https://www.ntpc.co.in/sites/default/files/downloads/NTPC-Sustainability-Report-Final.pdf

[32] https://www.nlcindia.com/investor/AnnualReport2018.pdf

[33] https://www.dvc.gov.in/dvcwebsite_new1/downloads/annual-report

https://www.dvc.gov.in/dvcwebsite_new1/?wpfb_dl=10430

[34] http://karnatakapower.com/wp-content/uploads/2014/03/KPCL-AR-Bi-Lingual-28-12-20181.pdf

[35] https://www.jsw.in/sites/default/files/assets//downloads/steel/Financials/Annual%20Reports/JSW_Energy_Deluxe_AR_2018_%2014-07-18_R4.pdf

[36] https://phys.org/news/2013-03-dead-forests-carbon-atmosphere.html
[37] https://climatepolicyinitiative.org/wp-content/uploads/2019/11/2019-Global-Landscape-of-Climate-Finance.pdf
[38] https://oem.bmj.com/content/oemed/64/12/827.full.pdf
[39] https://www.fs.fed.us/pnw/pubs/journals/pnw_2007_amstrup001.pdf
[40] https://link.springer.com/article/10.1007/s10584-008-9499-5
[41] https://climate.nasa.gov/vital-signs/ice-sheets/
[42] https://www.pnas.org/content/pnas/early/2009/11/20/0907998106.full.pdf
[43] https://universitybusiness.com/colleges-achieve-carbon-neutral-net-zero-sustainability/
[44] https://doi.org/10.1016/j.procir.2017.11.111
[45] https://doi.org/10.3390/su12010181
[46] https://doi.org/10.1016/j.jclepro.2011.10.007
[47] https://doi.org/10.17159/2413-3051/2011/v22i2a3208
[48] https://doi.org/10.1515/eces-2018-0021
[49] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018
[50] http://www.cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver13.pdf

III. APPENDIX A

Table 1 lists the sources from which BESCOM purchased electricity for the year 2017-18 :

Table 1 Electricity purchased by BESCOM (2017-18) **[30]**

Source name	Ownership	Source type	Units of electricity purchased / kWh (7 s.f.)	Percentage of total electricity purchased
NTPC Ltd	Govt of India	Multiple	3.680320 x 10^9	11.79 %
NLC India Ltd	Govt of India	Multiple	1.742290 x 10^9	5.58%
Madras Atomic Power Station	Govt of India	Nuclear	9.877000 x 10^7	0.32%
Kaiga Atomic Power Station	Govt of India	Nuclear	1.044740 x 10^9	3.35%
Vallur Thermal Power Project	Govt of India (JV)	Coal	4.318900 x 10^8	1.38%
Kudankulam Nuclear Power Plant	Govt of India	Nuclear	8.480300 x 10^8	2.72%
Damodar Valley Corporation	Govt of India	Multiple	1.337880 x 10^9	4.29%
NTPL Thermal Power Station	Govt of India	Coal	5.985500 x 10^8	1.92%
Kudgi Super Thermal Power Station	Govt of India	Coal	8.322600 x 10^8	2.67%
NTPC Bundled Power (Thermal)	Govt of India	Coal	4.017900 x 10^8	1.29%
Tungabhadra Hydroelectric Project	Govt of India	Hydel	8.710000 x 10^6	0.03%
Jurala Project	Govt of India	Hydel	4.284000 x 10^7	0.14%
Global Energy Pvt Ltd	Private	Unknown	8.237400 x 10^8	2.64%
PTC Industries Ltd	Private	Unknown	3.005700 x 10^8	0.96%
Maharashtra State Electricity Distribution Company Ltd	Govt of Maharashtra	Unknown	1.065000 x 10^7	0.03%
JSW Group	Private	Gas&Coal	6.712200 x 10^8	2.15%

Shree Cements	Private	Unknown	9.959000 x 10^7	0.32%
Indian Energy Exchange Ltd	Private	Unknown	1.197000 x 10^7	0.04%
Karnataka Power Corporation Ltd - Hydel	Govt of Karnataka	Hydel	1.744200 x 10^9	5.59%
Karnataka Power Corporation Ltd - Thermal	Govt of Karnataka	Coal	8.452650 x 10^9	27.08 %
Udupi Power Corporation Ltd	Private	Coal	3.336790 x 10^9	10.69 %
Co Generation	Multiple	NCE	5.746400 x 10^8	1.84%
Bio-Mass	Multiple	Bio	6.388000 x 10^7	0.20%
Mini-Hydel	Multiple	Hydel	3.425400 x 10^8	1.10%
Wind	Multiple	Wind	2.501280 x 10^9	8.01%
KPCL Wind	Govt of Karnataka	Wind	6.920000 x 10^6	0.02%
Solar	Multiple	Solar	9.447000 x 10^8	3.03%
KPCL Solar	Govt of Karnataka	Solar	3.620000 x 10^6	0.01%
NTPC Bundled Power (Solar) VVNL	Govt of India	Solar	6.626400 x 10^7	0.20%
NTPC Bundled Power (Solar) NSM 2	Govt of India	Solar	1.377900 x 10^8	0.44%
TOTAL			**3.121538 x 10^{10}**	-

Power generation that utilises coal and gas are the sole sources of CO_2 emissions from the power plants listed in Table 1. Each of these power plants have been analysed individually. The amount of CO_2 emitted from each power plant can be calculated using the following equation recommended by the GHG Protocol **[16]**:

Equation 1.1 Mass of CO_2 emitted (GHG Protocol)

$$E = A_{f,m} \times F_{c,m} \times F_{ox} \times 44 \div 12$$

where:

E	Mass emissions of CO_2	MT(CO_2)
$A_{f,m}$	Mass of fuel consumed	MT
$F_{c,m}$	Carbon content of fuel on a mass basis	MT(C) MT^{-1}
F_{ox}	Oxidation factor of the fuel	-
$44/12$	The ratio of the molecular weight of CO_2 to that of carbon	-

However, due to the limitations of this study, the carbon content analysis of fuel cannot be conducted. Therefore, the following equation used by the Government of India to calculate the same has been employed **[14]**:

Equation 1.2 Mass of CO_2 emitted (CEA India)

$$AbsCO_2 = FuelCon \times GCV \times EF \times Oxid$$

where:

$AbsCO_2$	Absolute CO_2 emission	gCO_2
$FuelCon$	Amount of fuel consumed	kg
GCV	Gross calorific value of the fuel	MJ kg^{-1}
EF	CO_2 emission factor of the fuel	gCO_2 MJ^{-1}
$Oxid$	Oxidation factor of the fuel	-

It must be noted that both equation 1.1 and equation 1.2 result in the same outcome, which is the mass of CO_2, but employ a slightly different set of variables and constants to arrive at it.

The data for the gross calorific value, the emission factor and the oxidation factor of imported coal, domestic coal and oil utilised in the calculation of the mass of CO_2 emitted needed for equation 1.2 are as follows:

Table 2 Data required for CO_2 calculation of fuels

	Gross calorific value **[17][18]** / MJ kg^{-1}	Emission factor **[14]** / gCO_2 MJ^{-1}	Oxidation factor **[14]**
Imported Coal	2.3012×10^{1}*	8.520×10^{1}	1.0
Coal	1.5690×10^{1}	1.025×10^{2}	0.98
Oil	4.5000×10^{1}	7.190×10^{1}	1.0

* Imported coal from Indonesia, South Africa and Australia **[35]**; value assumed to be 5500 kcal kg^{-1}

Once the total mass of CO_2 emitted by each power plant has been arrived at, the specific CO_2 emissions for each power plant is calculated as follows:

Equation 2 Mass of CO_2 emitted per unit

$$Mass\ of\ CO_2\ per\ unit = \frac{Total\ mass\ of\ CO_2\ emitted}{Total\ number\ of\ units\ generated}$$

Note:

Certain data for some power plants have been assumed. Power plants using imported coal for generating electricity have a lower specific CO_2 emission value being assumed than for those using domestic coal.

The increased gross calorific value of imported coal is likely to reduce the specific coal consumption, as more heat is supplied to the water in thermal power plants with the same mass of coal. This allows the generation of electricity to occur at a lower level of coal consumption, and would result in a lower value of specific CO_2 emission.

(1) NTPC Ltd**[31]**

NTPC's Southern region has about 95% of its installed capacity producing electricity from fossil fuels. But the actual generation of electricity is almost completely from fossil fuel sources only, of which 99.99% is from coal based power plants. In 2017-18, NTPC Ltd published the following details pertaining to its operations in its annual report.

Table 3 NTPC Ltd data for 2017-18

Total coal used / kg	1.6895×10^{11}
Specific coal consumption / kg kWh^{-1}	0.67
Total units generated / kWh	2.5×10^{11}
Total mass of CO_2 emitted / kg	2.7×10^{11}

The specific CO_2 emission is 1.055 kg kWh^{-1}.

NLC India Ltd **[32]**

In 2017-18, NLC India Ltd published the following details pertaining to its operations in its annual report.

Table 4 NLC India Ltd data for 2017-18

Total coal produced / kg	2.5153×10^{10}
Total coal sold / kg	1.6160×10^{9}
Total coal used for power production** / kg	2.3537×10^{10}
Total units of electricity produced / kWh	1.847255×10^{10}
Units of electricity produced from solar energy/ kWh	7.052000×10^{7}
Units of electricity produced from wind energy / kWh	1.239000×10^{8}
Total units of electricity produced from coal** / kWh	1.827813×10^{10}
Total mass of CO_2 emitted / kg	3.7×10^{10}

**It has been assumed that any unsold coal has been completely used in the production of electricity, and that no source of power generation has been employed other than coal, solar energy and wind energy.

The specific CO_2 emission is 2.030 kg kWh^{-1}

Madras Atomic Power Station

The method of power generation does not produce CO_2.

Kaiga Atomic Power Station

The method of power generation does not produce CO_2.

Vallur Thermal Power Project

Sufficient information required for the calculation has not been reported in the company's annual report. Being a joint venture with NTPC Ltd, the value of 1.055 kg kWh^{-1} for specific CO_2 emission has been assumed.

Kudankulam Nuclear Power Plant

The method of power generation does not produce CO_2.

Damodar Valley Corporation **[33]**

In 2017-18, Damodar Valley Corporation published the following details pertaining to its operations in its annual report.

Table 5 Damodar Valley Corporation data for 2017-18

Total coal used / kg	2.1949×10^{10}
Specific coal consumption / kg kWh^{-1}	0.62
Total units generated / kWh	3.5×10^{10}
Total mass of CO_2 emitted / kg	3.5×10^{10}

The specific CO_2 emission is 0.997 kg kWh^{-1}.

NTPL Thermal Power Station

Sufficient information required for the calculation has not been reported in the company's annual report. Being a joint venture with NLC India Ltd, the value of 2.030 kg kWh^{-1} for specific CO_2 emission has been assumed.

Kudgi Super Thermal Power Station

Sufficient information required for the calculation has not been reported in the company's annual report. Being operated by NTPC Ltd, the value of 1.055 kg kWh^{-1} for specific CO_2 emission has been assumed.

NTPC Bundled Power (Thermal)

The data of NTPC Ltd has been used for the calculation. The specific CO_2 emission is 1.055 kg kWh^{-1}.

Tungabhadra Hydroelectric Project

The method of power generation does not produce CO_2.

Jurala Project

The method of power generation does not produce CO_2.

Global Energy Pvt Ltd

The method of power generation is not known. This company's share in the power purchase by BESCOM has been ignored.

PTC Industries Ltd

The method of power generation is not known. This company's share in the power purchase by BESCOM has been ignored.

Maharashtra State Electricity Distribution Company Ltd

The method of power generation is not known. This company's share in the power purchase by BESCOM has been ignored.

JSW Group

Sufficient information required for the calculation has not been reported in the company's annual report. A value of 0.900 kg kWh^{-1} for specific CO_2 emission has been assumed, as it is known that imported coal is used for the generation of electricity.

Shree Cements

The method of power generation is not known. This company's share in the power purchase by BESCOM has been ignored.

Indian Energy Exchange Ltd

The method of power generation is not known. This company's share in the power purchase by BESCOM has been ignored.

Karnataka Power Corporation Ltd - Hydel

The method of power generation does not produce CO_2.

Karnataka Power Corporation Ltd - Thermal **[34]**

In 2017-18, Karnataka Power Corporation Limited (KPCL) operated 3 thermal power plants - Raichur Thermal Power Plant (RTPS), Bellary Thermal Power Plant (BTPS) and Yermarus Thermal Power Plant (YTPS) - in the state, each utilising coal sourced from the neighbouring states of Maharashtra and Andhra Pradesh, and Odisha. The power plants also use heavy fuel oil as a start up fuel **[12]**. The relevant data for each power station are as follows:

~~It must be noted that one unit of electricity is equal to one kilowatt hour (kWh) **[13]**.~~

RTPS

Raichur Thermal Power Plant is located at Deosugur in the Raichur district of the state of Karnataka. There are seven units of a capacity 210 MW (U1-U7) each and one unit of capacity 250 MW (U8) installed. The total capacity of the plant is therefore 1720 MW.

Table 6.1 RTPS data for 2017-18

Units generated (U1-U7) / kWh	8.967150×10^{9}
Units generated (U8) / kWh	1.867400×10^{9}
Total units generated / kWh	1.083455×10^{10}
Coal used (U1-U7) / kg	5.7370×10^{9}
Coal used (U8) / kg	1.1940×10^{9}
Total coal used / kg	6.9310×10^{9}
Specific oil consumption (U1-U7) / $m^3\ kWh^{-1}$	9.700×10^{-7}
Specific oil consumption (U8) / $m^3\ kWh^{-1}$	6.000×10^{-7}
Oil consumption (U1-U7) / m^3	8.698×10^{3}
Oil consumption (U8) / m^3	1.120×10^{3}
Total oil consumption / m^3	9.819×10^{3}

BTPS

Bellary Thermal Power Plant is located in Kudatini Village in the Bellary district of the state of Karnataka. There are two units of capacity 500 MW (U1 & U2) each and one unit of capacity 700 MW (U3) installed. The total capacity of the plant is therefore 1700 MW.

Table 6.2 BTPS data for 2017-18

Units generated (U1) / kWh	1.348300×10^{9}
Units generated (U2) / kWh	1.845950×10^{9}
Units generated (U3) / kWh	8.268800×10^{8}
Total units generated / kWh	4.021130×10^{9}
Coal used (U1) / kg	8.3700×10^{8}
Coal used (U2) / kg	1.1300×10^{9}
Coal used (U3) / kg	4.9300×10^{8}
Total coal used / kg	2.4600×10^{9}
Specific oil consumption (U1) / $m^3\ kWh^{-1}$	1.102×10^{-6}
Specific oil consumption (U2) / $m^3\ kWh^{-1}$	5.590×10^{-7}
Specific oil consumption (U3) / $m^3\ kWh^{-1}$	5.888×10^{-6}
Oil consumption (U1) / m^3	1.486×10^{3}
Oil consumption (U2) / m^3	1.032×10^{3}
Oil consumption (U3) / m^3	4.869×10^{3}
Total oil consumption / m^3	7.386×10^{3}

YTPS

Yermarus Thermal Power Plant is located at Yermarus village in the Raichur district of the state of Karnataka. There are two units of capacity 800 MW each. The total capacity of the plant is therefore 1600 MW. This power station is a joint venture between KPCL and BHEL (Bharat Heavy Electricals Limited). Generation of electricity by the second unit had not yet commenced in 2017-18.

Table 6.3 YTPS data for 2017-18

Units generated / kWh	9.963200×10^{8}
Coal used / kg	6.3400×10^{8}

The specific fuel oil consumption for YTPS has not been accounted for, as the data is not available. This, however, will not have a significant impact on the calculations as the amount of fuel oil used in power plants is, in itself, very little and YTPS contributes only about 6% of the total units of electricity produced by the three power plants.

Fuel oil has a density of 9.600×10^2 kg m^{-3}**[15]**. This is used to calculate the mass of fuel oil consumed by the power plants.

The total number of units produced, and the amount of coal and oil utilised across the three power plants are summarised.

Table 6.4 Total units produced and total coal consumed by KPCL for 2017-18

Total units generated / kWh	1.585201×10^{10}
Total mass of coal used / kg	1.0025×10^{10}
Total volume of oil used / m^3	1.720×10^4
Total mass of oil used / kg	1.652×10^7
Mass of CO_2 emitted from coal / kg	1.6×10^{10}
Mass of CO_2 emitted from oil / kg	5.3×10^7
Total mass of CO_2 emitted / kg	1.6×10^{10}

The specific CO_2 emission is 1.000 kg kWh^{-1}.

Udupi Power Corporation Limited

Sufficient information required for the calculation has not been reported in the company's annual report. A value of 0.900 kg kWh^{-1} for specific CO_2 emission has been assumed, as it is known that imported coal is used for the generation of electricity.

Co Generation

The method of power generation does not produce CO_2.

Bio-Mass

The method of power generation does not produce CO_2. It does produce methane, which is a GHG. However, this is excluded from the calculations for the three scopes as dictated by the GHG Protocol.

Mini-Hydel

The method of power generation does not produce CO_2.

Wind

The method of power generation does not produce CO_2.

KPCL Wind

The method of power generation does not produce CO_2.

Solar

The method of power generation does not produce CO_2.

KPCL Solar

The method of power generation does not produce CO_2.

NTPC Bundled Power (Solar) VVNL

The method of power generation does not produce CO_2.

NTPC Bundled Power (Solar) NSM 2

The method of power generation does not produce CO_2.

All the relevant data to calculate the CO_2 emissions by BESCOM due to purchasing electricity from the above sources are summarised below.

Table 7 Summarised relevant data

Source	Units purchased by BESCOM / kWh	Specific CO_2 emission / kg kWh^{-1}	Mass of CO_2 emitted / kg
NTPC Ltd	3.680320×10^9	1.055	3.886×10^9
NLC India Ltd	1.742290×10^9	2.030	3.536×10^9
Vallur Thermal Power Project	4.318900×10^8	1.055	4.561×10^8
Damodar Valley Corporation	1.337880×10^9	0.997	1.307×10^9
NTPL Thermal Power Station	5.985500×10^8	2.030	1.215×10^9
Kudgi Super Thermal Power Station	8.322600×10^8	1.055	8.788×10^8
NTPC Bundled Power (Thermal)	4.017900×10^8	1.055	4.243×10^8
JSW Group	6.712200×10^8	0.900	6.041×10^8

Karnataka Power Corporation Ltd - Thermal	8.452650×10^9	1.000	8.453×10^9
Udupi Power Corporation Ltd	3.336790×10^9	0.900	3.003×10^9
TOTAL			**2.349×10^{10}**

With the total mass of CO_2 emissions of 2.349×10^{10} kg from electricity purchased by BESCOM, and the total units of electricity of 3.121538×10^{10} kWh purchased by BESCOM - generated by both fossil-fuel based and non fossil-fuel based power plants - the CO_2 emission for each unit of electricity distributed by BESCOM is 0.7526 kg kWh^{-1}.

About 4% of the total units of electricity purchased could not be taken into account due to insufficient information pertaining to the method of generation. By assuming all this electricity has been generated using the lowest grade coal of 1.569×10^1 MJ kg^{-1} at the highest specific coal consumption of 2.030 kg kWh^{-1}, a reasonable estimate can be made that at most, 3.988×10^9 kg of CO_2 may have been left out of the calculation. Adding this to the original estimation results in a specific CO_2 emission of 0.8804 kg kWh^{-1}, which is a 17.0% uncertainty. As the true value most likely lies anywhere in between these two specific CO_2 emission values, their average of **0.8165 kg kWh^{-1}** can be considered as the best estimate for the CO_2 emission for each unit of electricity distributed by BESCOM.

IV. APPENDIX B

Table 1 CO_2 sequestration values (selected trees) **[22-28]**

Scientific name	Common name	CO_2 sequestration value / kg m^{-2} $year^{-1}$
Artocarpus integrifolia	Jackfruit tree	3.330×10^{-1}
Azadirachta indica	Neem tree	8.908×10^0
Bridelia retusa	Bridelia tree	1.034×10^{-1}
Butea monosperma	Sacred tree	9.056×10^0
Cassia fistula	Golden shower tree	1.118×10^{-1}
Cocos nucifera	Coconut tree	5.060×10^0
Dalbergia sissoo	Indian rosewood	8.885×10^0
Ficus benghalensis	Banyan tree	9.019×10^0
Ficus racemosa	Cluster fig tree	1.105×10^1
Grevillea robusta	Silver oak	7.665×10^{-1}
Mangifera indica	Mango tree	5.874×10^0
Phyllanthus emblica	Indian gooseberry	8.312×10^0
Polyalthia longifolia	False ashoka	1.152×10^1
Pongamia pinnata	Indian beech	8.191×10^0
Psidium guajava	Guava tree	1.134×10^{-1}
Syzygium cumini	Black plum	7.807×10^0
Tectona grandis	Teak	1.295×10^1
Terminalia catappa	Badam/Almond tree	7.077×10^0
Terminalia elliptica	Matti/Saaj tree	1.007×10^{-1}
Generic CO_2 sequestration value per tree: 2.177×10^1 kg $year^{-1}$		