Greenhouse Gas emissions from transportation sector at Indian Institute of Science, Bangalore

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Abstract

This article provides a comprehensive overview of greenhouse gas emissions from the transportation sector at the Indian Institute of Science, Bangalore. A minimalist cost-based approach is taken to approximate the GHG emission from various transit units on the campus. Several Mitigation steps have been suggested to deal with the emissions

Keywords: Transport emissions; university transit; GHG emission mitigation

1 Introduction

The Indian Institute of Science (IISc) is a public, recognized research university dedicated to science, engineering, design, and management. Bengaluru is the capital of the Indian state of Karnataka. It is one of India's most prestigious educational institutes. In 1958, it was designated as a deemed to be university, and in 2018, it was designated as an Institute of Eminence.

On the road to Yeshwantpur, the IISc campus is located in the north of Bangalore, around 6 kilometres from Bangalore City Railway Station. The Gulmohar Marg, the Mahogany Marg, the Badami Marg, the Tala Marg, the Ashoka Marg, the Nilgiri Marg, the Silver Oak Marg, the Amra Marg, and the Arjuna Marg are just a few of the paths that go through the university. The institute is totally residential and is located in the centre of Bangalore on 400 acres of land. With around 110 species of woody plants, the IISc campus is home to both foreign and indigenous plant species.

This study aims at quantifying the greenhouse gas emissions from the transportation sector on the IISc campus. The amount of risk associated is calculated, and practical mitigation measures are suggested. The novelty of the work is that no amount of expenditure was done for this study, making it possible to be carried out by students of any universality without any financial aid. The methods used, although naïve, help in reaching the overall objective in quite a detail.

The article is organized as follows: Section 2 deals with baseline studies looking into various data sources that would help in the quantification of GHG emissions; Section 3 deals with the calculation of GHG emissions from the transportation sector in the IISc Campus and finally, Section 4 discusses several mitigation steps to improve the current situation

2 Baseline Studies

All routes around the Indian Institute of Science, Bangalore campus were found using Open Street Maps (OSM). OSM is an open-source service that provides various road networks for geospatial analysis. The boundary of the campus was marked for further analysis, as shown in figure 1.

Figure 1: IISc, Bangalore Campus Boundary

Since it's a university campus, it becomes pertinent to understand the distribution of walkable, cyclable and motorized roads. This has been shown in figure 2.

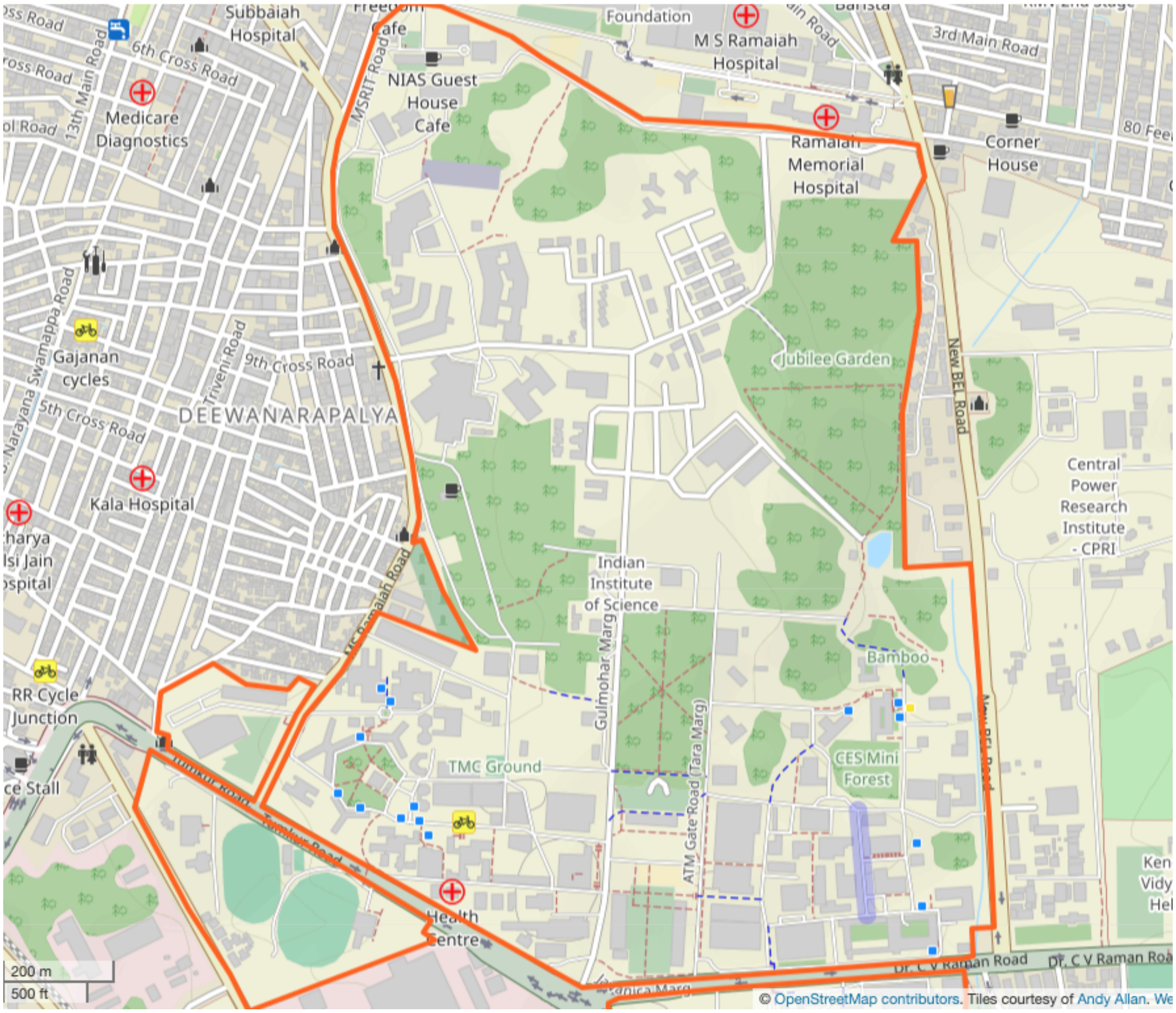


Figure 2: Types of roads in IISc campus, red dash refers to walkable, blue dash as cyclable and white dash as Motorway

Several parameters were used to understand the current scenario of greenhouse gas emissions in the Indian Institute of Science, Bangalore campus from transportation sector. We shall now discuss about each of them in details:

2.1 GPS based proxy for traffic distribution

Although, satellite imaging through Google Maps provides traffic data around the campus, no data was found inside the campus boundary. Hence, a GPS based proxy was used. The GPS based proxy works based on the following assumption: The locations were there is a strong moving GPS signal, presumably from mobiles would refer to the traffic movement in that area. Since, GPS signals are easy to find from satellite date, the use of GPS proxy as traffic density serves as a economical & easy to use proxy.

GPS as a proxy has been recently used extensively in literature (Al-Sobky and Mousa, 2016; Castro et al., 2012). GPS signals are received and processed by the vehicle module to generate vehicle data, including the vehicle's position, heading and velocity. The method used in this study is a simplified version of (Al-Sobky and Mousa, 2016). Based on the average strength of GPS Signal from various locations in the IISc Campus, the relative traffic density is computed.

It is important to note that the GPS based proxy has several limitations: It cant differentiate between people and transit units (TUs); There could be several false signals from non traffic sources.

On the other hand, GPS Signals provide data for larger period of time. It is also important to understand the magnitude of GPS signals can't be directly correlated with the number of TUs passing from that area in a particular time, but the GPS Signal strength would give us an idea of relative traffic density qualitatively, In simple terms, higher the GPS signal higher are the "chances" of more traffic density.

The GPS signal strength for the campus in given in Figure 3. A more detailed view is given in Figure 4 & 5.

Figure 3: GPS Signals in IISc Campus. Green refers low signal and red to higher signal. The gradient from green to red follows the strength of GPS signal from weak to strong

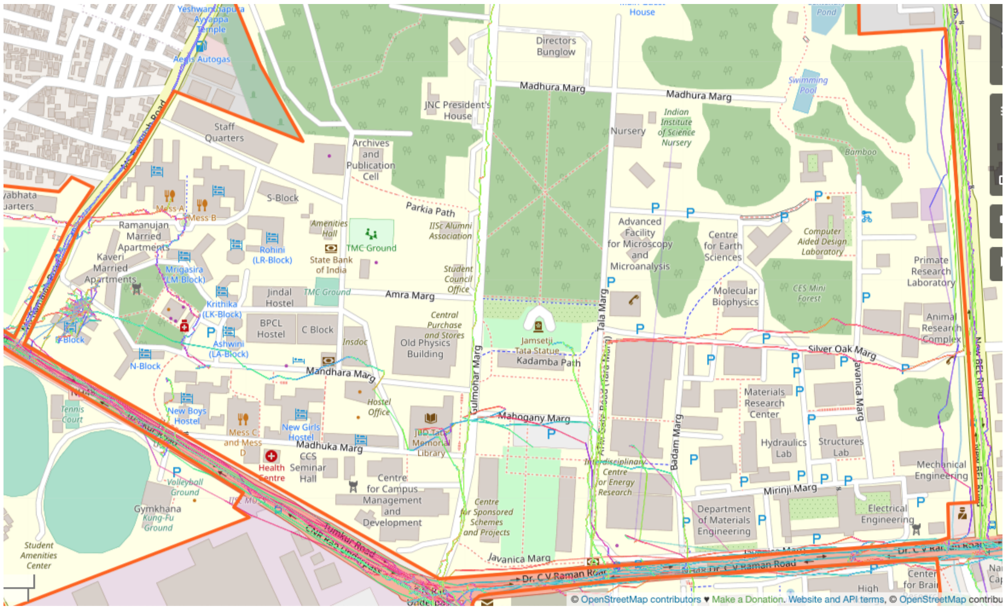


Figure 4

Figure 5

Based on Figure 3,4 and 5, A chart of highest traffic density places can be found and the same has been summarised in the table below:

Decreasing Traffic Density →

Decreasing Traffic Density ↓

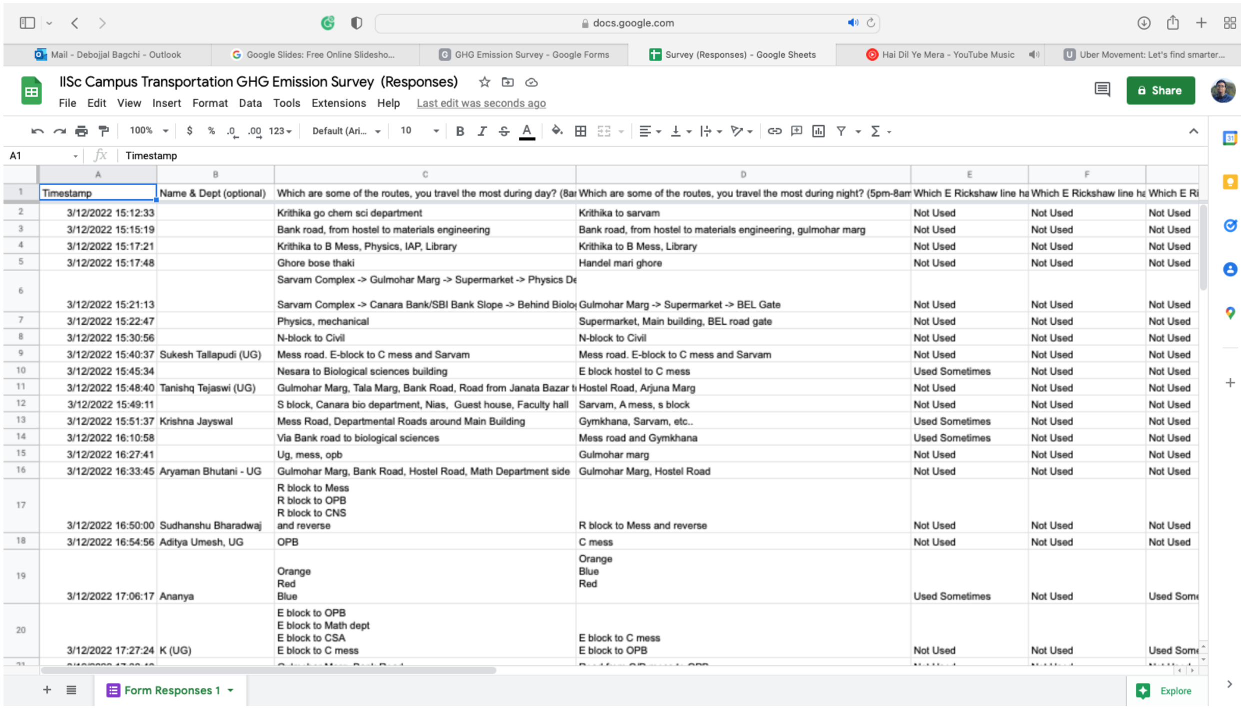
Road	Departments / Hostels / Sub Divisions		
Hostel Block	R Block	N Block	Krithika
Silver Oak Marg	Organic; IPC	Chemical Engg	Molecular Biophysics
Gulmohar - Mehogany Marg	JRD Tata Library	Mehogany Marg Parking	OPB
Tata Marg / Bank Road	CPDM	ICWR	ICER
Gulmohar Marg – Unnamed Rd	CNS	ECE	IISc Residential Quarters

Traffic Density – Top Contributers

The GPS based signal serves as proxy for traffic distribution inside the campus and from the previous discussion, its clear, using GPS signal to have a qualitatively idea of traffic distribution is a fairly good proxy.

2.2 Traffic Density Ground Survey

It becomes a challenging question on how reliable the GPS based proxy is when compared to real traffic density. In absence of sensors, due to this study being considered at the most economical scale possible, the best way to check out the authenticity of the GPS based proxy is by computing real traffic density via survey for a shorter period of time and co relating the same with the GPS Proxy Results. A campus wide survey was done to find out the most popular routes among students (Appendix A). The data was collected using Google Forms. A snapshot of the responses is given in figure 6.



IISc Campus Transportation GHG Emission Survey (Responses)

	Timestamp	Name & Dept (optional)	Which are some of the routes, you travel the most during day? (8ar	Which are some of the routes, you travel the most during night? (5pm-8am	Which E Rickshaw line ha	Which E Rickshaw line ha	Which E Ri
2	3/12/2022 15:12:33		Krithika go chem sci department	Krithika to sarvam	Not Used	Not Used	Not Used
3	3/12/2022 15:15:19		Bank road, from hostel to materials engineering	Bank road, from hostel to materials engineering, gulmohar marg	Not Used	Not Used	Not Used
4	3/12/2022 15:17:21		Krithika to B Mess, Physics, IAP, Library	Krithika to B Mess, Library	Not Used	Not Used	Not Used
5	3/12/2022 15:17:48		Ghore bose thaki	Handel mari ghore	Not Used	Not Used	Not Used
6	3/12/2022 15:21:13		Sarvam Complex -> Gulmohar Marg -> Supermarket -> Physics De Sarvam Complex -> Canara Bank/SBI Bank Slope -> Behind Biolo	Gulmohar Marg -> Supermarket -> BEL Gate	Not Used	Not Used	Not Used
7	3/12/2022 15:22:47		Physics, mechanical	Supermarket, Main building, BEL road gate	Not Used	Not Used	Not Used
8	3/12/2022 15:30:56		N-block to Civil	N-block to Civil	Not Used	Not Used	Not Used
9	3/12/2022 15:40:37	Sukesh Tallapudi (UG)	Mess road. E-block to C mess and Sarvam	Mess road. E-block to C mess and Sarvam	Not Used	Not Used	Not Used
10	3/12/2022 15:45:34		Nesara to Biological sciences building	E block hostel to C mess	Used Sometimes	Not Used	Not Used
11	3/12/2022 15:48:40	Tanishq Tejaswi (UG)	Gulmohar Marg, Tala Marg, Bank Road, Road from Janata Bazar t	Hostel Road, Arjuna Marg	Not Used	Not Used	Not Used
12	3/12/2022 15:49:11		S block, Canara bio department, Nias, Guest house, Faculty hall	Sarvam, A mess, s block	Not Used	Not Used	Not Used
13	3/12/2022 15:51:37	Krishna Jayswal	Mess Road, Departmental Roads around Main Building	Gymkhana, Sarvam, etc..	Used Sometimes	Not Used	Not Used
14	3/12/2022 16:10:58		Via Bank road to biological sciences	Mess road and Gymkhana	Used Sometimes	Not Used	Not Used
15	3/12/2022 16:27:41		Ug, mess, opb	Gulmohar marg	Not Used	Not Used	Not Used
16	3/12/2022 16:33:45	Aryaman Bhutani - UG	Gulmohar Marg, Bank Road, Hostel Road, Math Department side	Gulmohar Marg, Hostel Road	Not Used	Not Used	Not Used
17	3/12/2022 16:50:00	Sudhanshu Bharadwaj	R block to Mess R block to OPB R block to CNS and reverse	R block to Mess and reverse	Not Used	Not Used	Not Used
18	3/12/2022 16:54:56	Aditya Umesh, UG	OPB	C mess	Not Used	Not Used	Not Used
19	3/12/2022 17:06:17	Ananya	Orange Red Blue	Orange Blue Red	Used Sometimes	Not Used	Used Som
20	3/12/2022 17:27:24	K (UG)	E block to OPB E block to Math dept E block to CSA E block to C mess	E block to C mess E block to OPB	Not Used	Not Used	Used Som

Figure 6: Popular Routes Survey

The data was analyzed to find out the most occurrences of roads in the popular routes field. Figure 7 and 8 summarizes the result using a word chart. The roads which are larger in size have larger occurrences and vice versa.

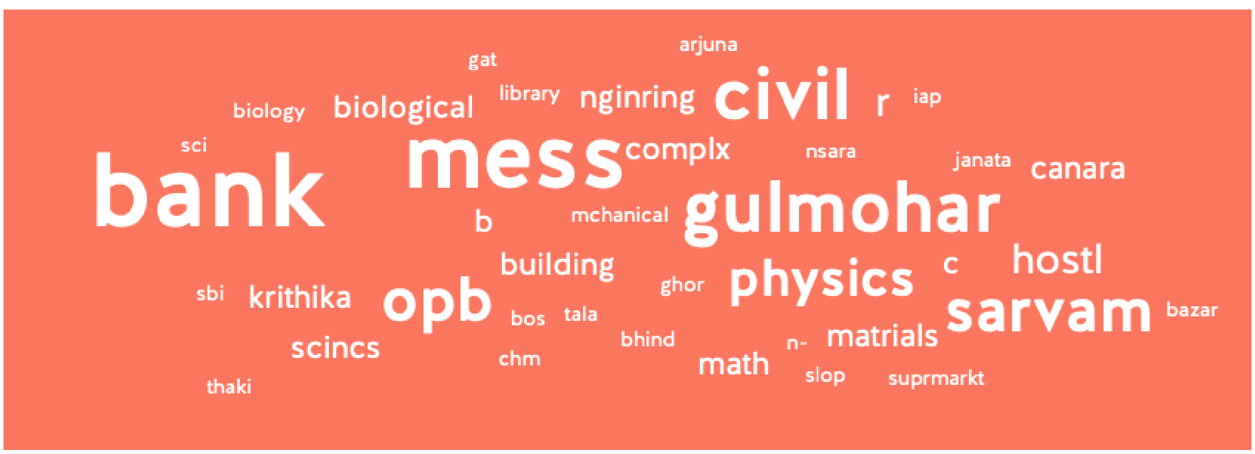


Figure 7: Day Time Word Chart

Figure 8: : Night Time Word Chart

Clearly the survey data shows strong correlation with the GPS proxy based traffic density. This further concretes the use of GPS Proxy as traffic density data.

2.3 Transit Units Quantification

Section 2.1 and 2.2 deals with how we can understand the traffic patterns inside the campus. The traffic pattern only makes sense when we have real data on number of Transit Units (TUs) entering and exiting the various gates of the campus.

IISc has 12 gates, out of which only 4 are functional: Main Gate, D Gate, SID Gate and Gymkhana Gate. CCTV Cameras from each of these gates were used to count number of Transit Units entering and exiting the campus. The data is summarized in the table below. (Appendix B)

Time	MAIN GATE			D GATE			SID GATE			GYMKHANA GATE		
	2 wheeler	4 wheeler	Total	2 wheeler	4 wheeler	Total	2 wheeler	4 wheeler	Total	2 wheeler	4 wheeler	Total
10am-11am	44	10	54	64	20	84	8	1	9	0	0	0
11-12pm	16	12	28	25	14	39	7	1	8	1	1	2
12-1pm	16	8	24	33	9	42	4	0	4	3	0	3
1-2pm	24	7	31	30	4	34	9	4	13	2	0	2
2-3pm	21	12	33	54	6	60	3	1	4	4	0	4
3-4pm	18	13	31	28	9	37	1	1	2	2	0	2
4-5pm	13	3	16	29	3	32	4	0	4	0	1	1
5-6pm	9	4	13	16	2	18	4	2	6	1	0	1
6-7pm	10	10	20	21	4	25	3	1	4	1	0	1
7-8pm	7	4	11	21	4	25	7	1	8	0	0	0

The data was analysed to have a better understading of the data. Figure 9 shows the total incoming traffic from the 4 gates per TU Type, Figure 10 shows the total distribution of TUs over all the 4 gates. Clearly D gate is the major contributor followed by Main Gate. Figure 11 shows distribution of TU types over the 4 gates. Figure 12 shows total TU entering at different times of the day. Clearly, 10-11am seem to be the most congested time. Figure 13 shows a time series of total TUs and Figure 14 shows the TU type at different times. The data clearly indicates peaks at 10-11am and 2-3pm. The first peak corresponds to TU entry as incoming people at office hours and the later corresponds to lunch time.

Since data was collected from 10am onward, Average TU count of morning (10am to 2pm) and Evening (2pm-8pm) time spans is considered for every one hour interval in time span from 8-10am and 8-10pm respectively. No TU entry / exit from 10pm at night to 8am in morning is considered for the study. These assumptions helps in calculating a very conservative GHG emission estimate. The same has been summarised below.

Time	MAIN GATE			D GATE			SID GATE			GYMKHANA GATE		
	2 wheeler	4 wheeler	Total	2 wheeler	4 wheeler	Total	2 wheeler	4 wheeler	Total	2 wheeler	4 wheeler	Total
8am-10am	50	20	68	82	21	103	12	3	15	4	0	4
8pm-10pm	23	14	40	46	9	54	8	2	10	2	0	2

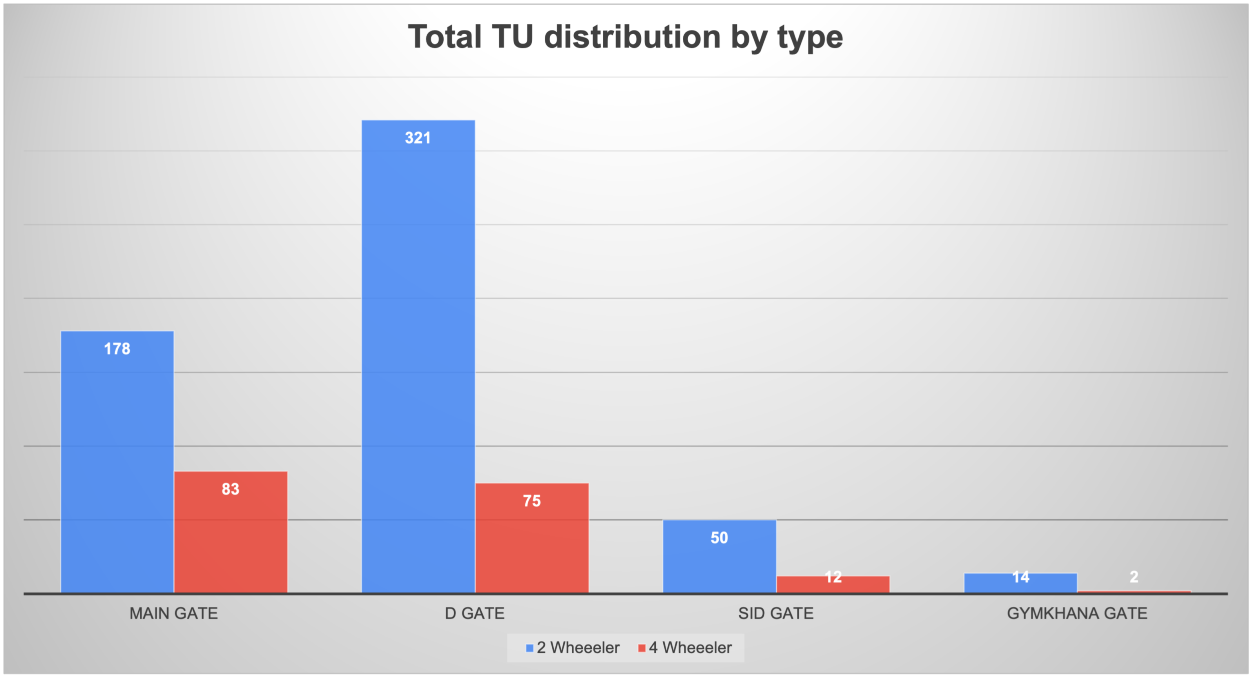


Figure 9

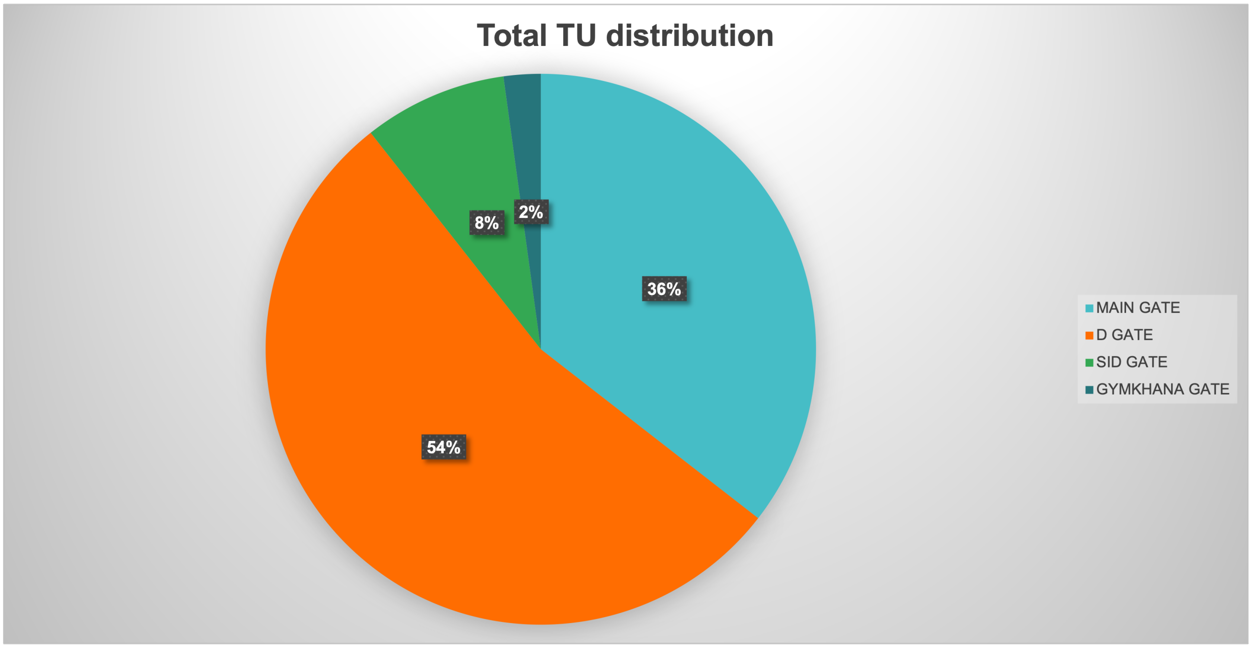


Figure 10

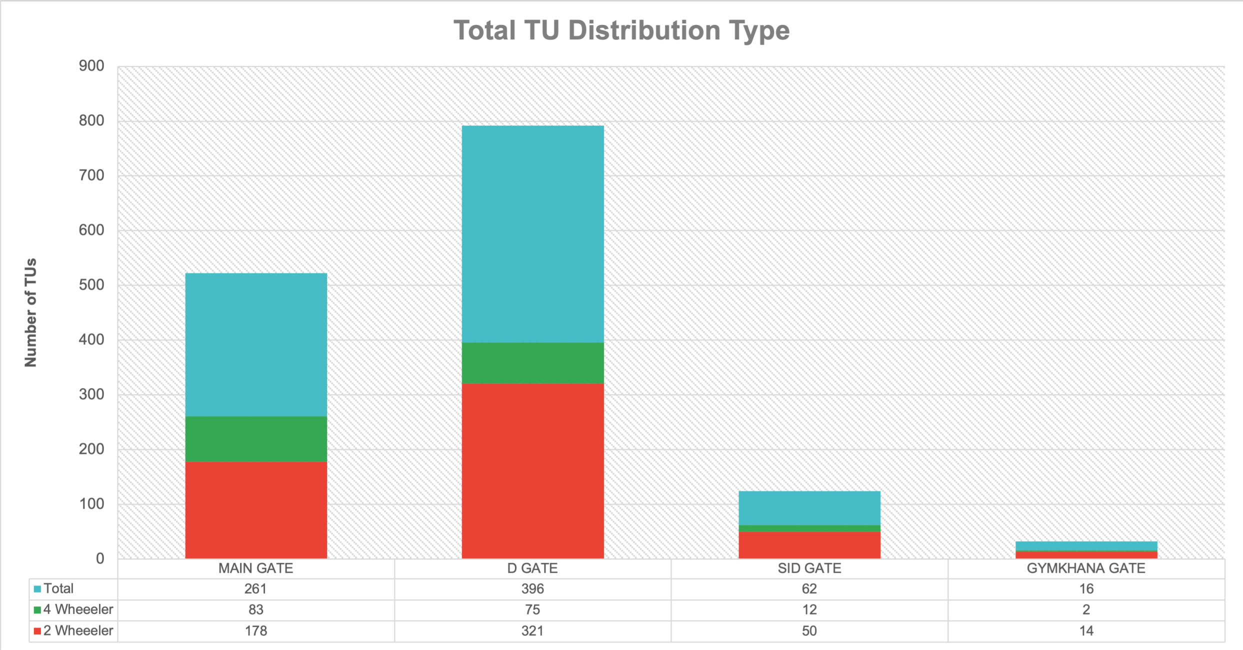


Figure 11

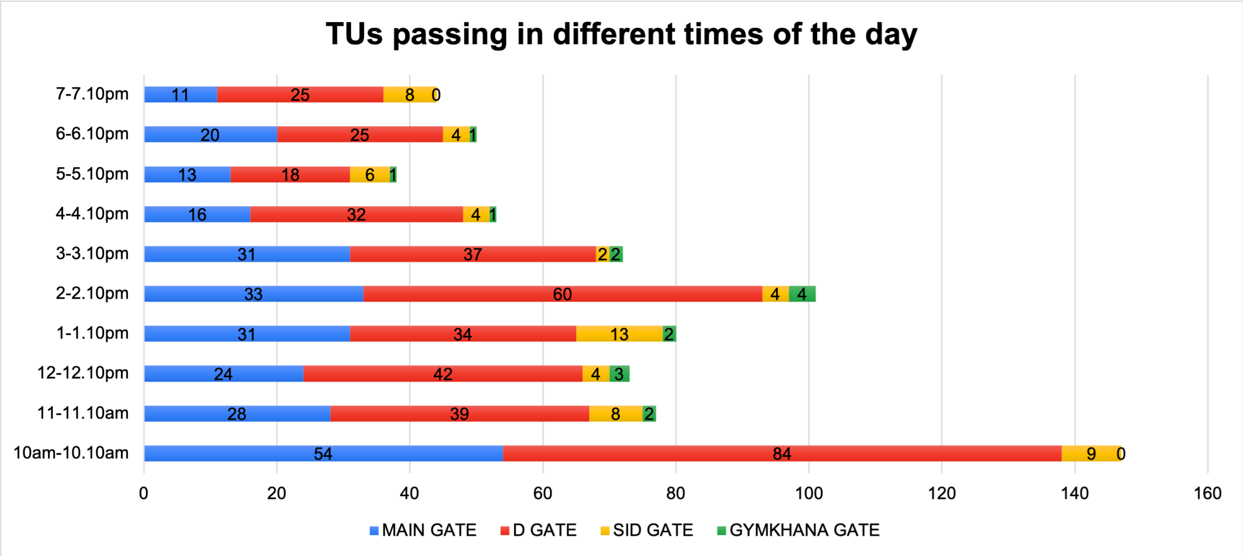


Figure 12

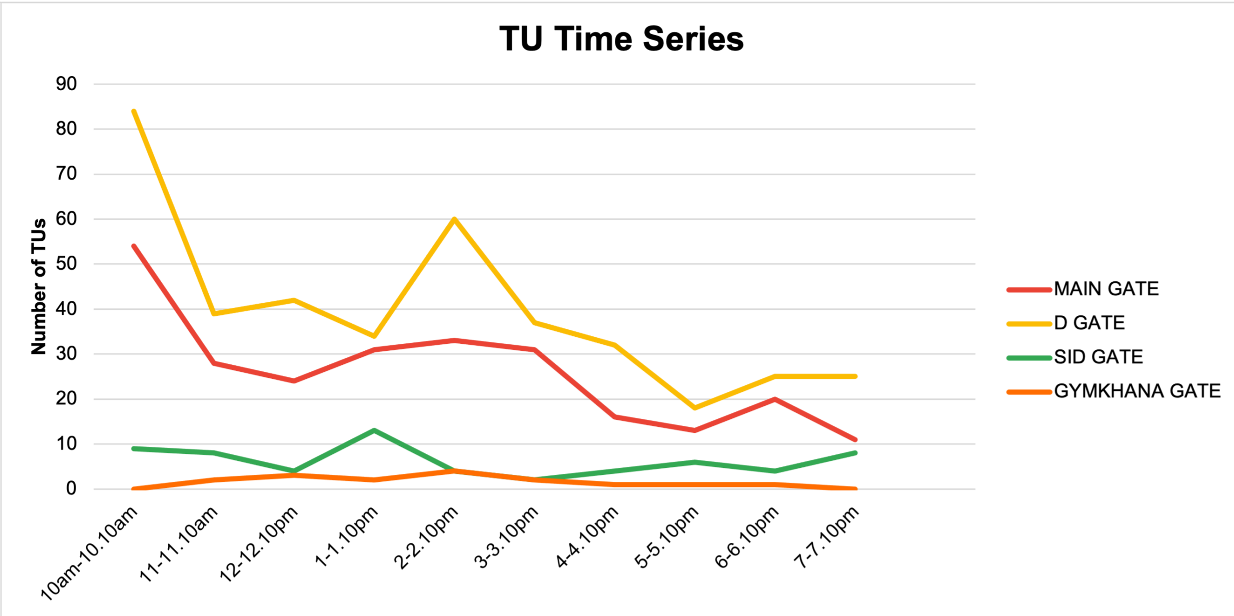


Figure 13

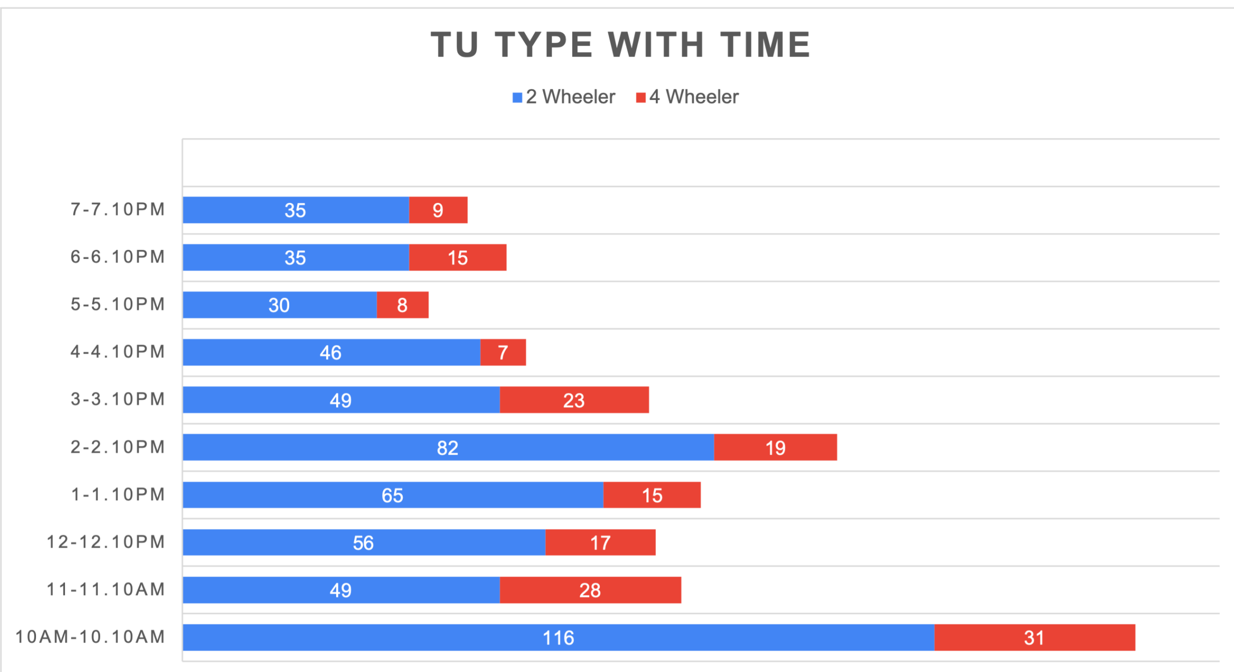


Figure 14

In addition to gates, data from one of the major road crossings at Nessera Restaurant was taken through CCTV camera. The data indicates the proportion of average 2 wheelers transiting at any point of the day to be much larger than average number of 4 wheelers transiting. The cause for this can be contributed to number of transits happening in the campus.

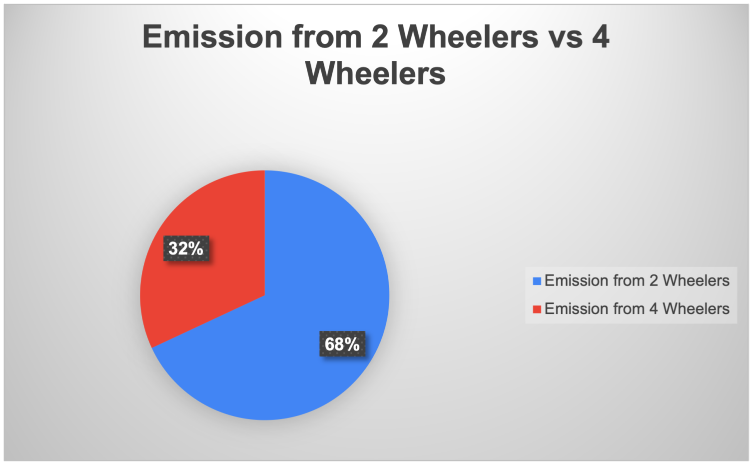


Figure 15

2.4 Transit Time and Average Velocity Quantification

The final set of data collected were used for calculation of average transit time of any TU in the campus and their average velocity. This was done with the help of UBER data. The data is summarised in image 16.

Figure 16 shows the graph generated from UBER data. It clearly indicates the average travel time of a TU inside IISc campus to be around 5 mins.

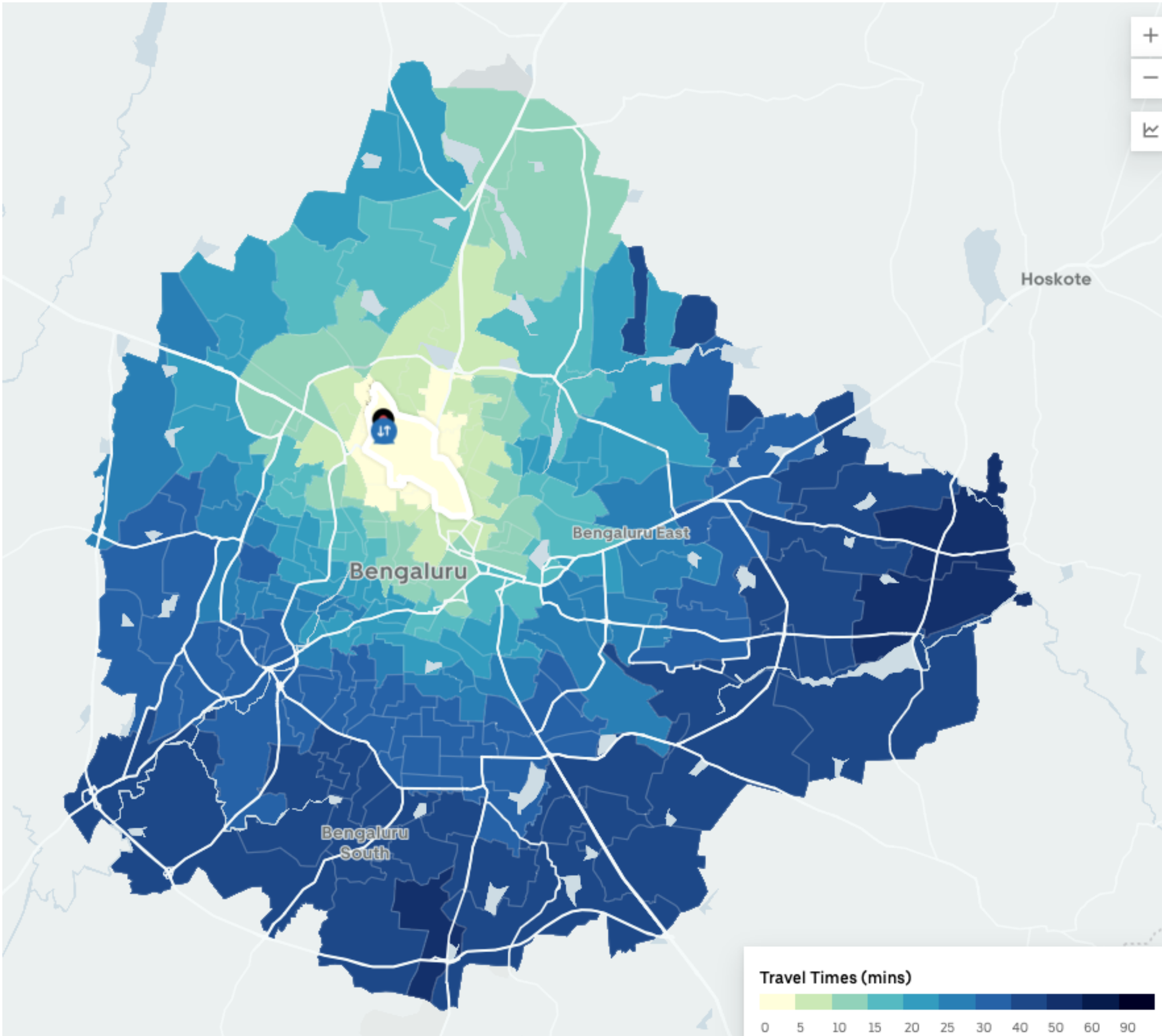


Figure 16: UBER travel times

For calculation of average velocity two methods were used. First, a survey was performed (Appendix A) to get the average speed of TUs in the campus using Google Forms. This indicated the average speed to be 12 kmph.

Second, A very simplified car simulation was used to drive a car using google maps. Velocity was calculated at every 3s interval. The car was made to travel from ECE Department to D Gate. The results are summarised in the following table. Since emissions are related to velocity (Heeb et al., 2002), a simplified parameter fit was done to calculate emissions.

Velocity	Time Interval	Emission
11	3	0.0013077
10	3	0.00108999
9	3	0.0008921
7	3	0.000555814
8	3	0.000714038
7	3	0.000555814
6	3	0.00041745

Velocity	Time Interval	Emission
5	3	0.00029898
4	3	0.000200475
3	3	0.0001221
3	3	0.0001221
4	3	0.000200475
9	3	0.0008921
12	3	0.001545225
23	3	0.00546523
29	3	0.008613341
32	3	0.010454709
37	3	0.013919668
10	3	0.00108999
9	3	0.0008921
7	3	0.000555814
8	3	0.000714038
10	3	0.00108999
12	3	0.001545225
13	3	0.001802562
12	3	0.001545225
11	3	0.0013077
13	3	0.001802562
16	3	0.002693419
21	3	0.004574271
19	3	0.003762521
8	3	0.000714038
7	3	0.000555814
10	3	0.00108999
13	3	0.001802562
27	3	0.007484767
43	3	0.01873103
TOTAL EMISSIONS:	111	0.101120926

Using the velocity to emission relationship, average emission was calculated.

$$Emissions = a/v + b + cv + dv^2$$

Figure 17 explains the various regions of the Velocity – Emission graph. (Shahid et al., 2014)

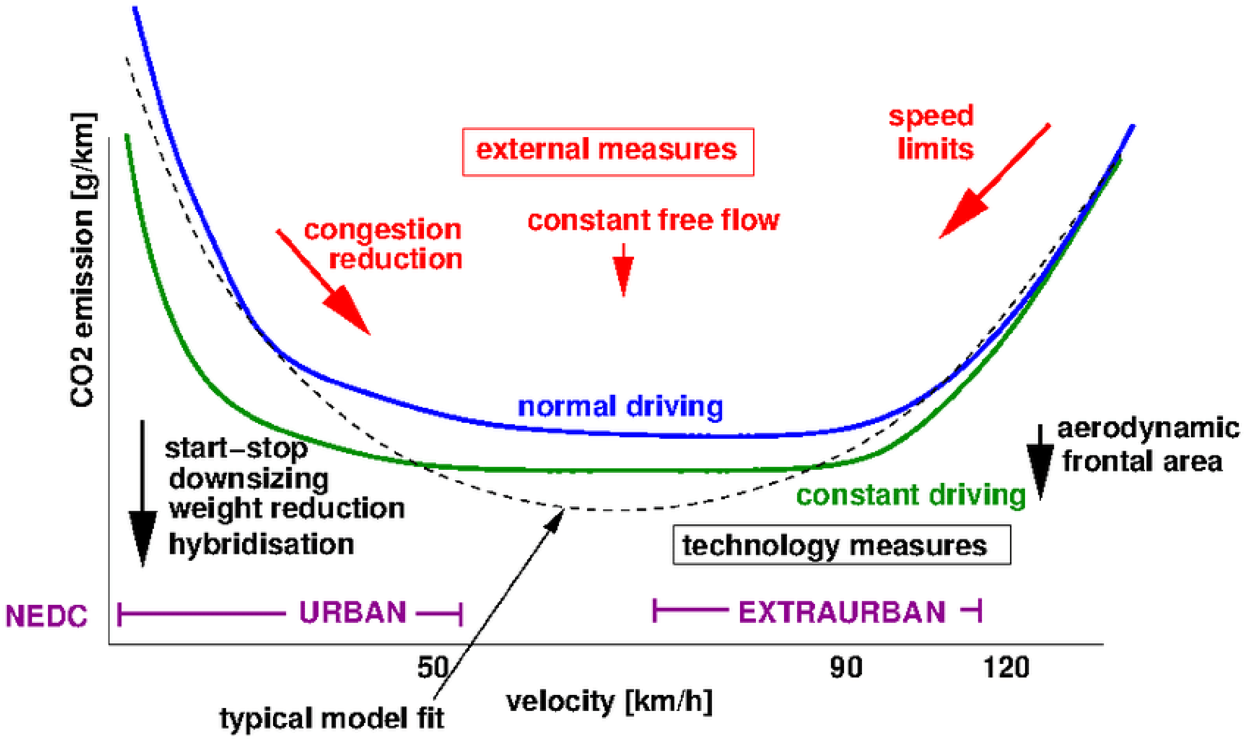


Figure 17: Velocity Emission Graph

3 Greenhouse Gas Emission Calculations

For the purpose of calculation of the total greenhouse gas emissions the following assumption were made which are based on what was discussed in section 2. The average velocity of TUs in campus was taken to be 12 kmph. Average travel time was taken as 5 mins. Figure 18 shows data which sums up the emission from different Transit Units. (Potter, 2003)

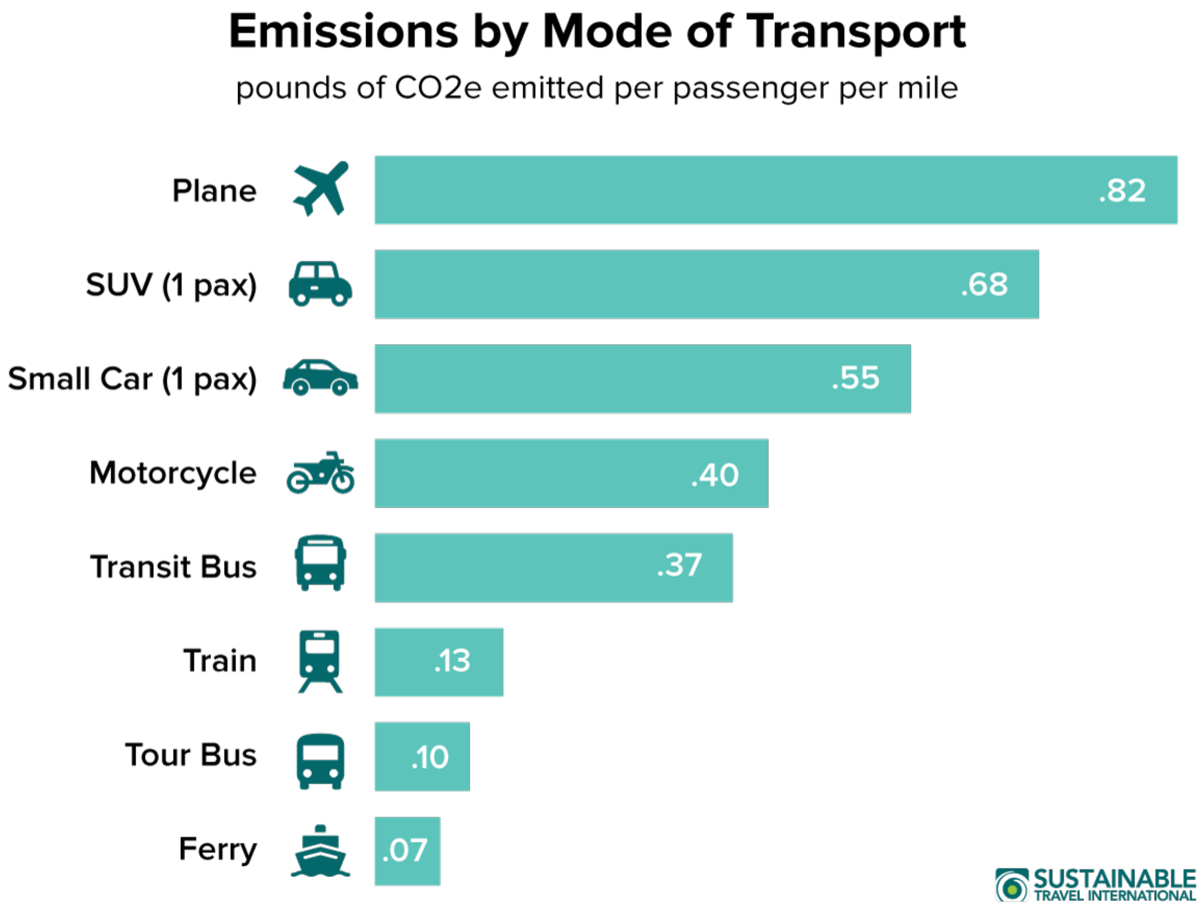


Figure 18

The calculation is tabulated below:

Average travel time	= 5 mins
Average velocity	= 12 kmph
Average Distance	= 12 * 5 / 60 = 1 km
1 pound	= 0.45 Kg
1 mile	= 1.61 km
1 pound / mile	= 0.45 kg / 1.61 km = 0.28 kg / km
Emissions	= 4-wheeler count * 0.5 * (0.68 + 0.55) + 2-wheeler count * 0.40 pounds per mile
	= [4-wheeler count * 0.5 * (0.68 + 0.55) + 2-wheeler count * 0.40] * 0.28 kg / km
	[1 km avg. travel] = [4-wheeler count * 0.5 * (0.68 + 0.55) + 2-wheeler count * 0.40] * 0.28 kg

Thus, the formulae for GHG emission in IISc Campus is:

Emissions = 4-wheeler count * 0.172 + 2-wheeler count * 0.112 kg CO2 eq.

It should be noted that the theoretical calculation of 0.172 kg/ km for 4 wheelers in IISc Campus matches with the simulation result of 0.183 kg /km (Refer section 2.4)

Using data from baseline studies in section 2:

Total avg. 2 wheelers	= 788 / day	
Total avg. 4 wheelers	= 241 / day	
	[4-wheeler count * 0.172 + 2-wheeler count * 0.112] kg	
	= 135.53 + 27.01 kg / day	
Emissions	= 162.54 kg / day	
	= 5038.4 kg / month	
	= 60461.2 kg /year	

Finally we have,

Total CO2 eq. emissions per year from IISc Campus from transportation sector is 60,461.3 kg or approx 60.5 tons.

4 Mitigation Measures

Based on calculation in section 3, 220 tons of carbons di-oxide equivalent emissions per year only from the transportation sector. As per a 2015 study (Ramachandra and Bharath, 2014) the total number of trees in the campus is 22,616.

Based on recent research (Marsupial, 2014), one tree can absorb 5.9kg of carbons di-oxide equivalent per year. That means to absorb 60.5 tons of carbons di-oxide, one would need 10247 trees. The current scenario shows that the number of trees required to absorb carbons di-oxide only from the transportation sector is 45.3% of the number of trees in the campus!

The situation becomes much more complex owing to recent deforestation measures and new medical buildings coming up.

With coming of the medical campus, large scale deforestation, this 45.3% figure is set to increase by huge margins. The road that would connect to newly coming Medical Campus is set to have highest emission levels due to Huge patient influx – out-flux. The newly formed roads that connect the medical building to the main road (20 ft road) is being built by clearing out 30 ft breadth of trees for construction purposes.

Certain plants form a surface capable of absorbing particulate matter, black carbon and dust thereby acting as a sink for pollution. Planting these trees around the roads of the proposed medical building will reduce GHG emission footprint that is set to increase. The same will also add top the aesthetic beauty. Of the 26 plants used in a recent CSIR Study to prevent emission from roadside traffic, silk oak or silver oak (*Grevillea robusta*), walnut plant (*Juglans regia*), Holly oak (*Quercus floribunda*), fig (*Ficus carica*) and red cedar (*Toona ciliata*) were found to be best performers. While choosing a tree best for the campus, whether the species are indigenous or not should be considered. Fig turns out to be the best solution for IISc Campus.

To understand the extend of increase we take the case of AIIMS Delhi which is expected to have similar stature as that of IISc, both being institute of national importance. According to internal traffic surveys of the institute, the average number of vehicles entering the AIIMS campus is around 14,000, including 5,400 cars on working days and 3,200 cars on Sundays and public holidays. (AIIMS, 2019) Being very conservative, and assuming 1/5th traffic, that's 4-wheeler count * 0.172 /5 = 185 Kg /day additional. **That is a 2.2 fold increase!**.

Thus with the above estimate, and being very conservative, all trees of the IISc Campus will be absorbing Carbon Dioxide, *just from the transportation sector* once the medical facility starts functioning. Clearly, the situation raises alarm! It should also be noted, the calculations were done assuming no further deforestation from 2015, which isnt true. Thus, there will already be an excess carbon dixoide production from the transportations secto0r.

This discussion provides strong motivation to discuss about mitigation steps. Few such recommendations of this study are mentioned in the subsequent subsections.

4.1 Electric Kick Scooters – Ideal for Large Campuses

Many large campuses in India has started using Electric Kick Scooters claiming shared e-kick-scooters reduce the carbon footprint. Also the learning curve for kick scooter is smooth and Electric scooters with a top speed of 25 km/h do not need a license. The electric kick scooter takes about 2.5 to 3 hours to fully charge and uses online technology for locking/unlocking and mapping the vehicle. All of this makes Electric Kick Scooters ideal for college campuses. Figure 19 compares various transit options according to their emission levels.

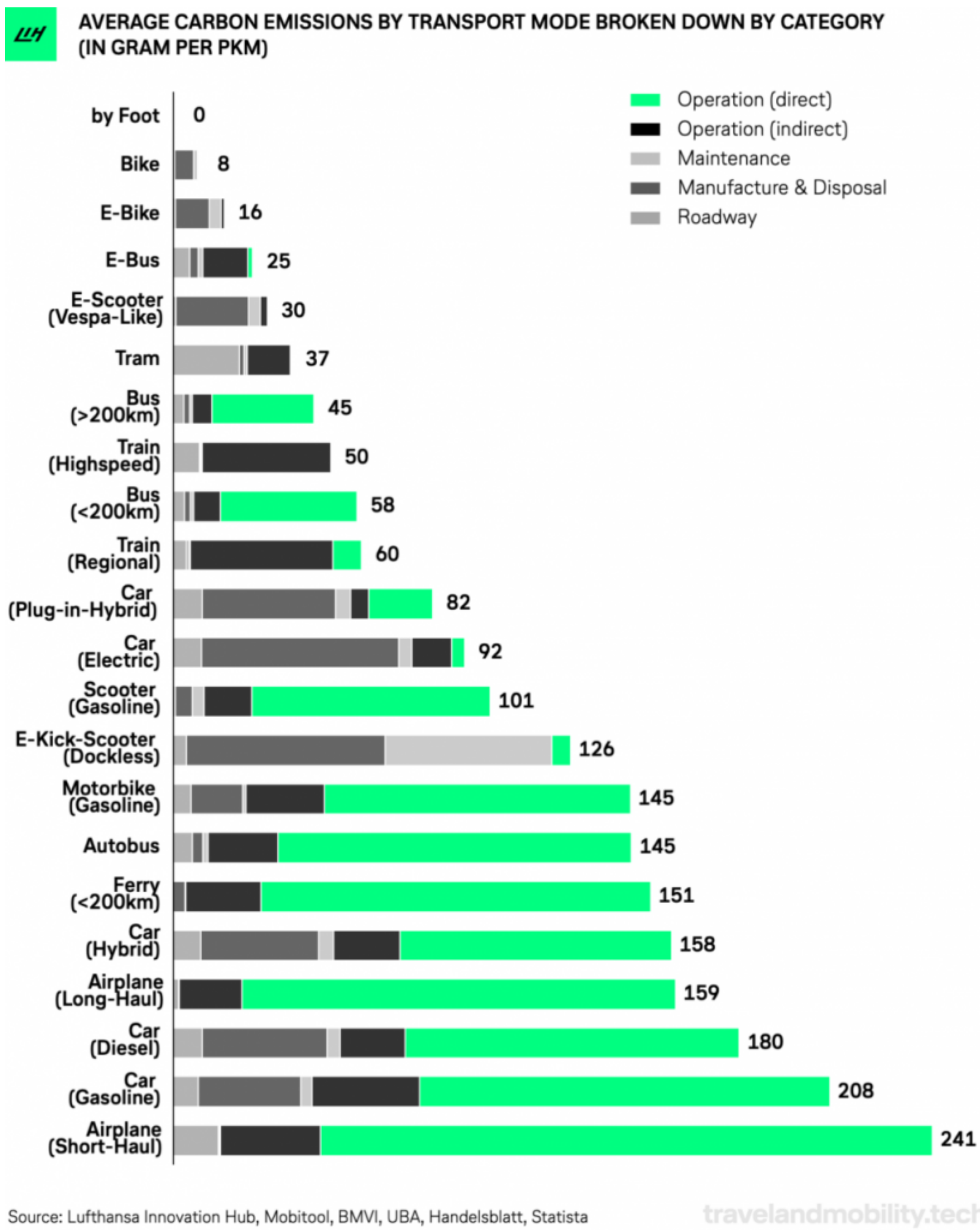


Figure 19

The vehicles are meant for rental-based electric transportation and Gujarat University has set an example by becoming the first campus in South Asia to implement such technology.

4.2 Dealing with Deliveries

As discussed in earlier sections, Deliveries from various E Commerce platforms are the major source of GHG Emissions in the campus.

Some recommendations in this sector are as follows:

- Common Pickup / Drop point for all E Commerce orders.
- (Cycle) Food delivery service from Sarvam Complex
- Extra Surcharge for Swiggy / Zomato delivery if order passes through inside campus gate directly debited from IISc Account. This will demotivate food orders and also prevent mess food wastage. (This recommendation is based on the fact the major reason for food deliveries are cheaper cost of foods)
- No bikes allowed inside gate for food delivery during high congestion times. Possibility of using campus based transports (Transvahan, Kick Scoters, Shuttle Bus) only inside campus
- Subsidized canteens near hostel campuses and departments. Food courts near/in departments' terrace.

One popular way around to prevent food deliveries are intelligent food vending machines. Such machines are installed in various departments and student can pay and buy healthy food automatically. The operation cost, also, is very less. To expand the fresh, healthy meal choices on campus, MIT Dining recently rolled out a pilot of 6am Health's Fresh Fridge vending machines in the 5th floor lounge of the Stratton Student Center (Building W20) and in the vending-machine area at the first-floor intersection of Buildings 16 and 26.

"Fresh Fridge's delicious meals are packed in reusable jars, which is great for students on the go who want something they can throw in their backpacks but is more healthful than a granola bar or instant ramen," said Mark Hayes, MIT Dining director. Options include quinoa bowls, salads, overnight oats, sandwiches, and fresh juices.

A simplified Cost Benefit Analysis of installing food vending machines is shown below in figure 20. (Daalchini, 2021)

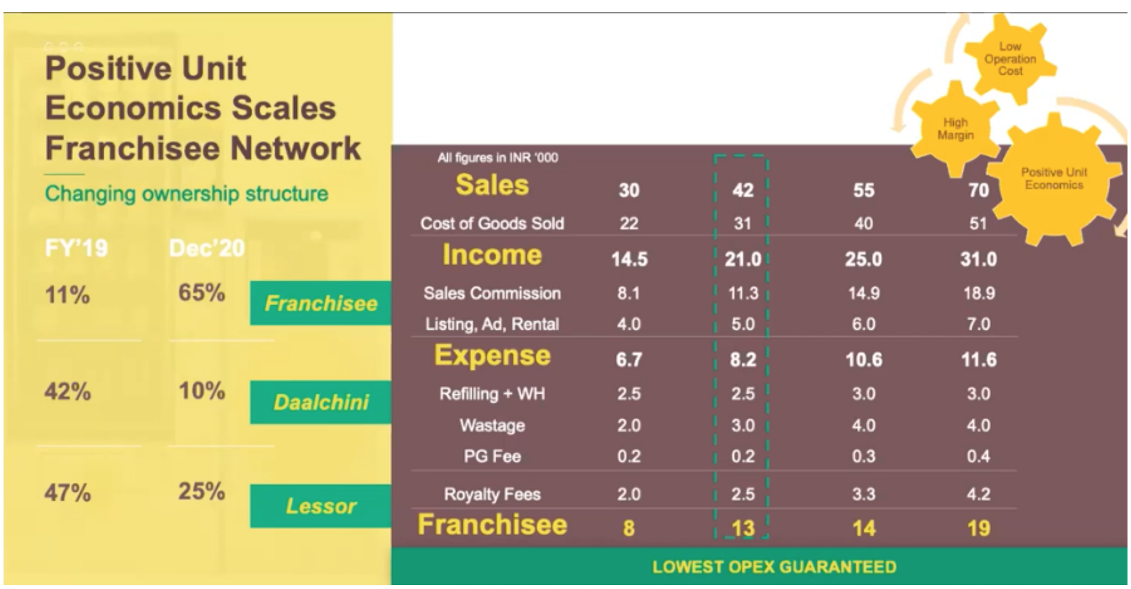


Figure 20

- Operational Cost: 8.2k
- Income: 21k
- Net Income: 13k
- Setup cost: 50k per machine.

Suppose 50k is invested at 6% compound interest rate instead. Time to recover the whole 50k amount would be 5.2 years. This is explained using figure 21.

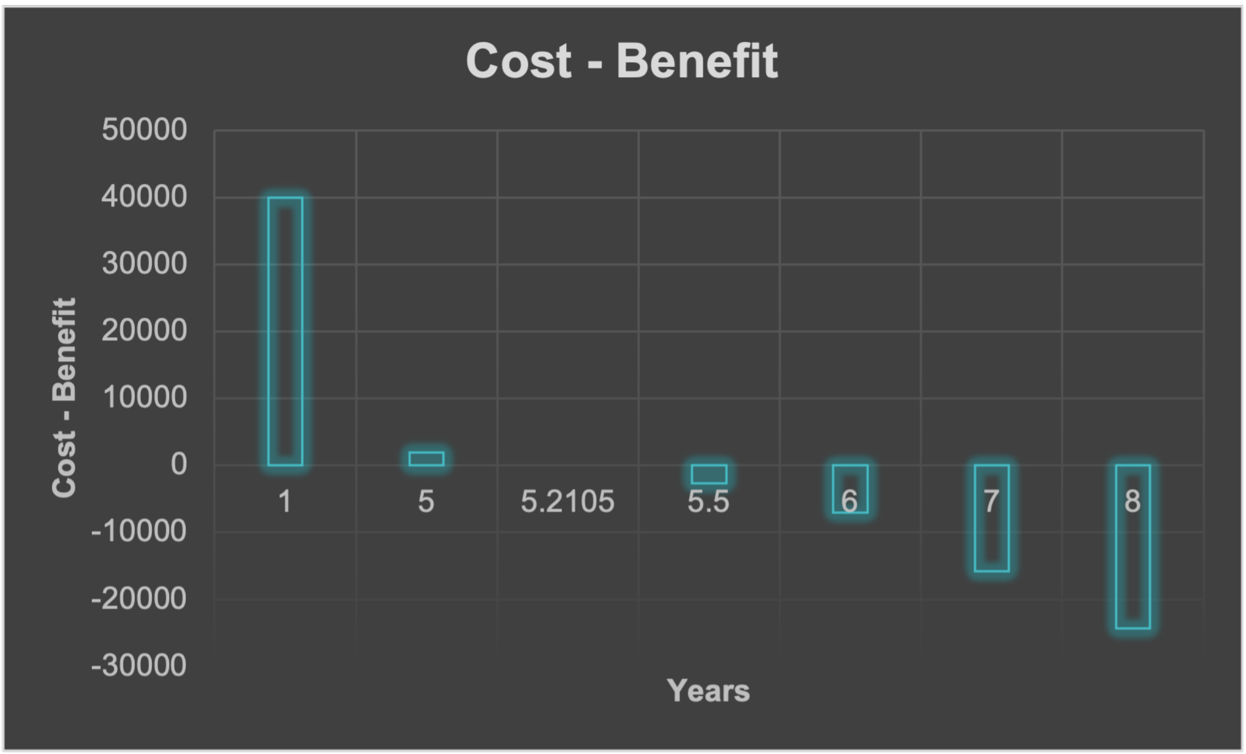


Figure 21: CBA

4.3 Transit Pass Program

Another source of traffic in campus is due to students and faculty who are non-campus residents and use personal vehicles to come to campus. This factor can be majorly dealt with Transit Pass Program (TPP). In TPP, the institute sets a tie up with the transportation counterpart of the government and gives Transit Passes to Campus Commuters, in place of transport allowance. A Transit Pass, allows unlimited use of Public Transport (Bus, Metro, etc). This can be even extended to reimbursement of shared ride through OLA / UBER. This motivates the commuter not to use personal vehicles and thus entry of personal vehicles in the campus is minimized.

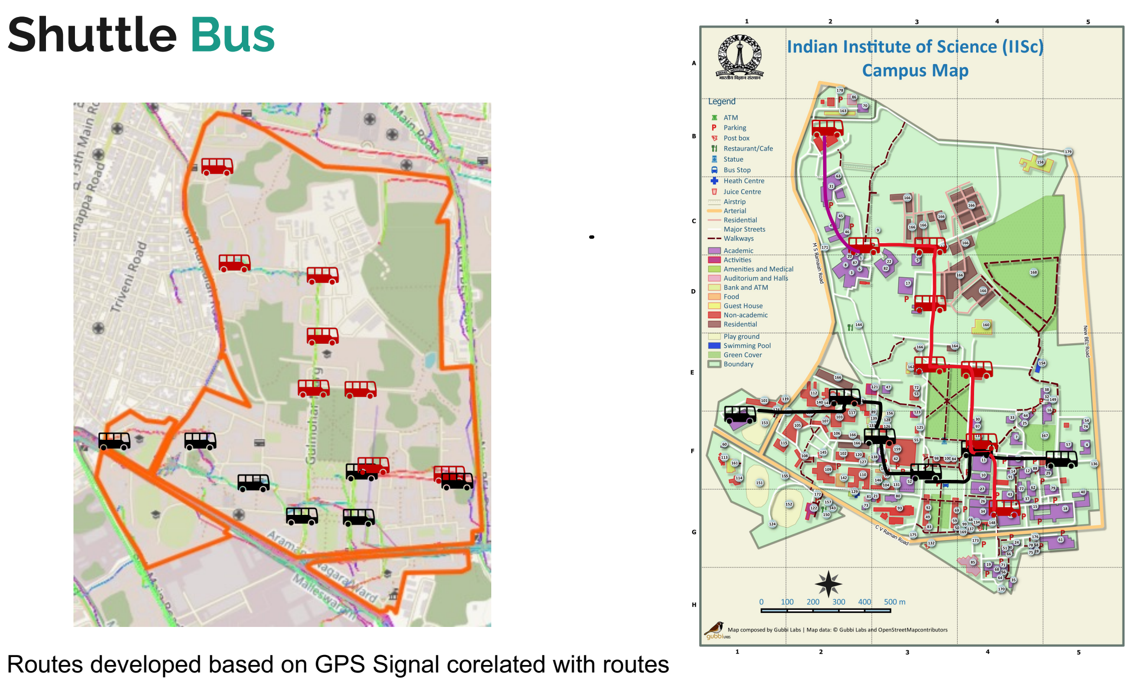
For example, The University of Colorado at Boulder began its employee bus pass program in January 1998 after a lengthy period of study and effort spent changing a Colorado state law restricting employee benefits. The employee Eco-pass program, as it is called, enables faculty and staff to have free unlimited access to all Regional Transportation District (RTD) buses in the Boulder / Denver metro region. The Eco- pass also includes a free guaranteed ride home by taxi in case of an emergency.

4.4 Shuttle Bus Service

The most important transit behavior is Discrete time interval movement of students and Few Popular routes across departments. 2 lines of shuttle bus across campus at each time period would solve the transit emission issue by great extent. The table below summarizes the most popular origin and destinations in IISc Campus. Other than transits happening inside campus, several buses connects IISc to other scientific institutions . (Appendix C)

Road	Departments / Hostels / Sub Divisions		
Hostel Block	R Block	N Block	Krithika
Silver Oak Marg	Organic; IPC	Chemical Engg	Molecular Biophysics
Gulmohar - Mehogany Marg	JRD Tata Library	Mehogany Marg Parking	OPB
Tata Marg / Bank Road	CPDM	ICWR	ICER
Gulmohar Marg – Unnamed Rd	CNS	ECE	IISc Residential Quarters

Based on the above trip distribution, the following 2 bus routes are recommended. (Figure 22)



Line	Dept. Circles
Red Line	(Proposed) Medical ->Biological Sc. ->ICTS ->Quarters ->IPC ->CPDM
Black Line	KV IISc ->B Mess ->NMR Res ->JRD Library ->Organic ->IPC ->ChE ->CDS ->SERC

Instead of electric shuttle bus based on fossil fuel energy, solar powered busses can also be used, keeping in mind Bangalore weather.

Before discussing solar busses, we give some details on the weather of Bangalore city

It is important to understand two parameters for solar power first. First being, Beyond a particular limit, the efficiency of a solar panel is inversely proportional to its temperature. Solar panels operate at a higher temperature than their surroundings because the panel glass traps the heat of the sun, akin to what happens in a greenhouse. For instance, if the surrounding temperature is 25°C, the solar panel's temperature is close to 45°C. The power generation efficiency reduces once the panel temperature rises beyond an optimum of 45°C. A 1°C rise in panel temperature leads to a 0.45% decrease in its efficiency. The phenomenon is known as the temperature derating factor.

Secondly, Windy Days improve the efficiency of solar power generation. There is a constant exchange of heat taking place between the photovoltaic cell module and its surroundings. Under normal conditions, this difference is maintained at about 25°C. However, when there is a lot of wind, the difference dramatically decreases. Hence, heavy winds can counteract the temperature degrading factor.

Figure 23 and 24 sums up the weather condition of Bangalore, based on the above two parameters – temperature and wind thereby showing Bangalore is ideal for solar energy.

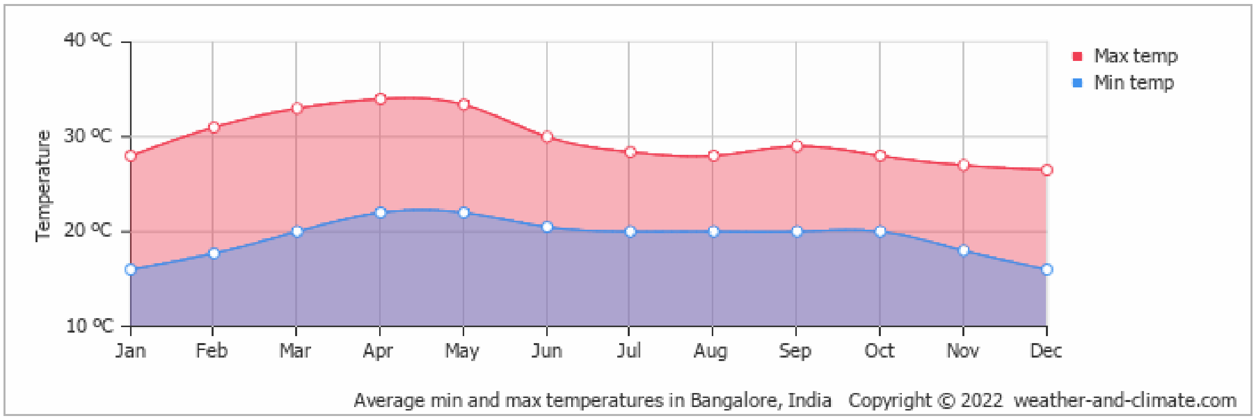


Figure 22: Temperature Distribution in Bangalore

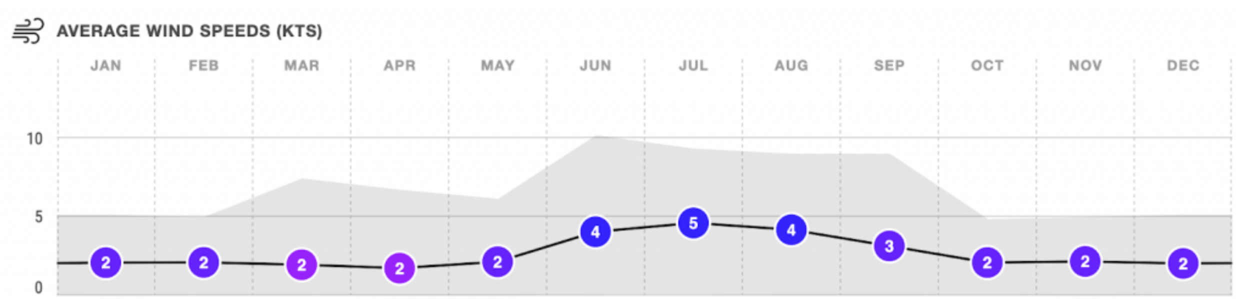


Figure 23: Wind Distribution in Bangalore

This makes solar busses ideal for IISc Campus. One example of a solar bus is the SunBus. The SunBus carries 30 people (incl. driver) with a range of approx 120km from a single battery charge. Available with full air-conditioning and strong suspension it is designed to give the passenger a smooth, comfortable ride that will greatly enhance the commuting experience. The SunBus generates no harmful emissions or noise pollution and runs on electricity alone. The obvious benefits to the operator are the vastly reduced operating costs with no petrol, no oil and low maintenance costs.

Next we provide a very simple Cost Benefit Analysis of introducing solar busses in IISc fleet.

A solar Jeepney (SunBus) costs US$38,600 = Rs 29,33,426. A fleet of 4 would cost 1 Crore.

The social cost of carbon (SCC) is used to estimate in dollars all economic damage that would result from emitting one ton of carbon dioxide into the atmosphere. It indicates how much it is worth to us today to avoid the damage that is projected for the future. According to the SCC (social cost of carbon) measure, For carbon dioxide, the social cost of releasing a metric ton is $86 for India (Only CO2 cost considered!). (Ricke et al., 2018)

$$
\begin{aligned}
347 \text{ kg / day} &= 0.347 \text{ tonne / day} \\
&= 86 * 0.347 \\
&= 29.842 \text{ \$ / day} \\
&= 2118.78 \text{ Rs / day} \\
&= \text{Rs } 7.73 \text{ Lakh / year.}
\end{aligned}
$$

The above cost, of 7.73 Lakh, is the social cost of environmental degradation happening due to transportation in IISc Campus. Considering all 4 busses were not purchased, The interest cost of Rs. 1 core at the end of 1 year at 6 % p.a compound interest rate is 6 lakh. Assume depreciation cost to be another 1%. That's a total of 7 lakh / year

Thus, a very conservative **Benefit / Cost Ratio is 1.01**(By taking NPV for just 1 year)

Just in one year, the benefits equals cost. We did not consider aesthetic costs, convenience costs and other opportunity costs of the busses while calculating benefits.

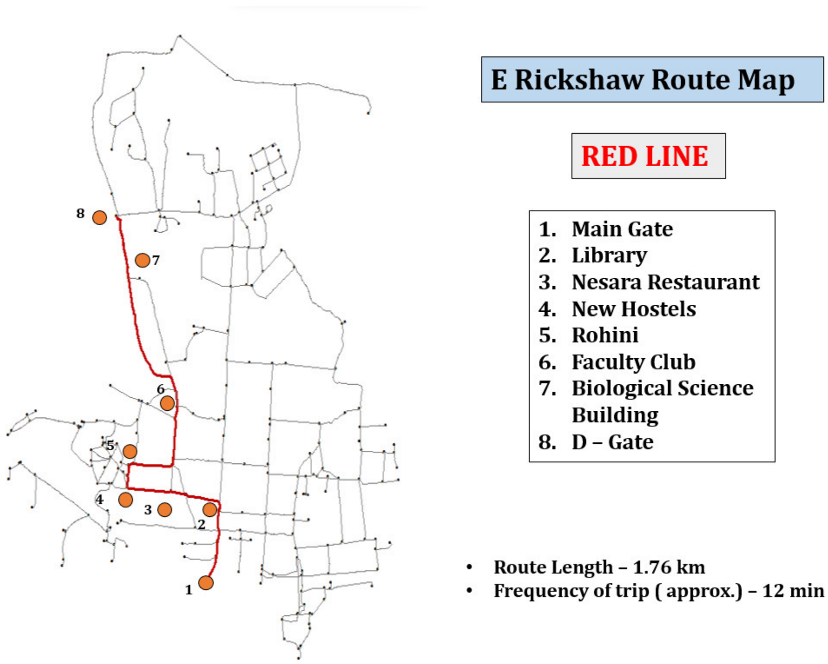
4.5 Encourage Bicycling Among Students

Bicycles are the most Eco friendly transit options for university students. Some recommendations in this sector are stated below:

- **Create Bicycle Education Programs**: One such example is Presentation that the New Jersey Ambassadors in Motion gave at Rutgers International Student Orientation. This event covered topics that all novice cyclists should be familiar with, such as local traffic laws, safety tips, basic bicycle equipment, and bike locking techniques.
- **Make it Easy to Obtain a Cycle:** One such example is The State University of New Jersey which recently launched a bicycle rental program in 2011, with a fleet of 150 bicycles. The program costs students only $25 a semester, which is far more economical than purchasing a bicycle and allows reuse.
- **Construct New Bicycle Infrastructure**: The University of California, Santa Barbara is an excellent example of a school that has made great strides to provide infrastructure for cyclists. To date, their campus contains 10 miles of on-road bicycle routes and 7 miles of separated shared use paths, which feature 7 bicycle roundabouts, and 3 underpasses, to avoid roadway conflicts.
- **Build Cycle Stations**: One prominent example is UC Davis. The University of California, Davis has a bicycle club that provides numerous benefits, including access to showers and changing rooms. This amenity, in addition to implementing several innovative bicycle friendly policies and projects have contributed to UC Davis's designation as one of the most bicycle friendly universities in the country, with approximately 39% of all commuters traveling by bicycle
- **Adopt Policies to Minimize the Use of Automobiles:** Another example at UC Davis, which has demonstrated a particularly innovative approach to minimizing the use of automobiles on campus: The University closed off the core area of campus to almost all vehicular traffic, resulting in a network of wide pedestrian walkways and bike paths. Having a campus core without cars has led to approximately 73% of on-campus residents choosing cycling as their preferred mode of travel

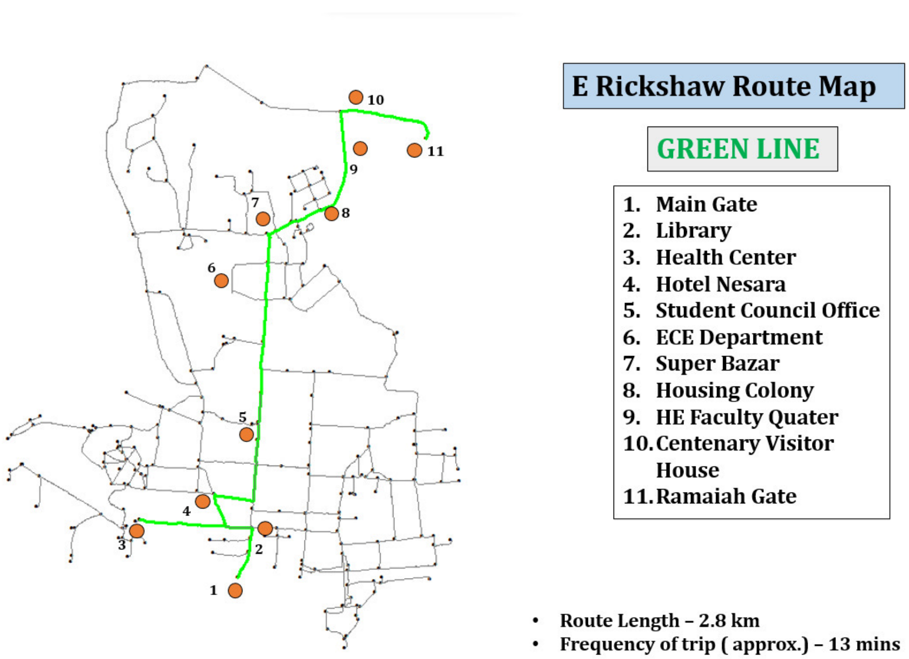
4.6 Improving the Transvahan Scenario

A recent Transvahan facility have started in the IISc Campus. The e-rickshaws plying on campus are designed, manufactured and operated by Transvahan Technologies India Pvt Ltd. The vehicles are battery operated and can be recharged by plugging in to a regular electric point. They seat upto four people and run at slow speeds (roughly around 10-15 km/hr), meant for sustainable, emission-free transport within small areas such as the campus of an institution or tech park, or on the grounds of a hospital. Each of the e-rickshaws run on separate identified routes, roughly every 20mins between 9 am and 6 pm (with a 45-minute lunch break from 1.30 pm to 2.15 pm). The service is free of cost. The transvahan timings is attached in Appendix D. The routes are shown in image 24 - 28



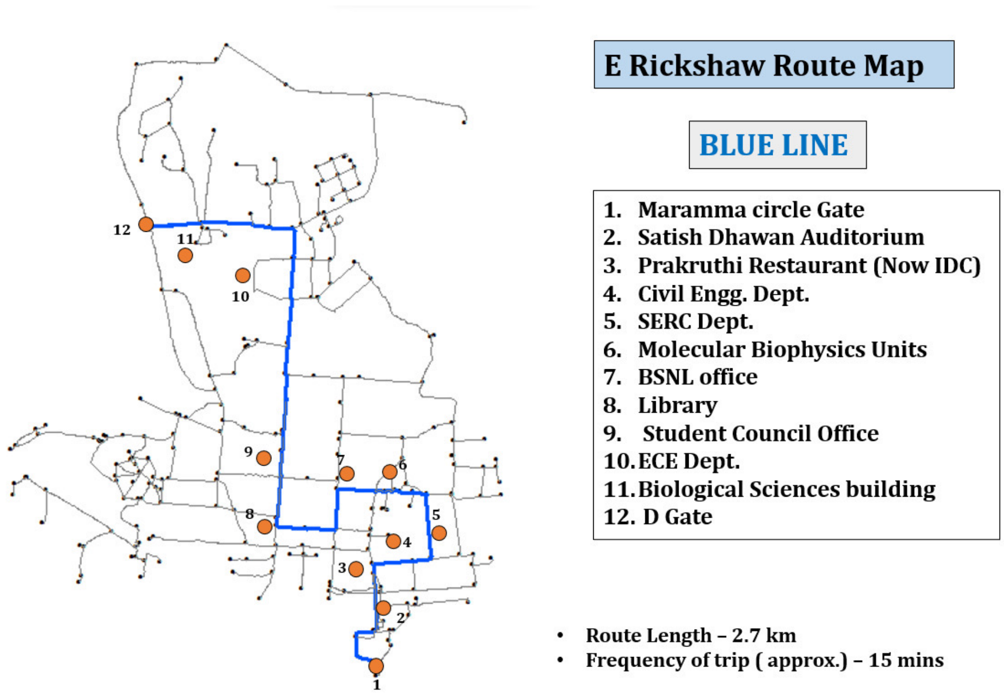
[!htb]

Figure 24: Transvahan Route : Line Red



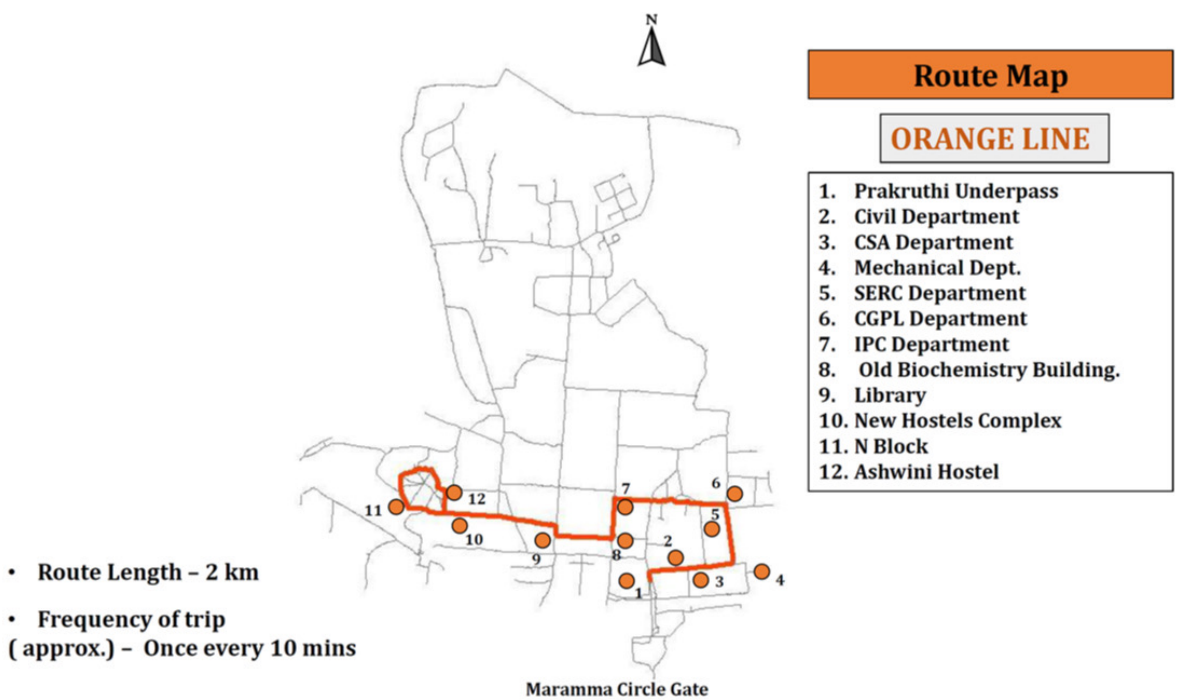
[!htb]

Figure 25: Transvahan Route : Line Green



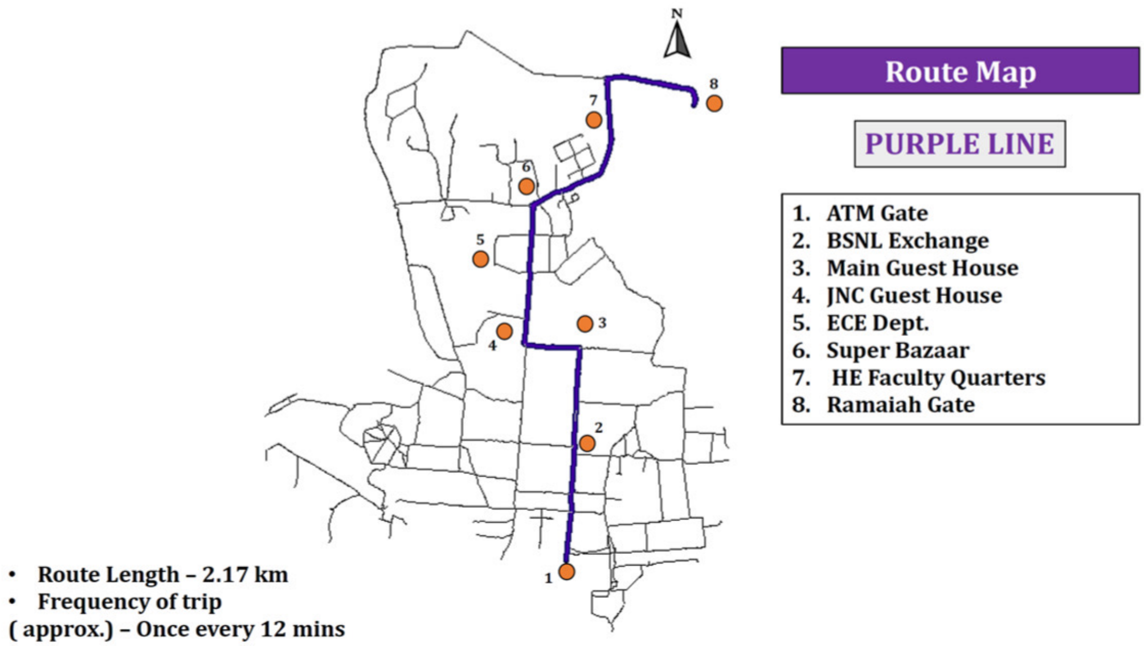
[!htb]

Figure 26: Transvahan Route : Line Blue



[!htb]

Figure 27: Transvahan Route : Line Orange



[!htb]

Figure 28: Transvahan Route : Line Purple

The routes of the Transvahan service is shown in figure

Based on a campus wide survey conducted, 86.4% of the campus commuters, did not use the E Rickshaw facility. The line wise result in summarised in image 29.

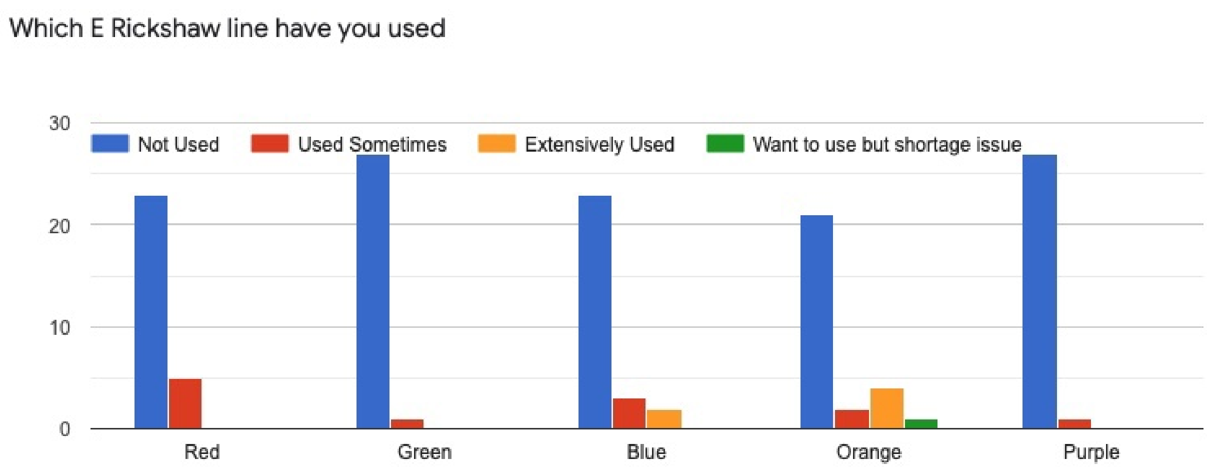


Figure 29: Transvahan Usage Survey

This pitfall can be attributed to two major reasons:

- There were no transvahan facility available when students wanted to use them.
- The transvahans were not available at the right place at the right time.

Both the issue can be addressed by re-routing the transvahans based on **time dependent traffic density analysis**. Different routes can be set up at different times of the day. It is observed there are enough transvahan service already available in the campus. The only problem is routing. A dynamic time based routing could pave way to have more commuters using transvahan service.

5 Conclusion

The study reveals quite alarming condition of greenhouse gas emission from the transportation sector in the campus. The study finds the situation to be grim with 60 tons of CO_2 eq emissions happening in the campus just from the transportation sector. The same was predicted matematically to grow by 2 folds with the starting of the medical facility. Mitigation measures are the need of the hour. The cost benefit analysis of the mitigation measures suggests any of them could be taken up and would improve the situation. A more detailed study is suggested for better understanding of the situation.

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