Internship Report
The Energy and Resources Institute

Duration of Internship: 1-6-2018 to 15-7-2018

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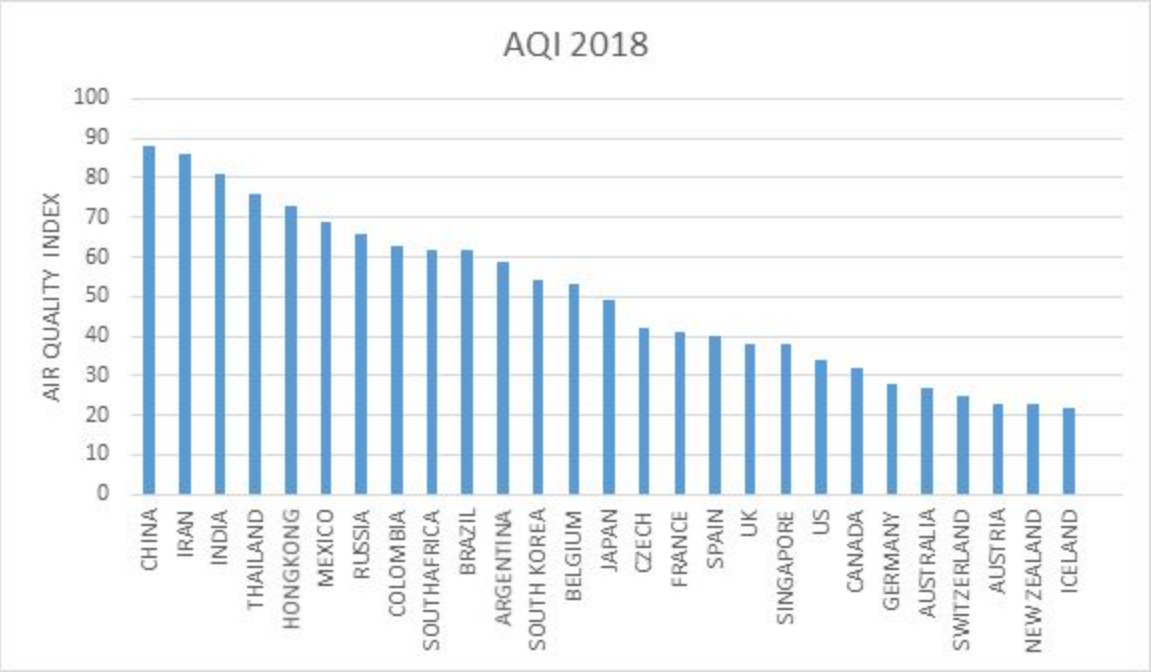
Week 1:

1.Basics of vehicular emissions:

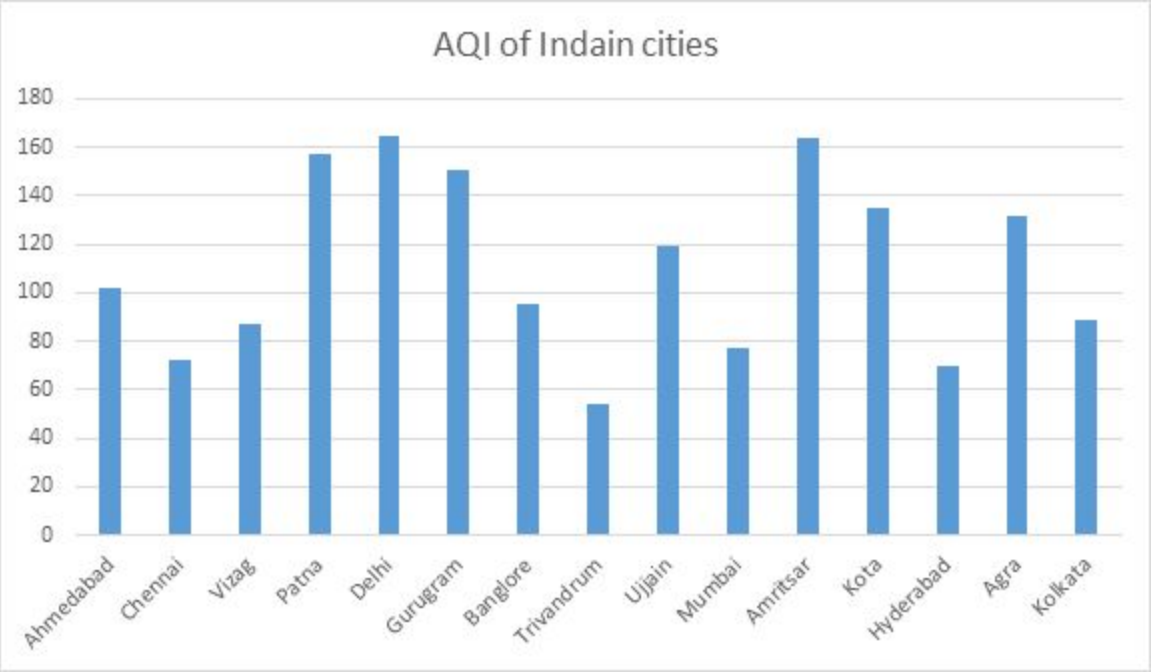
Air Pollutants:
Any substance in air that could, in high enough concentration, harm man, other animals, vegetation, or material is termed as an air pollutant. Air pollutants can be categorized into Primary Pollutants, Secondary pollutants.
Primary pollutants: are directly emitted from the source.
Secondary pollutants: are formed from the chemical reactions between the pollutants in the atmosphere.

Various sources of air pollution:
Biomass/agriculture burning, Power plants, DG sets, Construction, Industrial operations, Volatile Organic compound Natural disasters like Volcanoes, forest fire etc. One can refer to the source apportionment studies of the area of interest to see the different contributions of various sources to a particular pollutant.

Air Quality Index[1]:
It is used to communicate the air quality to the people in simple terms. The pollutants considered are $PM_{2.5}$, PM_{10}, NO_2, O_3, CO, SO_2, NH_3 and Pb (Criteria Pollutants[2]). The Sub-indices for individual pollutants at a monitoring location are calculated using its 24-hourly average concentration value (8-hourly in case of CO and O_3) and health breakpoint concentration range[3]. The worst sub-index is the AQI for that location.



Courtesy: WAQI[5]



Courtesy: NAQI[6]

This is AQI for 6th June 2018 of different indian cities. The above graph shows which cities need to pay more attention to the air quality and incentives should be taken. Let's say in particular city, major source of emission is from transport sector which we can see from the report of source apportionment studies, then incentives like

substitution of motorized transport with non-motorized transport, Policy and law framing etc. can help to reduce the AQI upto some extent. And at overall picture of all cities of India can help in formulating the norms.

Effect of climate on pollution:

It is observed that due to climate conditions, pollutants level in the air goes high in the winter and goes down during summer days which can be seen from the monthly trends of the PM concentrations. Winter season in the month of Nov-Jan, while summer and monsoon in the rest of the months. This would give us an idea on the level of pollution one is exposed to and how comfortable are people riding a bicycle in different seasons.

Vehicular Emissions:
Vehicular traffic is one of the important contributors to the pollution. With the combustion of fossil fuels in their engines, they release CO, CO_2, NO_x, VOCs, Particulate matter and other pollutants[4]. According to a report published in NCBI, personal cars and two wheelers contribute to around 95% of the CO emissions and Heavy commercial vehicles contribute to 92% of PM emissions in Delhi.
If the number and usage of fossil fuel vehicles can be controlled with the use of public transport, non-motorized vehicles it can lead to a great improvement in the air quality. Quantified analysis of this intervention is presented in the attached excel sheet.

This table shows some of the effects of the criteria air pollutants and their concentration in Hyderabad

Pollutant	Sources	Health Effects	Environmental Effects	NAAQS Avg for 24 hrs (μg/m³)	Avg in Hyderabad on 4-6-2018 (μg/m³)
Ozone	Secondary Pollutant formed by the chemical reactions between NO_x and VOCs in the presence of sunlight	Coughing, Throat irritation, and airway inflammation. It can also reduce lung function, harm lung tissue, worsen bronchitis, emphysema, and asthma.	It can reduce photosynthesis, slow the plant's growth.	180	81.82
$PM_{2.5}$	Particulate matter can be emitted from sources such as construction sites, unpaved roads, fields, smokestacks or fires. They can also form in the atmosphere result of chemical reactions between other pollutants	Irregular heartbeat, aggravated asthma decreased lung function, irritation of the airways, coughing or difficulty in breathing.	makes lakes and streams acidic, changes the nutrient balance in coastal waters depletes the nutrients in soil and contributes to acid rain effects Fine particles (PM2.5) are the main cause of	60	27.52
PM_{10}				100	53.91

			reduced visibility (haze).		
CO	Cars, trucks and other vehicles or machinery that burn fossil fuels.	short-term exposure to increased CO concentration may result in reduced oxygen to the heart accompanied by chest pain.		4000	254.086
Lead	Sources of lead in the air are ore and metals processing, engines operating on leaded fuel, waste incinerators, etc.	Depending on the level of exposure, lead can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system.	Decreased growth and reproductive rates in plants and animals, and neurological effects in vertebrates.	1.0	--
SO_2	Burning of fossil fuels, extracting metal from ore, volcanoes, locomotives, ships and other vehicles that burn fuel with a high sulfur content.	Can harm the human respiratory system and make breathing difficult. SO2 also contributes to particulate matter pollution	SO2 and other sulfur oxides can react with other compounds in the atmosphere to form fine particles that reduce visibility (haze).	80	1.067
NO_2	NO_2 primarily gets in the air from the burning of fuel. It forms from vehicular emissions and from power plants, and off-road equipment.	Exposure to NO_2 over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing)	NO_2 contributes to acid rain, haze and nutrient pollution.	80	19.02

Source: CPCB[7]

2. Emission Inventorization:

An emission inventory is an estimation and account of the emissions discharged from various sources in a certain time frame in a particular region.
Preparation of emission inventory requires the data from traffic surveys and parking lot surveys and the estimation of emission factors.

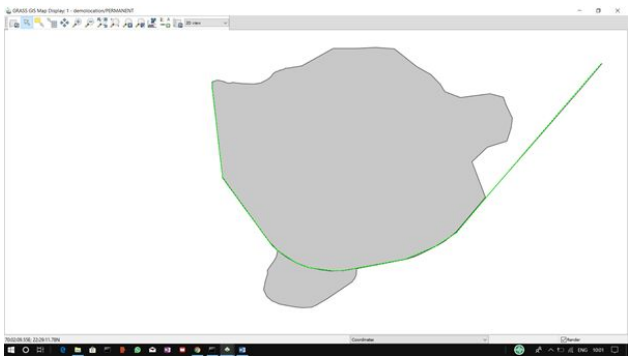
Traffic surveys are conducted to find the number and type of vehicles travelling in a given grid and the road lengths travelled by these vehicles in the grid. Parking lot surveys are conducted to find the distribution of vehicles over different parameters affecting the emission factors like vintage, distance travelled, engine capacity, model etc.

Emission factor: It is a representative value that relates the quantity of pollutants released to the atmosphere with a source activity associated with the release of that pollutant. Emissions factors can be determined at various levels (from a locality to the whole country) depending on the requirement of the study.

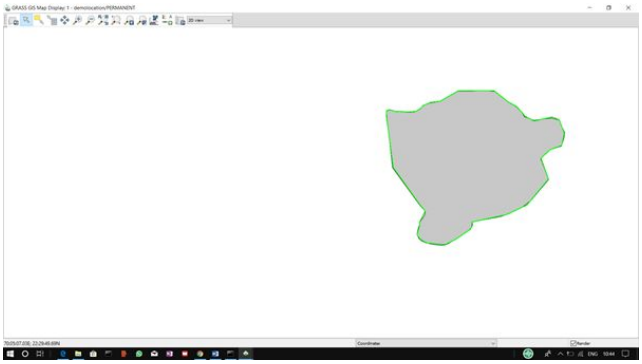
Emission factors are obtained by testing in controlled environment by organizations like ARAI. They can also be estimated in other ways like Source sampling, Emissions model, Surveying, Mass balance etc., depending upon the required accuracy and cost involvement.

Vehicle wise emission inventory is prepared with the data obtained from the traffic survey, parking lot survey and the emission factors. We had an hands-on experience analysing the data obtained for Ludhiana city.

GIS Modelling: We had learnt the basics of GIS modelling in Arc GIS software and prepared the GIS model of Jamnagar and Hyderabad cities.



Road length measurement



Boundary area measurement

Jamnagar City

The modelling can help to pay special attention to the grids which are more dense in pollution. This will help us in making strategy for bicycle sharing regions and making those grids somewhat greener.

Week 2:

3. Vehicular Exhaust modelling:

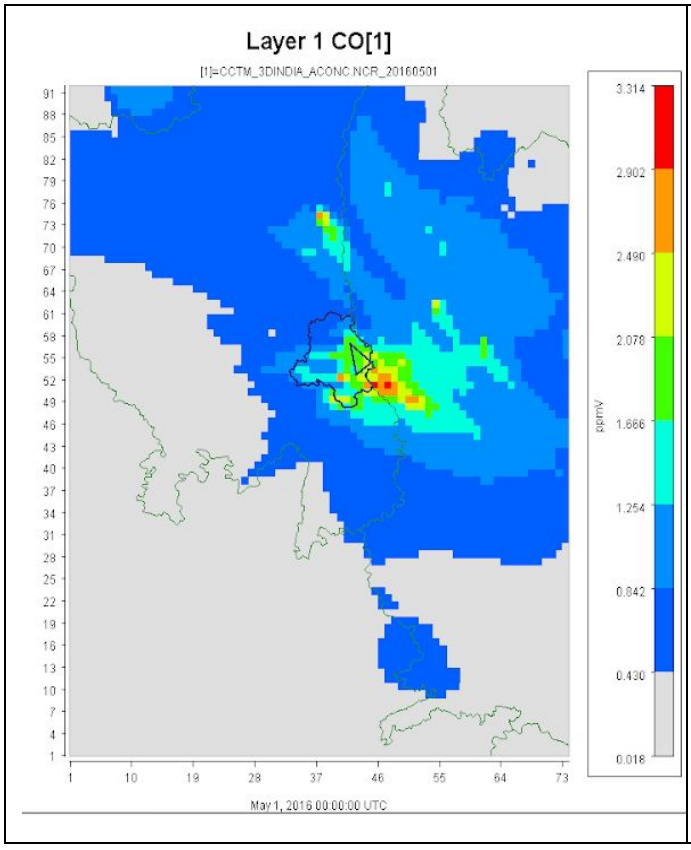
International Vehicle Emissions (IVE) model[8] incorporates the effect of speed and acceleration variations on emissions. It takes the average velocity, fleet plan, climatic conditions, fuel quality, road conditions, startups, driving characteristics, air conditioning usage as input and helps to calculate the emissions from the mobile source and how different transportation planning strategies affect local emissions. Though it is not suitable for indian conditions, using base adjustment ratios it can be used for the developing countries like india. It includes flexibility like emission calculations on hourly and day basis of various types of pollutants and toxic substances and global warming. We have learnt the basics of IVE model and used it on an assumed dataset to understand the working of the model.

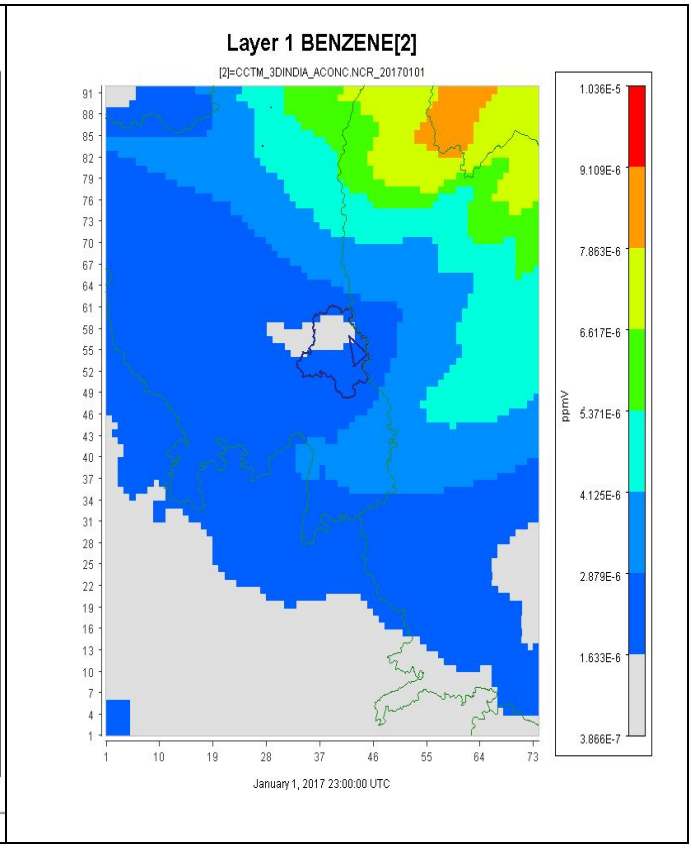
4. Dispersion modelling:

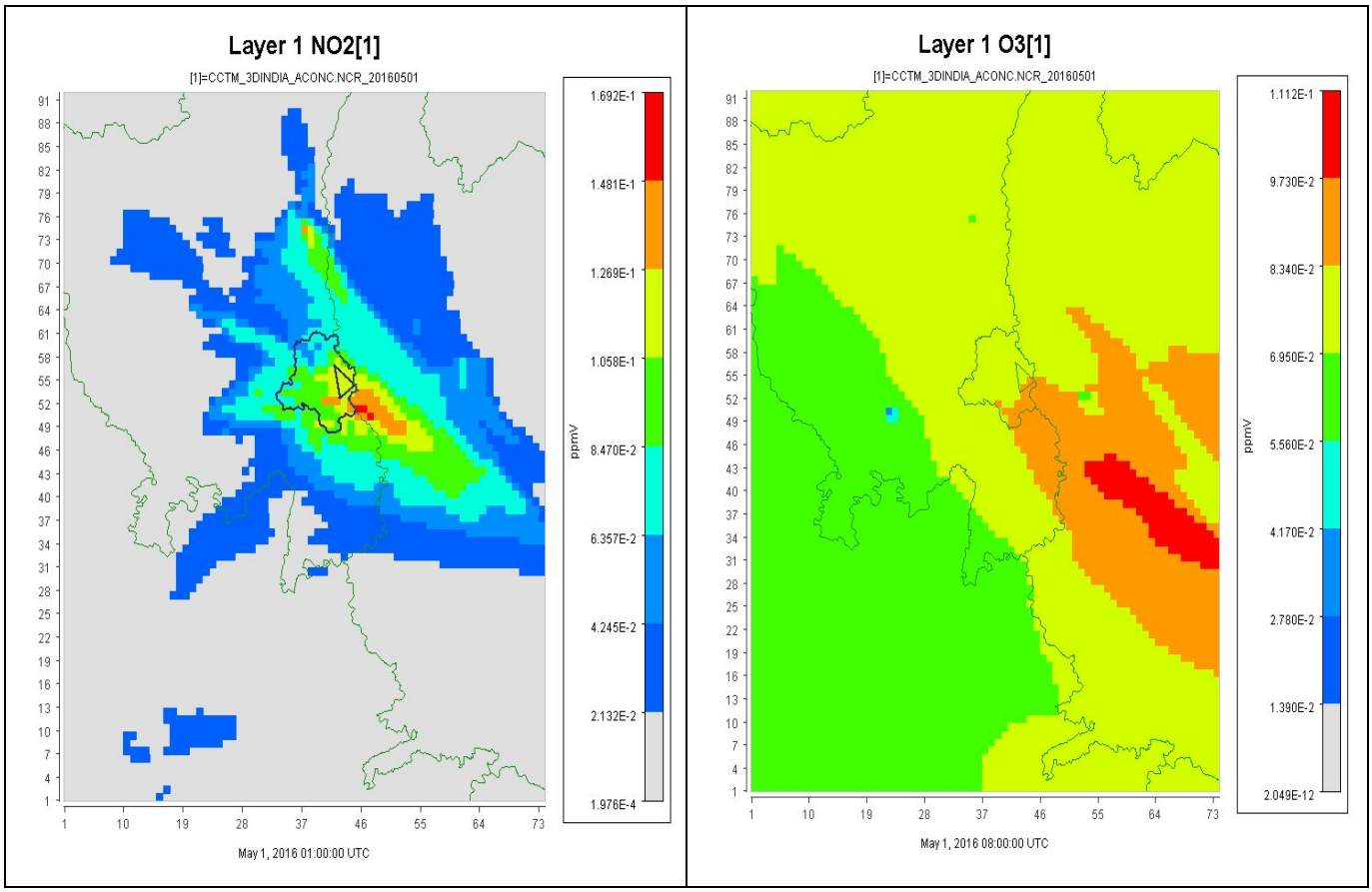
Dispersion modelling is the mathematical simulation of dispersion of air-pollutants in the atmosphere. It is used to estimate the ambient concentrations of air-pollutants emitted from various sources. Dispersion modelling helps in assessing the impact of an intervention in the ambient air quality and thus is crucial for policy making.

Use of CMAQ for Dispersion modelling:

CMAQ[9] is open-source development project of the US-EPA for conducting air quality model simulations. It is a three dimensional Eulerian atmospheric chemistry and transport modelling system to simulate the ambient concentration of various pollutants.It is capable of estimating the chemistry and transport of various pollutants like PM, Ozone, acidic and nutrient pollutant species as well as estimates of visibility degradation and deposition in a single run at domain sizes from urban to region level. The meteorology and emission rates from various sources are the primary inputs to CMAQ to obtain the required ambient emission concentration data.
We have studied the functioning and operation of CMAQ and the science involved in it. We also had worked on interpreting the data obtained from CMAQ using Verdi software.







Data used for visualisation: CMAQ-TERI

<u>Week 3:</u>

Work on Source apportionment studies

There have been quite a few source apportionment studies done in India. But not much work has been done in quantitatively comparing different source apportionment studies which could help in improving the quality standards of the source apportionment studies being done. We have started to work in determining the indicators which can validate and quantify different source apportionment studies based on the guidelines provided by agencies like US-EPA, CPCB[11] etc., best practices suggested and the uncertainties involved in each model.

Source apportionment studies[10], Review papers on different types of Receptor and Dispersion modelling have been studied to understand the usage of different types modelling in various source apportionment studies. From our study we have found out that in pollution modelling, Receptor modelling is used more often than Dispersion modelling and in Receptor modelling, Chemical Mass Balance technique is largely used even though Positive Matrix Factorization technique is said to give the best results[12]. This may be due to the fact that Receptor models are relatively less resource intensive when compared to Dispersion modelling. We have also found certain techniques to quantify the uncertainty involved in each type of Receptor models[13].
Further work on this subject will be continued by us after the internship with the support of Anju ma'am at TERI.

Takeaways from the first three weeks:

- Our study sensitized us towards the increasing levels of pollution in the country, and how diverse the sources of pollution are.
- We have also understood the importance of making strong decisions at the policy level like the BS norms to generate sustainable impact.
- With the understanding of pollution modelling, we will be able to better quantify the environmental impact our e-bicycle can create.
- The inputs on our e-bicycle from the experts on environment here at TERI will inspire us to improve our product and have a realistic viewpoint on the impact that we can create with our e-bicycle.

Week 4:

Analysis of the economic, health, time saving impact of intervention of replacing the existing transport system with electric bicycles in Chennai and Hyderabad cities:

Four major benefits of cycling: Fuel savings, Emissions reduction, Time Saving, Health benefit from exercise.

Assumptions:
All trips taken into consideration are upto 10 km only.
Power required to charge is 6 INR per unit of power consumption.

Fuel savings and Emission reduction:

Chennai

Vehicle Type	**Source**	**Fuel consumption (litres)**	**Cost of fuel (INR)**	**Energy consumption (TJ)**	**Tonnes of CO2 emitted**
Currently Used					
Car (running cost)	petrol,diesel,LPG,CNG	5.52 millions	400 million	208	14.3 kilo tonnes
		1.20 millions			
		0.41 millions			
		0.15 millions			
Two wheelers(running cost)	Petrol	11 million litres	637.25 million	364.24	25.24 kilo tonnes
E-Bicycle	After substituting all the above cars and motorized two wheelers with e-bicycles				

Normal E-BIke (After substituting all cars,two wheelers by e-bike)	Electric	0	64.61 millions (recharging cost)	38.77	8.83 kilo tonnes(source emissions)
Proposed E-Bike (After substituting all cars,two wheelers by e-bike)	Human + Electric	0	48.46 million (recharging cost)	29	6.62 kilo tonnes (source emissions)

Hyderabad

Vehicle Type	**Source**	**Fuel consumption (Litre or Kg)**	**Cost of fuel (INR)**	**Energy consumption (TJ)**	**Tonnes of CO2 emitted**
Currently Used					
Car(running cost)	Petrol	2.3 million	180 million	102.63	6.74 kilo tonnes
	Diesel	0.48 million			
	CNG	0.16 million			
	LPG	0.06			
Two wheelers(running cost)	Petrol	5.2 million	349 million	174.4	9.59 kilo tonnes
E-Bicycle	After substituting all the above cars and motorized two wheelers with e-bicycles				
Normal E-Bicycle	Electric	0	24.92 million (recharging cost)	14.9	3.40 kilo tonnes (source emissions)
Proposed E-Bicycle with increased range	Human effort + Electric	0	18.69 million (recharging cost)	11.2	2.55 kilo tonnes (source emissions)

Source: TERI data

Travel time savings:

The work trips of in the distance range of 1km to 10km are considered.

- In Chennai, an average of 2.3 hours per day can be saved by each person by cycling the same distance which was travelled by walking earlier. It results in an additional economic benefit of **1.36 billion INR** per year if the time saved in travel is used for productive purposes.

- In Hyderabad, an average of 1.3 hours per day can be saved by each person by cycling the same distance which was travelled by walking earlier. It results in an additional economic benefit of **1.53 billion INR** per year if the time saved in travel is used for productive purposes. .

Source: TERI data

Health Benefits:

We have used the HEAT[14] tool to calculate the health benefits of cycling in Chennai and Hyderabad.

Chennai

No. of days people used bicycle in a year to commute to work	240	120
Average distance travelled by a person each day	5.15 km	5.15 km
Reduction in mortality compared to people not cycling	10%	5%
Benefit year	10 years (2025)	10 years (2025)
No. of deaths prevented per year by cycling	272	136
Expected no. of people to die over 10 years if they weren't cycling	2668	2668
Current value (year:2015) of the total benefits accumulated over 10 years	58.26 billion	29.13 billion

Hyderabad

No. of days people used bicycle in a year to commute to work	240	120
Average distance travelled per person per day	4.97	4.97

Reduction in mortality compared to people not cycling	10%	5%
Benefit year	10 years (2025)	10 years (2025)
No. of deaths prevented per year by cycling	116	58
Expected no. of people to die over 10 years if they weren't cycling	1178	1178
Current value (year:2015) of the total benefits accumulated over 10 years	24.83 billion	12.42 billion

Source: HEAT

Link for the detailed calculations here: Excel sheets

Week 5:

Study of Reports of Studies on E-bicycles:

The Reports on different studies done on electric bicycles worldwide have been studied. Below are some of the inferences and understanding we have got from these reports.

Report on promoting cycle in India TERI:

The report shows the importance of bicycle as a sustainable mode of transport and affordable to the lower income groups. But the growth rate of the household cycle ownership has been very low at 3% per annum. One of the key issues is the lack of financing available to buy a bicycle in India.

To what extent do e-bikes substitute travel by other modes?Evidence from the Netherlands[15]:

1.The e-bike ownership strongly reduces the use of the conventional bicycle and by lesser extent car, public transport use.
2.the transport usage of car and public buses etc, get reduces significantly by the owners of e-bike as compared to the owners of the conventional bike users.
3.At the level of vehicle ownership, the e-bike acts as a substitute for the conventional bicycle and does not act as a substitute for the car.

Also, in this study, it was observed that in a particular country, the most dominant mode of transport mostly gets replaced by an intervention like an electric bicycle. For example, in three different kind of regions say chinese cities,cities of australia,US and Canada and European countries the transport is dominated by bus, cars, and conventional bicycle. Then in chinese cities most no. of trips by bus transit get replaced by the e-bicycles while in Austria,US and Canada regions most no. of cars get replaced and similarly in European regions, most number of bicycle trips get replaced.

Survey of difference of cycling experiences and perceptions between E-bike and bicycle users in USA[16]:
The survey results show that e-bikes play a more important role in utilitarian travel, such as commuting and running errands, compared to a conventional bicycle. Conventional bicycle-owning respondents use their bicycles more for recreation and exercise. Also, e-bike owners tend to ride longer distances and take more trips per week. Both e-bike respondents and bicycle respondents stated that improved health was a key factor for cycling.

Energy consumption and CO2 emission impacts of vehicle electrification in three developed regions of China[17]:
This study focuses major on what type of vehicles should be promoted depending on the source of electricity. Three types of vehicles are considered here, Pure electric vehicle (which only runs on electric power), Hybrid electric vehicle(which runs on both fossil fuel and electricity) and Plug-in hybrid electric vehicle (PHEV). If major source of electricity in a region is generated from coal based power plants, then usage of Hybrid Electric Vehicle is prescribed for maximum reduction in overall emissions. While in regions where renewable energy (cleaner grid) is available usage of pure Electric Vehicles should be prefered.

This paper also gives hint that if the emissions from coal and fossil fuel extraction are ignored, the tank to wheel emissions of EVs will be higher than those of conventional Vehicles.

Week 6:

Survey on Electric Bicycles:

The aim of this survey is to know the consumer perception and expectations about electric bicycle so as to identify

the potential market for the electric bicycle. Polldaddy is used as the platform to conduct the survey. It offered a free alternative with necessary features.
The questions try to understand the socio-economic status of the respondent, his willingness buy e-bicycle, perceived benefits and challenges in using e-bicycles etc. If the respondent is unaware of E-Bicycles relevant information was provided before proceeding further with the survey. Electric bicycles owners will be asked additional questions like the model and cost of their cycle, time spent on charging etc.

Link to the flowchart of the survey:
https://drive.google.com/file/d/151OfaCyWY1R8IaHyaw5ZUG6CiivWNShZ/view?usp=sharing

Link to the survey: https://ebicycle.polldaddy.com/s/survey-on-expections-experience

Takeaways from the last three weeks:

- We have understood the level of economic and health benefits our e-bicycle can bring in.
    - This would help us in better promotion of our product and identify the areas where we can create maximum impact.
- From the study of reports and papers on e-bicycles,
    - The need for incentivization and finance to increase the mode share of bicycles.
    - The changing trends the challenges being faced by the bicycle industry.
    - The type of usage and the consumer behaviour of an e-bicycle.

- From the survey, we expect to understand the consumer expectations, identify the potential market and the existing challenges in the usage of e-bicycle.

On behalf of the Hybrid Bevel Bike Team,CFI we thank CCAPC and TERI for their support. The internship has been very fruitful for us and had not only sensitized us towards the well-being of the environment but also guided us to understand the impact our bicycle can create. The internship has equipped us with the knowledge and skill which would help us in the promotion of our bicycle and also to make an informed choices in regard to pollution as an individual. With the survey, we also understood the consumer expectations and the challenges we may face in our bicycle commercialization. Keeping them in mind the we shall improve our bicycle to make it more affordable and efficient.

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