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Predictive Mathematical Modelling To Analyse the Feasibility of Infiltrating Solar Hybrid Vehicles in Smart Cities of India

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Abstract: *'The Smart Cities Mission' is a new initiative by the Government of India to increase economic growth and improve the quality of life of people by enabling overall development and using technology as a means to create smart outcomes for citizens[3]. Accomplishment of smart city mission will bring enormous amount of population and eventually, vehicles on road. This sudden population explosion will contribute significantly to global warming and consumption of conventional energy resources [4,3]. Our research paper presents a simple predictive mathematical model which clearly states the contribution of particular smart city in vehicular emission reduction, currently or after known years, if city's vehicle market is fully penetrated by solar hybrid vehicles. Model gives a clear idea to the government agencies about the smart city which is a potential major contributor to vehicular pollution and, henceforth should be allowing only solar hybrid vehicles on its roads. Mathematical model is used as an analytical tool in determining Emission Reduction factor due to solar hybrid vehicles at any space-time combination depending on various parameters. Our predictive mathematical model provides an approach in forecasting the effect of solar enabled vehicles on vehicular emission reduction in smart cities in coming years.*

Keywords: *Mathematical Modelling, Solar PV Technology, Smart Cities, Solar hybrid vehicles, Emission pollution*

1. Introduction

Smart city mission is an ambitious plan of the government of India. Total 98 cities across the country are selected by the government through rigorous selection criteria based on various factors [see appendix]. Government is supposedly providing 500 Crore Rupees to respective state governments [14]. Smart cities mission focuses on development of infrastructure, maintenance of historical monuments, promoting trade and industry .Government looks forward to promote mixed land use which includes planning and development of unplanned areas. The mission focuses on providing housing facility to all. Moreover, smart city mission looks forward to improve standard of living of people by preserving playgrounds, parks, recreational centres. Smart cities mission will attract population from all parts of country as it will provide opportunities along with quality of life. This population explosion will bring enormous number of vehicles on the road [3]. From the above mentioned features we can understand that smart cities will be both boon and bane. In one way these cities will boost country's economy and improve quality of life, but on the other hand they will be the ocean of opportunities which will attract a huge chunk of population from other parts of the country, which will lead to exponential increase in pollution due to vehicular population. Indian government has vowed to reduce country's emissions intensity by 33 to 35 percent by 2030 at the United Nations framework Convention on climate change. Many experts raised their fingers stating that India could do much better if it focuses on its renewable energy need goals. Many studies have been done in the area of solar energy which clearly throw light on both advantages and disadvantages of deploying it in a practical aspect [6, 9, and 11]. However, with better technology and cost control, solar energy power system has a very promising future. It is a well-known fact that solar energy power system is capable of replacing the conventional energy power system. Vehicles equipped additionally with well-connected solar panels , battery , and a switch to alter power system are proving to be an efficient design which can replace the conventional forms of power system in a long run. Total 98 smart cities have a potential to contribute immensely in vehicular emissions. It is the need of hour that government should observe closely the feasibility of penetrating solar vehicles in the city's market .Penetration of solar hybrid vehicles in a smart cities by the government means allowing only solar vehicle for a fresh buyer.However; this does not seem to be an easy task. Realizing the complications involved with the

applications of solar PV modules such as weather dependence, high initial cost and others, it will be very huge gamble to implement a law or policy which allows only solar hybrid vehicles in a smart city by the government. Moreover, characteristics of city, like population, vehicular population, total area, total road length growth rate of city in terms of vehicular population ,annual mean temperature and most importantly future modifications like introduction of metro/bullet train, expansion of road length decides the amount of vehicular pollution in coming years. Therefore, it is quite clear by the above mentioned points ,that selecting the smart city for solar hybrid vehicle implementation scheme involves lot of serious considerationsRole of Solar Power towards the smart cities will not only make them technologically equipped but also make them less dependent on conventional forms of energy.

2. Problem Statement

Environmental impact due to harmful emissions from vehicles is a vital point of consideration. According to UNFCCC report, Indian government has given an assurance to reduce its emission of greenhouse gases by 33 percent to 35 percent. Around 72 percent of total air pollution is caused by vehicular emissions in New Delhi which is shortlisted in a smart city mission by the government of India [5]. Controlling traffic or finding an alternative is a need of the hour. Controlling traffic seems less viable option as smart cities, hub of technology and full of opportunities will attract a major portion of population. Solar energy operated power system is an alternative which when used efficiently helps in reducing the emission by little if not significant amount. Therefore, imagining all vehicles on smart city roads as solar hybrid vehicles could be a solution to the problem. This imagination, if actually made realistic, will definitely yield results in emission reduction. However, as discussed above in the introduction part, selection of smart city which is to be experimented with this plan is a big question. Reason for the earlier statement can be illustrated in some examples. First being the unpredictable population growth of some smart cities. Government of India has selected 98 cities as a part of their smart city mission. Many amongst 98 cities are already developed in all aspects, examples are New Delhi, Bangalore, Hyderabad, Chennai, Navi Mumbai and few others. Implementing solar vehicles in those cities would not bring much change in emission intensity as they are already full with conventional vehicles and are not going to experience any further significant change in population. The annual growth of vehicles in Delhi increased from 4.72 per cent in 1999-2000 to 8.33 per cent in 2006-07. There after it decreased to 7.27 in 2011-12[25] .As we can see the vehicular population depends on many factors but it seems to be decreasing or at least at a constant level in the case of developed and big cities. Preferring solar hybrid vehicles over conventional fuel dependant vehicles though, has many obstacles. According to studies, average solar cells can convert only 12.5 to 15 percent of energy **into electricity** (11). To overcome this problem high efficiency solar cells are used. Most commonly used high efficient solar cells are multi junction photovoltaic cells which are made up of **poisonous materials like gallium arsenide(GaAs) and Cadmium Telluride (CdTe) (12).**

3. Methodology

To understand the Role of Solar Power in reducing the vehicular emissions in smart cities and to henceforth working on a mathematical model a study area of Lucknow, Uttar Pradesh is selected. Lucknow city is a capital city of state Uttar Pradesh which has a population of 2,817,105 as per provisional reports of Census India (3). As per Road transport office in 2014 May 1552695 registered vehicles ply on the city roads. Before starting mathematical analysis we focussed on conversion of conventional power system into solar power system and eventually find out the percentage reduction in emissions. The value of percentage reduction in emissions will clearly state the city which is needed to be implemented as a further work progress we worked mathematically on the factors which are known as pollution impact factor (PIF) and fresh pollution impact factor (FPIF). Both the factors are linear functions of four coefficients a,b,c,d representing number of vehicles, vehicles progression coefficient, traffic congestion coefficient and temperature coefficient respectively .Pollution impact factor directly leads to β coefficient and ultimately to Percentage emission reduction of a particular city. Minimum 1hour to 15 years as a time duration is taken so as to appropriately analyse mathematically now and after .

4. Solar hybrid vehicles: An Insight:

Many studies have revealed that air pollution from the vehicles can be reduced using many available technologies. These technologies require skill, huge amount of money and adequate research before being implemented. Solar powered vehicles demand high initial but low maintenance cost. Various studies have suggested solar powered vehicle to be only 20 to 30 percent effective ,that too if we use high efficiency solar cell panels. It is accompanied with couple of problems like

dependence on sun, batteries etc. According to many studies rate of conversion of solar energy is very low (15 percent). However, ultra-efficient solar cells have given lot of hope in this area by increasing the efficiency by 200 percent. Conversion of conventional vehicle energy system is under research and almost every day new technology is coming forward to increase the efficiency of solar cells.

4. Analysis and modelling

Instantaneous emission from a running vehicle or still, but running engine vehicle primarily depends on the efficiency and age of the vehicle and means temperature of the city. While age and efficiency of vehicle decides the amount of fuel consumed for a particular running distance, temperature of the city decides the amount emission of pollutants. However, total emission reduction after particular time duration at a particular city depends on following factors represented by coefficients

1. A = Present Vehicle population (table 1)
2. B = Progression coefficient (Rate at which vehicle population of city is increasing) (table 2)
3. C = Congestion Coefficient (table 3)
4. D = temperature coefficient (depends on Annual Mean temperature of the city throughout the year) (table 4)

Current vehicle population of all smart cities are compared and vehicle population coefficient is formulated as shown in table 2 which is vital in modelling the impact after certain period of time. The value includes 2- wheelers, 4-wheelers private vehicles and 3, 4- wheelers public transport vehicles.

Table-1

Current vehicular population	Vehicular Population coefficient
>5 Million	10
1.5- 5 Million	8
1-1.5 Million	7
0.75-1 Million	5
0.5-0.75 Million	3
0.25- 0.5 Million	2
Less than 0.25 Million	1

Progression coefficient value is selected according to the cities vehicular population growth seen after successive years, we have categorised in three ways as shown below in table 2

Table- 2

Percentage Increase in vehicular population	Category	Value of progression coefficient
0 to 5	Gradually Increasing	0.3
5 to 10	Steeply Increasing	0.6
> 10	Exponentially Increasing	0.9

The progression coefficient associates with the vehicular population coefficient so as to give collective picture of impact of vehicular population over the years. The stratification is done while keeping in mind that few of the smart cities like Rampur in Uttar Pradesh is having a high probability to see population explosion owing to its recent state of development but not seeing now whereas city like Lucknow is experiencing situation where increase is either steep or exponential but may get in the category of gradual increase.

Congestion Coefficient (4) (5) refers to the pollution factor which is raised due to non-uniform speed of vehicles because of huge traffic density . Optimum speed of vehicle will lead to optimal release of emissions. Non uniform speeds are attributed to the driver's characteristics, non-systematic road plan in a city. Congestion, traffic signals and freeways discriminate travel speeds, and thus raise combustion and emission levels (4). Congestion coefficient depends also on the relation between vehicular population and net cross sectional area of the city excluding forests, farms river bodies and agricultural land.

It seems quite plausible to assume traffic and road characteristics of cities to be fairly same. Focus is given however, on a calculable factor which is known as Net congestive area factor which reflects to congestion coefficient

NCAF (Net congestive Area factor)

$$= \frac{Vehicular\ Population(in\ thousands)}{Total\ length\ of\ roads\ in\ a\ city}$$

Congestion coefficient is calculated on the basis of NCAF Value as shown in table 3

Table- 3

NCAF	Congestion Coefficient
>1.5	8
1.25-1.5	7
1-1.25	6

0.75-1	5
0.5-0.75	4
0.25-0.5	3
<0.5	2

Temperature coefficient signifies the behaviour of vehicular emissions at different temperature (5).Emissions rate are high if the temperature is low because engine of a vehicle takes a little more time to warm up. Considering these factors individually a combined effect, according to their weightage net factor is known as PIF.

Table- 4

Annual Mean Temperature ($^{\circ}$C)	Temperature Coefficient
< 8	9
8-15	7
15-25	5
>25	3

Generally temperature has a combined effect on vehicular emissions with humidity. A study has been done showing inverse relationship of temperature , humidity on vehicular emissions [35]
PIF is a function of x, a, b, c, d given by:-

PIF = (x + 2ab + c/2 + d/5)/6 (1)
Where x = Existing pollution impact factor
However ignoring the existing pollution impact factor x
FPIF (Fresh pollution impact factor) ignores the existing pollution impact in a city which gives mathematically as:-

FPIF= (2ab + c/2 + d/5)/6 for an instant of time (2)

In case of 'n' years FPIF will be

$$\text{FPIF} = \sum \frac{2ab+\frac{c}{2}+\frac{d}{5}}{6n} \qquad (2)$$

Where n is number of years taken into account. In the case of Lucknow city coefficients are
Lucknow data

Vehicular Population = 15,52,695 [8]
Road length =3387 km [22]
Vehicular growth rate = 20 % [22]
Average Temperature= 25.7°C [27]

a = 8 ; b = 0.6 ; c = 7; d = 5 (7),

Delhi Data
vehicular population 74.53 lakh [25]
Road length 28508 [26]
Annual growth 7% [23]
Temperature= 25.2°C [28]
Bangalore Data
Vehicular Population 1.5 million [16]
Annual growth 7 to 10 percent [16]
Total road length 10,200 km [17]
Temp. 25.1°C

Vishakhapatnam Data
Vehicular population 5 lakh [20]
Road length 6922 km [19]
Growth rate 17.2 % [21]
Annual average mean temperature [29]

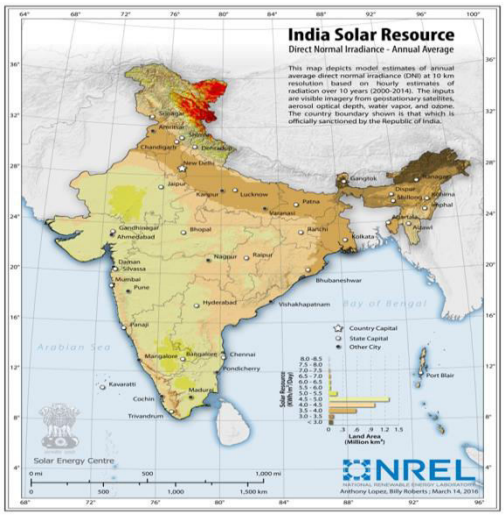
FPIF value for end of the current year in a Lucknow city is :-
A= 8 NCAF=0.458 D=3
B=0.9 C= 3
FPIF value for Lucknow , for current year is 2.75 { from equation 1}
For Vishakhapatnam
A= 3 NCAF=0.0722 D=3
B= 0.9 C= 2
FPIF value for Vishakhapatnam, for current year is 1.166 { equation 1}
FPIF Value of Delhi
A=10 NCAF= 0.26 D= 3
B= 0.6 C= 2
FPIF value of New Delhi,for current year is 2.2667 {from equation 1}
For Bengaluru
A= 8 NCAF=0.014 D=3
B= 0.6 C= 2
FPIF Value of Bengaluru for current year is 1.8667
Fresh Pollution Impact factor is a numerical value which depends on current vehicle population in a city, congestion of traffic in a city, future population of vehicle in a city and annual mean temperature of a city. FPIF value is helpful in predicting the Emission Intensity Reduction Impact of any smart city.

5. Effect of Solar Irradiance

Smart cities in India are spread over the entire country and are subjected to different solar radiation. As an example we can compare solar irradiance of Srinagar city in Jammu and Kashmir state and Jaipur city of Rajasthan state. Both of the cities experience difference in their annual average daily solar irradiance. Magnitude of solar irradiance determines the efficiency of solar panel.
Solar Irradiances (Kwh/m^2/day)

1. Bangalore 5.26 [31]
2. Lucknow 4.72 [32]
3. New Delhi 5.34 [33]
4. Vishakhapatnam 5.07 [34]

Solar irradiance on the country is shown in a figure below:-



Source-National Renewable Energy Laboratory

Table-5

Solar Irradiance(Kwh/m2/day)	SIR
>8	7
7-8	6
6-7	5
5.5-6	4
5-5.5	3
2-5	2
<2	1

6. Modifications in FPIF (Fresh Pollution Impact Factor)

FPIF calculation is applicable for any duration of time. It may vary from 1 hour to 50 years which completely depends on the value of coefficients. FPIF value is designed in such a way that it gives us rough explanation of air pollution due to vehicular population. However, FPIF does not include any aspect of variations in coefficients value which depends on area expansion, introduction of modern transit rail-metro system, awareness of environment amongst people, government policies, up gradation of transport system by effective planning and others. It also does not include the effect of solar irradiance of particular city. These all above mentioned factors affect the values of coefficients which ultimately affect the value of FPIF. To overcome the non-foreseeable effects on FPIF value, we have come up with a modification factor* which depends on the area expansion, introduction of modern transit rail-metro system, awareness of environment amongst people, government policies, up gradation of transport system and others along with Solar irradiance coefficient, which can be obtained from table 5.

$$\beta = \text{FPIF} + \text{Modification factor*} + [(\text{SIR})^2 / 100]$$

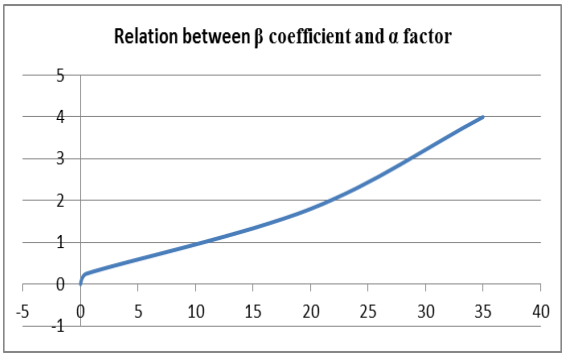
β coefficient is the absolute measurement of impact of air pollution due to vehicles in a smart city. Implementation of solar powered vehicles reduces the significant amount of emission intensity. Reduction of emission intensity will vary from city to city as we know clearly that β coefficient value depends on various factors. Relation between β coefficient and Emission intensity reduction Impact is shown in a graph below

β coefficient for Bengaluru = 2.1437

β coefficient for New Delhi = 2.552

β coefficient for Lucknow = 2.97

β coefficient for Vishakhapatnam = 1.423



*Horizontal scale refers to Emission intensity reduction factor and vertical scale represents β coefficient *35 is the optimum value assuming vehicle runs one third of the total running time in a day. More β coefficient value does not signify that percentage EIR will increase. It may go to higher value depending upon better technological advancement.

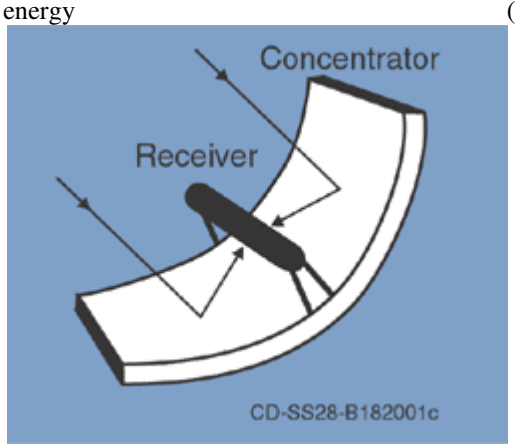
7. Implementation Scheme

Solar powered cars do not essentially have to be equipped with solar panels. It is certainly not advisable though , until highly efficient and economical solar cell panels are available .This is attributed to low surface are of vehicles roof and practically very less in case of two wheelers.Solution lies in the installation of solar panel arrays at homes,offices , residential apartments, common parks , commercial hubs. These places provide a station to charge vehicles while owner does his work. Moreover, these vehicle charging stations would work more efficiently by the help of CSP (Concentrated Solar

Power) technology . CSP technology allows solar radiation to converge large amount of solar energy onto a photovoltaic system which converts solar energy into electricity at very high rate (12). Population migrating [27]

Source:https://www.youtube.com/watch?v=- SsJBobMpAk

However, Solar PV technology remains the most commonly used technology in the field of solar energy (13).



Source: http://solareis.anl.gov/guide/solar/csp/

7. Results and Discussions

Above graph clearly states that β coefficient has almost linear relationship with the percentage Emission intensity reduction. Smart cities having high β coefficient value are needed for implementation of solar powered vehicles as they contribute better in emission control. Coordinate (0,0);(0.1,0);(0.2,0)states that cities having β coefficient as negligible need not to be taken into consideration. Smart cities having negligible β coefficient reflects:

FPIF=Modification factor

Modification factor having same value as FPIF clearly states the effort of government in the area of environment protection which surely is an ideal condition and nearly unachievable. Lucknow city's current statistics revealed its FPIF value to be 2.35 and assuming its modification factor to be zero* percentage emission reduction comes out to be nearly 24 percent which should be considered by the authorities. . Mathematical modelling which we used in this paper clearly requires further attention which depends on the changes smart cities are going to experience. An attempt is made to cover those changes in a form of modification factor but clearly the expression of β coefficient will be more effective after few years when exact aftereffects of smart cities are visible.

*Modification factor can only be analysed after few years when development in city start showing visible progress in an aspect of smart city mission by Government of India

8. Conclusion

Feasibility of implementing the idea of penetrating solar vehicles in a smart city involves lot of monetary attention from the government. Apart from cost parameter it involves several other factors like efficiency, reliance, performance, dependence on weather, inability to deliver at night etc. It seems from the above research that many smart cities are going to be huge emission source and needed to be acted upon. FPIF value clearly reflects the amount of emissions reduced from the city, if solar powered vehicles are introduced. Various studies have concluded that major source of air pollution in a developed or developing city is due to vehicular pollution. The vehicular pollution is what that needs to be reduced if not eradicated, if India wants to lead globally in sustainable development and environment protection.

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