A Sustainable Way to Mitigate Ozone Pollution by Reducing Biogenic Vocs Through Landscape Management Programme

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Abstract- *Trees can affect air quality in several ways: ozone pollution, pollutant deposition, temperature reduction, carbon sequestration, and emission of biogenic volatile organic compounds (BVOCs). Ideally, all tree effects on air quality especially ozone pollution would be included in tree selection to maximize net benefits. This control measure claims reductions for BVOC emissions only. BVOCs were included as an initial step in air quality planning because they were most readily quantified. Reductions were achieved by planting lower-emitting species than would be the case in the absence of the control measure. The Tree BVOC Index (TBI) is an alternative prescriptive approach that provides an estimate of projected and actual emission reductions, gives users a clearly defined target to reach and a method to continuously monitor progress, is completely transparent to users and regulators, and eliminates labeling of tree species, thereby facilitating verification and enforcement in a regulatory environment. A TBI less than or equal to 1.0 informs the user that their tree planting program is on track to meet its goal. In the present study, four tree species were selected viz. Dalbergia sissoo, Butea monosperma, Mangifera indica and Azadirachta indica at two sites namely Site I, traffic intersection and Site II, industrial for determination of Tree BVOC index by calculating ratio of future emissions from a proposed or current planting of trees at particular sites annually in a capital city of India, Delhi. The results indicated that Dalbergia sissoo and Butea monosperma calculated Tree BVOC index was found to be 3.22 and 2.11 at Site I and 3.79 and 2.43 at Site II respectively while 0.66 and 0.22 at Site I and 0.69 and 0.22 at Site II in case of Mangifera indica and Azadirachta indica respectively. Hence, the study concludes that among four selected trees, Mangifera indica and Azadirachta indica which have calculated TBI values less than 1 were found to suitable for planting and can be used as in greenbelt development programmes while Dalbergia sissoo and Mangifera indica which have values more than 1 were not recommended for planting especially for mitigating ozone pollution. Hence, Tree BVOC index can be used as a sustainable way to mitigate ozone pollution and can be used for landscape development programmes.*

Keywords — *Ozone, BVOC, Tree, Air quality and Mitigation.*

I. INTRODUCTION

Trees play important roles in the abatement of air quality through sequestration of carbon dioxide, emission of oxygen and providing surfaces for deposition of airborne particles and gases. Many processes have been influenced directly or indirectly related to air quality such as building up of energy, runoff reduction, infrastructure repair and property values [1].

Various methods have been used to measure BVOC emissions. More sophisticated models are used with more focusing towards the development of process-based emission models and away from empirically-based approaches. The models can be improved by using multiple canopy layers which can be used to account for analyzing the effects of solar radiation extinction [2], leaf energy balance models for temperature effects [3], and other process-based strategies ([4]–[7]). Empirical models are easy to use and can perform well with more process-based approaches [3,8,9].

In case of developing biogenic emission inventories for photochemical modelling, a number of regional to global scale models have been used [3,10,11]. Emission factors are assigned on the basis of land area based on grouping of species into plant functional types by land use. Urban Tree Air Quality Score (UTAQS) was developed for the Birmingham area of the United States [12]. This score is helpful in relation to BVOC emission rates and deposition rates based on relative change in ozone, NO_2 and particulate matter. As per this score, trees are ranked as per their potential to improve air quality categorized into high, medium and low. Emitter classes were defined as Low (1 or less), Medium (1-10), and High (greater than 10 µg C g^{-1} dry leaf hr^{-1}) [13] based on combined emissions of isoprene, monoterpenes, methylbutenol (MBO) and other VOCs (OVOCs). This type of small and cost effective method claims reductions for BVOC emissions only. The planning of planting trees are based on the basis of their rate of BVOC emission viz. low emitting or below detectable limit. Trees which are in moderate or high emission BVOC rate are often avoided. Reduced emissions of BVOCs from trees help in reducing rate of formation of tropospheric ozone [14].

The Tree BVOC Index (TBI) is another alternative method that provides an estimate of projected and actual emission reductions. The TBI is the dimensionless ratio of emissions from a proposed planting to that of target (reduced) emissions necessary for a particular project development. Calculations are readily implemented in a spreadsheet application using numbers of each species planted over the life of the project, the number of years in the project, and tabulated daily emissions values, which account for differences due to species, size, and local climate. A TBI less than or equal to 1.0 informs the user that their tree planting program is on track to meet its goal. This type of method is very useful in greenbelt development of a particular. The trees were segregated as per their scores and planted accordingly. The present study therefore, focuses on selection of four tree species viz. *Dalbergia sissoo*, *Butea monosperma*, *Mangifera indica* and *Azadirachta indica* at two sites namely Site I, traffic intersection and Site II, industrial for determination of Tree BVOC index by calculating ratio of future emissions from a proposed or current planting of trees annually in a capital city of India, Delhi.

II. METHODOLOGY

Four commonly tree species viz. *Dalbergia sissoo*, *Butea monosperma*, *Mangifera indica* and *Azadirachta indica* were selected on the basis of their abundance at both the chosen sites viz. Site I (traffic intersection) and Site II (industrial) (Table 1).

Table 1 Diversity of Selected Plant Species

S.N.	Site	*D. sissoo*	*B. monosperma*	*M. indica*	*A. indica*
1	I	1050 (approx)	770 (approx.)	250 (approx.)	542 (approx.)
2.	II	1300 (approx.)	850 (approx.)	176 (approx.)	720 (approx.)

(Source: Forest Department, Delhi)

TBI

The TBI is the ratio of future emissions from a proposed or current planting project with target emissions for a particular site:

$TBI = E_{proposed}/E_{target}$ ....(1)

where $E_{proposed}$ is emissions from a proposed planting and E_{target} is maximum emissions allowed (g-C/tree/day). Emissions can be evaluated annually. If $TBI \leq 1.0$ (dimensionless), it means reaching this target means that tree planting program is on track to meet its goal. $E_{proposed}$ values were taken from Varshney et al. [15].

Baseline Emissions

Daily BVOC emissions were found as the product of daily emission factor (accounts for differences in emissions related to species, tree size and climate), foliar biomass, species fraction and survival:

$$E = \sum_i^{ni}[eci\ X\ \sum_j^{ni}(mi.j\ X\ npi.j\ X\ survj)]\ \ (g - Ctree/day) \text{ .... (2)}$$

where eci is the environmentally corrected emission factor (g C kg^{-1} dry leaf day^{-1}) for isoprene, monoterpenes, MBO, and other VOCs combined, mi,j is foliar biomass and npi,j is number of trees planted of species i in the jth year after planting, and survj is the fraction of trees surviving in the jth year after planting. Baseline emissions result when the baseline species mix is used in equation (2).

Daily BVOC emissions were also estimated using a simplified form of equation (2):

$$E = \sum_i^{ni}[eci\ X\ mi\ X\ npi\ X\ surv]\ (g - \frac{\frac{C}{tree}}{day}) \text{ .... (3)}$$

where mi is foliar biomass of species i for average years after planting, npi is total number of species i planted during the project and surv is the average number of trees surviving for all years being analyzed.

Emission Factors

Daily emission factors for each species were calculated from mass-based emission factors (mg C g^{-1} dry leaf hr^{-1}) under standard conditions (30°C and 1000 $\mu molm^{-2}s^{-1}$, photosynthetically active radiation or PAR), environmentally adjusted for hourly changes in air temperature and solar radiation using emission algorithms from [16,17].

Foliar Biomass

After the emission flux measurements were complete, the entire branch enclosed in the chamber was harvested and the leaves were dried in an oven at 70°C to a constant weight.

III. RESULTS AND DISCUSSION

Baseline and Target Emissions

Four trees were selected viz. *Dalbergia sissoo*, *Butea monosperma*, *Mangifera indica* and *Azadirachta indica* were selected on the basis of their abundance at both the chosen sites from the years 2007-2012 viz. Site I (traffic intersection) and Site II (industrial) and measured and calculated for baseline and target emissions used from Equation (2) and (3). As the population of these trees were found to be abundant at these two selected sites, therefore, only these four species were chosen for planting. These trees were planted in the year 2007 and then regularly monitored till year 2012 with respect to BVOCs emission.

The baseline and target emissions were measured according to Equation (2) and (3) and from this reduction in BVOC emissions can be calculated from the above selected trees. From this value, an estimation can be made that which tree/trees is/are suitable for planting at these two sites so that indirect production of tropospheric ozone can be reduced. Table 2 shows the reductions, baseline and target emissions of all the sites. On the contrary, tree specific emissions are reported in Table 3 (a) – (d).

Table 2 Emissions Additions/Reductions, Baseline and Target Emissions of Selected Trees at selected sites

a) *Dalbergia sissoo* (Site I)

S.No.	Emissions	Total Emissions tpd	
		Equation (2)	Equation (3)
1.	Baseline	1.07	0.87
2.	Target	1.34	1.23
3.	Additions	-0.27	-0.37

b) *Dalbergia sissoo* (Site II)

S.No.	Emissions	Total Emissions tpd	
		Equation (2)	Equation (3)
1.	Baseline	1.87	0.98
2.	Target	1.95	1.68
3.	Additions	-0.08	-0.70

a) *Butea monosperma* (Site I)

S.No.	Emissions	Total Emissions tpd	
		Equation (2)	Equation (3)
1.	Baseline	0.88	0.65
2.	Target	1.23	0.94
3.	Additions	-0.35	-0.29

b) *Butea monosperma* (Site II)

S.No.	Emissions	Total Emissions tpd	
		Equation (2)	Equation (3)
1.	Baseline	0.97	0.82
2.	Target	1.77	1.26
3.	Additions	-0.80	-0.44

a) *Mangifera indica* (Site I)

S.No.	Emissions	Total Emissions tpd	
		Equation (2)	Equation (3)
1.	Baseline	0.33	0.21
2.	Target	0.20	0.12
3.	Additions	0.13	0.09

b) *Mangifera indica* (Site II)

S.No.	Emissions	Total Emissions tpd	
		Equation (2)	Equation (3)
1.	Baseline	0.56	0.44
2.	Target	0.33	0.29
3.	Additions	0.23	0.15

a) *Azadirachta indica* (Site I)

S.No.	Emissions	Total Emissions	
		Equation(2)	Equation (3)
1.	Baseline	0.21	0.15
2.	Target	0.08	0.04
3.	Reductions	0.13	0.11

b) *Azadirachta indica* (Site II)

S.No.	Emissions	Total Emissions	
		Equation (2)	Equation (3)
1.	Baseline	0.54	0.34
2	Target	0.25	0.66

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3 .	Reductions	0.32	0.54

From the above tables 2 (a & b), it has been clearly depicted that overall emission reductions/additions in BVOCs were observed by taking all the sites into concerned. While, in specific, in terms of trees, M*angifera indica* and *Azadirachta indica* showed high reduction in BVOCs as compared to other trees like *Dalbergia sissoo* and *Butea monosperma*. From this observation, it can be suggested that these two trees viz. M*angifera indica* and *Azadirachta indica* can be recommended for planting at both the sites.

TBI

The TBI is calculated for the selected tree species over a 5 year period at both the sites (2007-2012) (Table 4). Equation (3) is used to illustrate the potential utility of this approach (equation (2) yields similar results). The example planting is in compliance because the TBI is less than 1.0 in case of M*angifera indica* and *Azadirachta indica.*

Table 3 Tree BVOC Index of Selected Plant Species at both Sites

Sites	Plant Species	Tree BVOC Index
I	*Dalbergia sissoo*	3.21
	Butea monosperma	2.11
	Mangifera indica	0.6
	Azadirachta indica	0.22
II	*Dalbergia sissoo*	3.79
	Butea monosperma	2.43
	Mangifera indica	0.69
	Azadirachta indica	0.21

This type of approach is very user friendly. It is used to select the right species to best match local site conditions, as long as they achieve a TBI of one or less at year-end. A TBI greater than one will force the city to reduce BVOCs from the population planted in following year(s) by adjusting the numbers planted of each species in the way that best suits their circumstances. Alternatively, a TBI less than one affords more flexibility in species selection the following year.

IV. CONCLUSION

Tree BVOC Index is specifically developed to target those plant species which emit less BVOC and ultimately proven to be a sustainable way to mitigate ozone pollution. The present study concludes that among four selected trees, *Mangifera indica* and *Azadirachta indica* which have calculated TBI values less than 1 were found to suitable for planting and can be used as in greenbelt development programmes while *Dalbergia sissoo* and *Mangifera indica* which have values more than 1 were not recommended for planting especially for mitigating ozone pollution. Hence, Tree BVOC index can be used as a sustainable way to mitigate ozone pollution and can be used for landscape development programmes.

REFERENCES

[1] E.G. McPherson, J.R. Simpson, P.J. Peper, S.E. Maco and Q. Xiao, "Municipal forest benefits and costs in five U.S. cities", *Journal of Forestry*, Vol. 103, pp.411-416, 2005.

[2] A. Guenther, C.N. Hewitt, D. Erickson, R. Fall, C. Geron, T. Graedel, P. Harley, L. Klinger, M. Lerdau, W.A. McKay, T. Pierce, B. Scholes, R. Steinbrecher, R. Tallamraju, J. Taylor and P. Zimmerman, "A global model of natural volatile organic compound emissions", *Journal of Geophysical Research*, Vol. 100, pp.8873-8892, 1995.

[3] S. Pressley, B. Lamb, H. Westberg and C. Vogel, "Relationships among canopy scale energy fluxes and isoprene flux derived from long-term, seasonal eddy covariance measurements over a hardwood forest", *Agricultural and Forest Meteorology*, Vol. 136, pp.188-202, 2006.

[4] A. Arneth, R.K. Monson, G. Schurgers, U. Niinemets and P.I. Palmer, "Why are estimates of global terrestrial isoprene emissions so similar (and why is this not so for monoterpenes)?", *Atmospheric Chemistry and Physics*, Vol.8, pp.4605-4620, 2008.

[5] R. Grote,"Sensitivity of volatile monoterpene emission to changes in canopy structure: a model-based exercise with a process-based emission model", *New Phytologist* Vol. 173, pp.550-561, 2007.

[6] T. Keenan, U. Niinemets, S. Sabate, C. Gracia, and J. Penuelas, "Process based inventory of isoprenoid emissions from European forests: model comparisons, current knowledge and uncertainties", *Atmospheric Chemistry and Physics*, Vol. 9, pp.4053-4076, 2009.

[7] U. Niinemets, L. Copolovici and K. Hüve,"High within-canopy variation in isoprene emission potentials in temperate trees: implications for predicting canopy-scale isoprene fluxes", *Journal of Geophysical Research*, Vol. 115, pp.G04029, 2010.

[8] D.E. Millstein and R.A. Harley,"Impact of climate change on photochemical air pollution in southern California", *Atmospheric Chemistry and Physics Discussions*, Vol. 9, pp.1561-1583, 2009.

[9] A.L. Steiner, R.C. Cohen, R.A. Harley, S. Tonse, D.B. Millet, G.W. Schade and A.H. Goldstein,"VOC reactivity in central California: comparing an air quality model to ground-based measurements", *Atmospheric Chemistry and Physics*, Vol. 8, pp.351-368, 2008.

[10] L.E. Gulden and Z.L. Yang, "Development of species-based, regional emission capacities for simulation of biogenic volatile organic compound emissions in land-surface models: an example from Texas, USA", *Atmospheric Environment*, Vol. 40, pp.1464-1479, 2006.

[11] K.I. Scott and M.T. Benjamin, "Development of a biogenic volatile organic compounds emission inventory for the SCOS97-NARSTO domain", *Atmospheric Environment*, Vol. 37 (Suppl. 2), pp.S39-S49, 2003.

[12] R.G. Donovan, H.E. Stewart, S.M. Owen, A.R. Mackenzie and C.N. Hewitt, "Development and application of an urban tree air quality score for photochemical pollution episodes using the Birmingham, United Kingdom, area as a case study", *Environmental Science and Technology*, Vol. 39, pp.6730-6738, 2005.

[13] M.T. Benjamin, M. Sudol, L. Bloch and A.M. Winer, "Low-emitting urban forests: a taxonomic methodology for assigning isoprene and monoterpene emission rates", *Atmospheric Environment: Urban Atmospheres*, Vol. 30, pp.1437-1452, 1996.

[14] SMAQMD,"Sacramento Regional 8-hour Ozone Attainment and Reasonable Further Progress Plan", *Appendix C, Proposed Control*

Measures. Sacramento Metropolitan Air Quality Management District, Sacramento, CA, 2008.
[15] C.K. Varshney and A.P. Singh, "Isoprene emission from Indian trees", *Journal of Geophysical Research*, Vol.108(D24), pp.4808, 2003.
[16] A. Guenther, P. Zimmerman, P. Harley, R. Monson and R. Fall, "Isoprene and monoterpene emission rate variability: Model evaluation and sensitivity analysis", *Journal of Geophysical Research*, Vol. 98, pp.12609–12617, 1993.
[17] P.C. Harley, R.K. Monson and M.T. Lerdau, "Ecological and evolutionary aspects of isoprene emission from plants", *Oecologia*, Vol. 118, pp.109–123, 1999.