EMISSIONS INVENTORY FOR SURAT CITY

PREPARED BY WRI India

INTRODUCTION

Air pollutants emissions inventory is a fundamental tool in air quality management, evaluating air pollution emissions from different sources. It is a critical tool for planning pollution control strategies. Air pollution emissions inventories for the Surat city for different air pollution sources were developed for 2019 using primary and secondary data. This inventory data was then used in air quality dispersion modeling to estimate air pollution source contributions in Surat city. The modeling framework for this study consists of a meteorological model, an air quality model, and an emissions inventory database, which were integrated to simulate the local and regional atmospheric circulation and estimate the ambient pollutant concentration in the Surat.

The Weather Research and Forecasting (WRF) - Community Multi-scale Air Quality model (CMAQ) combination was used to simulate the Surat city's ambient PM_{10} and $PM_{2.5}$ concentrations. The receptor modeling approach was used to analyze the chemical and physical characteristics of gaseous and particulate pollution in different locations of the Surat via the Chemical Mass Balance (CMB) model for the receptor-based source apportionment study. To carry out receptor modelling, air pollution ambient concentration data were collected from seven representative monitoring locations of Surat. To capture seasonal variation in pollutant concentrations, 24-hourly sampling was carried out at each of the selected locations for a period of 15 continuous days covering both summer (May-June 2019) and winter (December 2019 – January 2020) seasons of the year. At the background station, the monitoring was carried out for 30 continuous days during each season.

EMISSION INVENTORY

The current emissions inventories of particulate matter (PM_{10}, $PM_{2.5}$), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and non-methane volatile organic compound (NMVOCs) from different sources were developed by TERI for the Surat city and Surat district for the year 2019. These emissions inventories are further distributed into 2-km X 2-km grids. The major sectors covered in current emissions inventories are given in **Table 1.**

Table 1: Air Pollution source sectors covered in the current emissions inventory

Sr.No.	Type of Source	Sectors
1.	Line Source	Transportation
		Road Dust Resuspension from Transportation
2.	Area Sources	Residential Cooking
		Crematoria
		Municipal Solid Waste Burning
		Diesel Generator Sets (DG Sets)
		Construction Processes
		Aviation
		Eateries and Restaurants

		Landfill Open Waste Burning
3.	Point Sources	Industries
		Power Plants
		Brick Kilns

Emission estimates for different sources and sectors were based on the air pollution, emission factors, pollution control technologies, and efficiency of the control technologies. For each sector, activity data were collected by primary survey and secondary sources. A primary survey was conducted to fill the data gaps and limitations observed in secondary data for transport, industries, diesel generator (DG) sets, and restaurants/hotels. The estimated emissions from different sectors have been suitably allocated over the study domain as per line, area, and point source categories. The methodologies applied to estimate emissions from different sectors have been described in detail section below:

EMISSION ESTIMATION FROM DIFFERENT SECTORS

Industries

To estimate the emissions from industrial sources, different activity data such as fuel consumption in the industrial processes, fuel type, and type of air pollution control device (APCD) installed in the industry were obtained from the secondary survey and personal communication with GPCB and SMC. The industrial sector emissions were then estimated using fuel consumption, emissions factor, and APCD using the following equation:

$$Ep = Cf \times EF \times (1 - \eta)$$

Where Ep is the emission of pollutant p from industrial fuel consumption, EF is the emission factor of the fuel consumed, Cf is the fuel consumed in the industry, and η is the efficiency of the APCD installed in a particular industry.

Transportation

Transport sector emissions have been estimated using vehicle characteristics (VKT) and emission factors based on the vehicle characteristics approach. Data on vehicle characteristics (age, mileage, fuel efficiency) were obtained from traffic count and parking lot surveys at different locations in Surat. The following equation was used to estimate the tailpipe emission for the transport sector:

$$E_p = \sum_{c=1}^{n} \sum_{s=1}^{4} VKT_{c,s} \times EF_{c,s,p} \times \varepsilon_{c,s} \times n_c$$

Where Ep is the total emission of a pollutant (p), c is the category of the vehicle, s is the emission control norm (BSI to BSIV) and CNG penetration, VKT is the Vehicle Kilometer Traveled, EF is the emission factor of pollutant p, ε is the percentage of the vehicle under an emission control norm, and n is the total number of vehicles in category c.

The emissions factors for PM_{10}, $PM_{2.5}$, NOx, SOx, hydrocarbon, and CO are adopted primarily from the Automotive Research Association of India (ARAI, 2016). In addition, both VKT and ε are considered based on primary survey results analyzed from the traffic count survey and parking lot survey conducted for the SCAP project.

Road Dust Resuspension

Emissions from road dust re-suspension due to the movement of vehicles are calculated using United States Environmental Protection Agency (USEPA, AP-42) method. Dust emissions due to vehicle movement vary with the silt loading on the road surface and the average weight of the vehicles plying on the road. Therefore, 38 dust samples were collected from various roads in the study area as per the USEPA method and tested for their silt content. They were then converted into silt loading (g/m^2) and further used to estimate emissions from that sector. A portable vacuum cleaner was used to collect samples from a $1m^2$ area in the middle of the road. The filter bag of the vacuum cleaner was emptied and weighed before the sampling. Sampling material was collected only from the portion of the road over which the wheels and carriages travel routinely. PM emissions from the re-suspension of road dust due to the movement of vehicles on paved roads were calculated using the following equation:

$$[E_p]_t = \sum VKT_r \times k \times w^{1.02} \times Mo^{0.91}$$

Where [Ep]t is the fugitive emission of pollutant (p) from the transport sector, r is the type of road (arterial, sub-arterial and local), VKT is Vehicle Kilometer Travelled, k is the function of particle size (0.62 for PM_{10} and 0.15 for $PM_{2.5}$), w is the average weight of vehicle traveling on the road, and Mo is road surface silt (≤ 75 μm in physical diameter) loading in a unit area. The [Ep]t is directly proportional to the silt loading on the road surface and the average weight of the vehicles plying on the road. Therefore, 15% of the [Ep]t was considered $PM_{2.5}$, while 62% was considered PM_{10}.

For Surat, an average value of silt loading was estimated from samples collected from different categories of roads such as arterial, sub-arterial, and local roads. The VKT for Surat was estimated by using the method explained in the transport sector emission estimation. After estimating [Ep]t using the above equation, the effect of rainy days was considered to finalize the fugitive emission (f[Ep]t) from road dust re-suspension using the following equation:

$$f[E_p]_t=[E_p]_t\times(1-D_p)/(4\times365)$$

Where Dp is the number of rainy days in a year, and 112 days is considered rainy days in a year based on the meteorological conditions in Surat.

Household Cooking Sector

Data on access to cooking fuel by population, per capita cooking fuel use, and fuel-specific emission factor of different pollutants were used to estimate air pollution emissions. The following basic equation was used to estimate the emissions from the household cooking sector:

$$[E_p]_R = \quad op_{(a,f)} \times C_{(a,f)} \times EF_{(f,p)}$$

where [Ep]R is the emission of a particular pollutant (p) from the household cooking, Pop(a,f) is the population of Rural (a=1), and Urban (a=2) region in Surat district and Surat city using a particular type of fuel (f), C(a,f) is region-specific per capita consumption of a particular fuel, and EF(f,p) is emission factor of the particular pollutant (p) of the particular fuel type (f).

As most fuel access data is available for the year 2011, the projected population using different fuels were estimated using the following equation:

$$Pop_{2019} = Pop_{2011}[1 + R\%]^t$$

Where 〖Pop〗2019 is projected population of Surat City, 〖Pop〗2011 is the population of Surat City in 2011, R% is the district-specific population growth rate in rural and urban areas, and t is the period between 2011 and 2019.

Annual consumption of different fuels revealed that the residential households of Surat City using LPG for cooking had a higher consumption, at 167.05 kt/annum, followed by coal at 68.85 kt/annum and fuelwood at 66.28 kt/annum. **Table 2** lists the consumption of different fuels for Surat for the base year 2019.

Table 2: Consumption of different fuels (kt/Year) in residential households of Surat

Location	Fuelwood	Crop residue	Cow dung cake	Coal	Kerosene	Kerosene_ Lightening	LPG
City	59.75	6.41	0.79	71.00	5.39	0.04	167.06

Open Waste Burning

To estimate the air pollution emissions from waste, primary waste burning data were first collected by WRI in the primary survey using the survey method developed by Nagpure et al. (2015). The primary waste burning data were then used to estimate the emissions from waste burning by multiplying it with the emissions factor from Akagi et al. (2011) and Sharma et al. (2019). The following equation was used for emissions estimation from the open waste burning sector:

$$E_p = W_B \times E_f$$

Where Ep is the emission of pollutant p, WB is the quantity of waste burnt, and Ef is the emission factor.

Landfill emissions – Municipal Solid Waste Burning Sector

Emissions from landfills were estimated based on MSW generation, collection, treatment, and quantity of MSW on landfills. The MSW left untreated finally lands into open sites or landfills. TERI estimated the quantity of MSW on the landfill and assumed that 2% of dumped MSW was burnt every day in the Surat city. The following equation was used to estimate emissions from landfill MSW burning:

$$E_p = 2\% \times W_L \times E_f$$

Where Ep is the emission of pollutants p, WL is the waste collected at the landfill site, and Ef is the emission factor adopted from USEPA, AP-42.

Eateries

To estimate the emissions from hotels, restaurants, and informal and formal eateries, a primary survey was conducted by WRI and TERI to collect fuel consumption data. Data collected in the 12 grids of the Surat were extrapolated for other grids in the study domain based on population density and land-use patterns. The following equation was used to estimate emissions from hotels, restaurants, and eateries of Surat:

$$Ep = C_f \times E_f$$

Where Ep is the emission of pollutant p, Cf is the fuel consumption by the hotel/ restaurant, and Ef is the emission factor of different fuels used in cooking. Emission factors for different fuel types were collected based on a review of published literature.

Construction

To estimate the emissions from the construction sector, high-resolution images using GIS tools were used to identify different construction sites and areas of construction. With the digitization of the identified sites, polygons were created manually with the help of Google Earth's in-built tools. For map creation and post-processing for the polygons marked in Google Earth, ArcGIS software was used to estimate the study domains under construction or earmarked demolition areas. The following equation was used for emission estimation:

$$E_p = A_c \times T \times E_f$$

Where E is the suspended particulate emissions, AC is the area of construction, T is activity duration, i.e., time duration of construction or demolition for a site (Rainy Months (RM) not considered as activity duration, i.e., activity duration considered as (12 – RM), and EF is emission factor (tons/month/acre)). The particulate matter emissions from construction activities were estimated using an emission factor (1.2 tons/acre/month) (USEPA, 2019).

Other sectors – Aviation, Crematoria, Agriculture Activities, DG Sets, Thermal Power Stations, Brick Kilns

The emissions from aviation, crematoria, agriculture activities, DG sets, thermal power stations, and brick kilns sectors were assessed by TERI. The details of the methodology for each sector can be found in Source Apportionment Study for the Surat, Gujarat, by TERI (TERI, 2021). These sectors contributed approximately 1% emissions each of PM_{10}, $PM_{2.5}$, NOx, and CO. In comparison, the aviation sector contributed 5% of the SO2 emissions, and 4% of the NMVOC emissions share was from landfills, crematoria, and aircraft. The sectoral contribution of various pollutants is presented in **Figure 1**.

Total Emissions Estimations

The emission contribution of different sources based on emission inventory in the Surat City area is summarized in **Table 3**. The air pollution sources such as industry, transport, road dust resuspension, solid waste burning, DG Sets, residential cooking, eateries, landfills, construction, crematoria, and aircraft together contribute approximately 35.467 kt, 14.248 kt, 5.232 kt, 38.59 kt, and 139.568 kt of PM_{10}, $PM_{2.5}$, SO_2, NOx and CO emissions, respectively, in the Surat City.

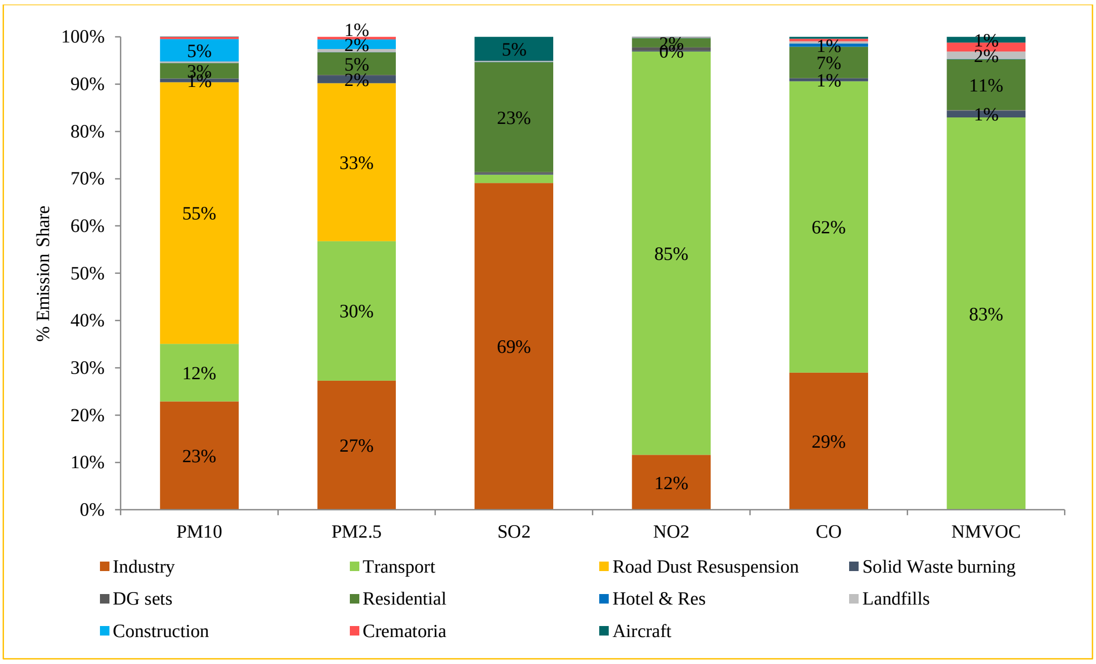
Table 3: Total Emissions from pollutants in the Surat City

Sector	Emissions (kt/year)				
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO
Industry	8.1	3.87	3.59	4.46	40.42
Transport	4.31	4.19	0.09	32.86	85.78
Road Dust Re-suspension	19.55	4.73	-	-	-
Solid Waste Burning	0.27	0.23	0.01	0.09	0.87
DG Sets	0.02	0.015	0.017	0.258	0.056
Residential Cooking	1.14	0.68	1.21	0.76	9.29
Eateries	0.111	0.073	0.042	0.072	1.14

Landfills	0.13	0.089	0.008	0.049	0.686
Construction	1.67	0.29	-	-	-
Crematoria	0.156	0.077	0.003	0.021	0.783
Aircraft	0.004	0.004	0.262	0.02	0.543
Total	**35.461**	**14.248**	**5.232**	**38.59**	**139.568**

Figure 1 shows emissions allocations to different sectors affecting the Surat City's air quality**.** It is evident from **Figure 1** that industries hold the major share of SO_2 and accounts for 69% of the total emissions, followed by the residential sector (23%). Similarly, NOx pollution is largely emitted from the transport sector, which shares 85% of the total NOx emissions, followed by a 12% share from industries. Transport holds a 62% share in the total CO emissions, and industries contribute about 29%. As per the emissions inventory data, road dust re-suspension accounts for a major proportion of PM_{10} and $PM_{2.5}$, followed by transport exhaust emissions and industries. Road dust re-suspension in the Surat City accounts for 55% of the total PM_{10} and 33% of the total $PM_{2.5}$. Transport exhaust emissions account for 12% PM_{10} and 30% $PM_{2.5}$, whereas industries account for 23% PM_{10} and 27% $PM_{2.5}$. NMVOC is mainly emitted by the residential sector (63%), followed by crematoria (11%) and landfills (9%). Apart from the transport sector, 29% of CO is emitted by industries and 7% from the residential sector. Construction activities share about 5% and 2% of the PM_{10} and $PM_{2.5}$ emissions, respectively. The aviation sector emits 5% SO_2 and 1% NMVOC. The transport sector emits 83% NMVOC.

Figure 1: Total Emissions in the Surat - Source wise percentage share



PROJECTION OF SECTORAL EMISSIONS (BUSINESS-AS-USUAL)

Scenario analysis for the future was carried out to understand how growth in different sectors would contribute to air pollution in the region. In this regard, possible future growth scenarios were prepared for 2025 and 2030. A business-as-usual (BAU) scenario was developed, which considered the growth trajectories in various sectors and the policies and interventions that have already been notified for air pollution control. To assess the potential of various strategies to control air pollution, interventions in different sectors were tested on the air quality model. Strategies that could provide significant air quality benefits were identified for constructing an alternative scenario (ALT) to reduce the air pollution towards meeting their prescribed National Ambient Air Quality Standards (NAAQS) for those by 2030.

Business-as-Usual Considerations for the Surat City

The BAU scenario depicts changes, both growth, and controls, taking place in different sectors, such as transportation, industries, domestic, open burning, crematoria, and restaurants up until the year 2030. This scenario does not account for any additional interventions to manage air quality, and the growth rates of different sectors have been adopted through a review of published literature. The growth rate in energy consumption in industries in Surat is projected to be 5.9%, as per the 2012 Surat solar city master plan of the Ministry of New and Renewable Energy, Government of India. The annual average growth rates of 6.33% and 1.82% in coal and gas in industries were also projected based on the Surat solar city master plan by the Ministry of New and Renewable Energy, Government of India, 2012. The hotels/restaurants sector is projected to grow at a rate of 11.2% in 2025 and 2030, on the basis of the growth rate of district gross domestic product (GDP) of hotels and restaurants in Gujarat during the last five years (India Statistical Handbook, 2020). However, for small unorganized eateries, a growth rate of 7% was projected (FICCI, 2017). In the crematoria sector, based on previous trends in the crude death rate of Surat City for the last five years, the crude death rate for the urban population is estimated to be 4.14 per 1,000 inhabitants by 2030. For the rural population, the crude death rate is estimated based on previous trends in the crude death rate of the rural population for Gujarat state (Census of India, 2001 and 2011). It is estimated as 6.1 per 1,000 inhabitants by 2030. As power cuts are already rare in Surat City and are projected to be negligible by 2025 (as Surat is one of the Smart cities in India), it is projected that there will be no usage of DG sets in 2025 and 2030. Based on the GDP of construction activities in Gujarat during the year 2011-2018, the compound annual growth rate of this sector is projected to be 3.07% (RBI handbook, 2019) for both 2025 and 2030.

Different vehicle registration growth rates in the transport sector are obtained from the statistical yearbook for the road transport sector (MoRTH, 2019). Accordingly, the vehicular sector is projected to grow at 7% up until 2025 and at a rate of 4% post-2025. Furthermore, as notified, BS-VI emission norms are to be effective from 2020.

In the domestic sector, a population growth rate of 4.93% per annum has been projected for 2025 and 2030, based on the decadal growth rate of population in Surat as per census data (Census of India, 2001 2011). The annual growth rate of domestic LPG connections in Surat was estimated at 3.75%. The annual PNG growth rate in Surat was estimated at 7.65%, following the Ministry of New and Renewable Energy (MNRE, 2014). The annual growth rate of kerosene for cooking was estimated at -6.5% (a decline). It is also expected that kerosene will cease to be used for lighting purposes in Surat by 2025 and 2030. A 2% growth rate is projected for electricity use for cooking purposes. Simultaneously, the number of fuelwood and kerosene-consuming households would fall by 5.75%. The number of crop residue, dung cake, and coal-consuming households is projected to fall by 1.25% annually by distributing the 3.75% annual growth rate of LPG-consuming households among the three fuels equally. The brick kiln sector is expected to grow at 7.5% annually based on the Centre for Science and Environment data (2017). It is expected that no new coal-based power plants will be installed in the district for the power sector, and accordingly, no growth in emissions in power plants has been projected for 2025 and 2030. In the aviation sector, the number of flights from Surat airport is projected to increase due to increased passenger counts for various national and international destinations. Based on the data from 2015 to 2019 and the growth trends in the number of flights, the annual growth rate for the aviation sector is projected to be 9.46% for 2025 and 2030. Based on the trends in waste disposed at landfills in Surat during 2012-19 (SMC, 2021), an 8% increase is projected in the disposal of waste at the landfill site both for 2025 and 2030. For the refuse sector, the Surat's population growth rate of 4.93% per annum is projected for both 2025 and 2030. Also, according to the SMC database, the per capita waste generation and collection efficiency in the Surat city during 2019 was reported as 0.45 kg/day and 97.7%, respectively. The quantity of non-biodegradable waste generated in Surat was reported as 35% in the same year. Therefore, similar projections have been made for the emissions from this sector for 2025 and 2030.

The growth rates adopted for projections of various sectors under the BAU scenario are summarized in **Table 4**. The BAU scenario has been developed based on the growth rates under various sectors, and emission loads for different pollutants like PM_{10}, $PM_{2.5}$, SO_2, and NOX have been estimated.

Table 4: Growth rate adopted for various sectors under BAU scenario.

Sector	Growth rate	Reasoning	Controls assumed
Transport/ Road Dust	7% growth rate up to 2025, after that 4%	Based on the past trends of different types of vehicle registrations in Surat (MoRTH, 2019)	BSVI norms from 2020 No further control for road dust
Crematoria	The crude death rate for the rural population is 6.1% in both 2025 and 2030, and for the urban population, 4.14% in both 2025 and 2030	Based on past trends of the crude death rate of Gujarat state in India Census (2001,2011)	No further control
Restaurants	11.2% in both 2025 and 2030 and for unorganized eateries, 7% in both 2025 and 2030	Based on the growth rate of gross district domestic product of hotels and restaurants in Gujarat during the last 5 years and for unorganized sector FICCI report, 2017	No further control
DG sets	No DG sets in 2025 and 2030	DG set usage is presently very low and is expected to further decline with improvement in the power situation.	
Construction	3.07% for both 2025 and 2030	Based on the gross domestic product of construction activities in Gujarat during the year 2011-2018. RBI Handbook, 2019	No further control
Industries	5.9% for other fuels, 6.33% for coal, and 1.82% for Natural gas in both 2025 and 2030	Based on the growth rate in energy consumption in industries in Surat as per the Surat solar city	No further control

		master plan by the Ministry of New and Renewable Energy	
Domestic	The annual population growth rate of 4.93% in 2025 and LPG penetration will increase at the rate of 3.75% in Surat and annual PNG growth rate of 7.65 % in both 2025 and 2030	Based on the decadal growth rate of population in Surat as per census data 2030 (India Census 2001, 2011) MNRE report 2014	100% LPG penetration by 2030
Brick kiln	The annual growth rate of 7.5% for both 2025 and 2030	Based on Rajaratnam et al. 2014 & Presentation by J. S. Kimora (Director, CPCB) in Anil Agarwal Dialogue 2015, CSE & Surat action plan	50% kilns will be converted into Induced draught in 2025, and 100% kilns will be converted into Induced draught in 2030
Power plants	Same as in 2019 for both 2025 and 2030	No new power plants will be installed in the district and hence not projected to grow any further in future	100% implementation of Power Plant emission norms by 2025
Aviation	The annual growth rate of 9.46% in both 2025 and 2030	Based on the annual growth rate in the number of flights during the last 5 years as per Airport Authority of India statistics	No further control
Landfill	The annual growth rate of 8% for both 2025 and 2030	Based on the past years (2012-2019) trend in waste disposed at landfills in Surat.	No further control

Source: Source Apportionment Study and Preparation of Air Quality Action Plan for Surat City, TERI, New Delhi (TERI, 2021).

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