Air pollution is a big concern in a city like Delhi where more than 16 million people are exposed to severely high pollutant concentrations on an annual average basis. It is in this regard that the Government of Delhi introduced Odd-Even scheme in which plying of privately owned cars was restricted on alternate days based on the last digit (odd/even) of the registration number. However, there were exemptions to the cars under certain categories. The first phase of the scheme was launched in January 2016 and thereafter it was re-introduced from 15–30 April 2016. TERI analysed the effectiveness of the scheme in reducing air pollution and also congestion in Delhi.

Traffic and congestion
During Odd-Even phase-II, TERI carried out traffic counts at six locations—Ghaziapur border, DND Noida, Gurgaon border, Shankar Road, Ring Road (Hyatt Hotel), and BSZ Marg. The counts were carried out between 7 am to 11 pm on 11/04/2016, 14/04/2016, 18/04/2016, 21/04/2016, 25/04/2016, and 02/05/2016, on Mondays and Thursdays, during, before, and after the Odd-Even scheme period. The counts show that between 8 am to 8 pm the numbers of cars were reduced by 17 per cent. However, during 7 am to 11 pm the cars were reduced by 11 per cent only. In phase-I of the Odd-Even scheme, car counts on Vikas Marg were 21 per cent lower during operation of the scheme between 8 am to 8 pm.

Average speeds of cars were monitored using a GPS device on 13/04/2016, 21/04/2016, 28/04/2016, and 05/05/2016, on a selected route, traversing through a total distance of about 90 km. The route was planned to cover different parts of the city in north, west, south, and east directions. An increase of 13% was observed in the average speeds of cars. In phase-I of the Odd-Even scheme, an increase of 17% in car speeds was registered.

In comparison to phase-I of the Odd-Even scheme, lower reductions in cars and lesser increase in speeds have been observed in the second phase (Figure 1). This could be probably due to people opting for second cars with alternative number plates, CNG kit installations or enhanced use of taxis.

![Figure 1 Percentage reduction in cars and percentage increase in speeds during the two phases of odd-even scheme](image-url)
Air quality analysis
TERI carried out an analysis of air quality in Delhi and nearby towns, based on monitoring stations shown in Table 1.

<table>
<thead>
<tr>
<th>Station</th>
<th>Type</th>
<th>Parameters</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahadurgarh</td>
<td>Upwind of Delhi</td>
<td>PM10, PM2.5, NO2</td>
<td>TERI</td>
</tr>
<tr>
<td>Anand Vihar</td>
<td>Delhi</td>
<td>PM10, PM2.5, NO2</td>
<td>DPCC</td>
</tr>
<tr>
<td>RK Puram</td>
<td>Delhi</td>
<td>PM10, PM2.5, NO2</td>
<td>DPCC</td>
</tr>
<tr>
<td>Punjabi Bagh</td>
<td>Delhi</td>
<td>PM10, PM2.5, NO2</td>
<td>DPCC</td>
</tr>
<tr>
<td>Mandir Marg</td>
<td>Delhi</td>
<td>PM10, PM2.5, NO2</td>
<td>DPCC</td>
</tr>
<tr>
<td>Lodhi Road</td>
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<td>TERI</td>
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<tr>
<td>Ghaziabad</td>
<td>Downwind of Delhi</td>
<td>PM2.5, NO2</td>
<td>TERI</td>
</tr>
<tr>
<td>Gurgaon</td>
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<td>Noida</td>
<td>Downwind of Delhi</td>
<td>PM2.5, NO2</td>
<td>TERI</td>
</tr>
</tbody>
</table>

The 24-hourly data was collected and analysed for the period between April 4, 2016, to May 6, 2016, accounting for both odd-even and non odd-even days in between. The air quality trends for different locations is attached in Annexure-I.

During phase-II of the Odd-Even scheme, the averaged PM2.5 concentrations at 5 locations in Delhi were 1.4–4.3 times higher than prescribed 24-hourly standard. NO2 concentrations were 0.6–1.36 times the prescribed standard, while PM10 levels were 1.8–4.0 times above the prescribed standard. It is to be noted that the average concentrations of the pollutants were lower in summers (Phase-II) than in winters (Phase-I), during the Odd-Even scheme.

The 24-hourly PM2.5, PM10, and NOx concentrations during the odd-even period were higher than in the non odd-even periods (just before and after the odd-even scheme). During Odd-Even phase-I (January, 2016), there was an increase of 25%, 22%, and 27% in PM2.5, PM10, and NOx concentrations, respectively. In odd-even phase-II, the increase was 39%, 26%, and 25%, respectively.

The main reasons for the increase were meteorological factors and background influences. During both the Odd-Even scheme periods, lower wind speeds and mixing height values led to relatively lesser dispersion of the pollutants, leading to higher concentrations. In phase-II (April, 2016), the monitoring station established by TERI at the outskirts of Bahadurgarh (in the upwind direction of Delhi) showed the influences of outside sources to the air pollutant levels in Delhi. Higher background concentrations were detected at the station during the Odd-Even scheme, especially during the second week (23 April–1 May).

To ascertain the effect of the Odd-Even scheme on PM2.5 concentrations, a box model was applied. The model was used to delineate the effect of odd-even scheme from daily changes in air quality due to meteorological factors like wind speeds and mixing height. The model estimates showed that the Odd-Even scheme in Phase-II led to a reduction of 4% in 24-hourly PM2.5 concentrations, largely because of the fewer number of cars on road as shown in Figure 1. In other words, the concentrations could have been 4% higher than those observed in absence of the Odd-Even scheme. It may be noted that vehicular sources account for at most 25% of PM2.5 concentrations in Delhi (as per the source apportionment study by IIT-Kanpur); cars alone account for 10% of the vehicular
emissions. The 4% decrease in PM2.5 attributable to a 17% decrease in car numbers is because the lower number of cars on the roads also reduce idling emissions from other category of vehicles (2-wheelers and buses), and reduce the amount of road dust re-suspension.

This reduction in Odd-Even phase-II is lower than 7% reduction, which was estimated during phase-I of the Odd-Even scheme. The coefficient of variation which depicts the general variation of PM2.5 concentration during the study period (4th April to 6th May 2016) was 42%. This variation is a result of daily changes in local emissions, meteorology and background concentrations (influences from outside Delhi). The reduction achieved from Odd-Even scheme seems too small (~4%) to be captured, among the other more dominating factors (Figure 2).

![Figure 2 Percentage change in daily PM2.5 concentrations with respect to the mean value of the whole period of analysis](image)

The absolute reduction in PM2.5 concentrations due to the Odd-Even scheme is estimated to be ~5 µg/m³ in summers. In winters, due to higher ambient PM2.5 concentrations, the absolute reduction was much higher (~20 µg/m³) due to the Odd-Even scheme.

Inferences and way forward

The Odd-Even scheme is a step taken by the government to curtail air pollutant levels in Delhi which are significantly high, on an annual average basis, especially in winters. To its credit, the scheme has made a significant impact on public awareness levels in the city on the issues of air pollution and its impacts on human health. Moreover, there was a positive impact on number of cars on the road and on the speed of travel. However, a decline in impact in both of these parameters has been observed in the second phase in comparison to the first phase. As mentioned earlier, this decline is probably due to people opting for second cars with alternative number plates CNG kit installations or enhanced use of taxis.
On the air quality front, the Odd-Even scheme has provided limited benefits. This is because as discussed earlier that the share of private cars is small in the PM2.5 levels in Delhi (source apportionment study, IIT-K), and consequently, only marginal reductions could be achieved through the Odd-Even scheme. In winters, the Odd-Even experiment led to a ~7% reduction in 24-hourly PM2.5 concentrations; however, in summers, when the pollution levels are relatively lower and the share of vehicular sources is lower too, the impact of the scheme is further reduced.

The analysis of the two phases of the scheme suggests that regularizing this scheme can reduce its impact. As in the case of other cities in the world that have tried out the Odd-Even scheme in the past, people could look for alternatives by purchasing new/old cars or motor bikes, which would, over a period of time, neutralise and negate the positive impacts. This is likely to happen as the public transportation system is not reliable and attractive enough to encourage the car users to shift to public transport. Hence, the odd-even scheme should be used only as an emergency measure when the pollution levels are expected to be very high, such as in winters. Regularizing it or its frequent use may only reduce its impacts, unless public transportation is improved and sales of alternative vehicles are checked.

Other measures to control congestion and related pollution

Odd-Even scheme should be considered as a step forward in the direction of air pollution control. However, it is time now to step up and introduce further controls so that air quality in the city can be effectively improved. As an alternative to the Odd-Even scheme, ‘congestion pricing’ can be introduced which is based on ‘pay as you use’ principle. Congestion pricing aims to reduce number of vehicles to encourage modal shift by charging vehicles on entry in restricted zones/times. This can be complemented by providing exemptions to higher occupancy vehicles. This strategy has been used successfully in cities such as Singapore, London, Sweden, Rome, Durham, Seoul, San Diego, etc. It is consistent with economic principles for attaining economic efficiency, but could be considered iniquitous, since the rich would obviously be better placed to buy permits. The equity concern may be taken care of by carefully setting up the congestion charges and earmarking the revenues from congestion pricing for providing mass transport options in these zones as a public responsibility. It may also be noted that car users in general are much richer than the non-car users and should pay for the additional pollution caused due to their car use. Congestion charges can be applied to more categories of vehicles and may not be restricted to only one category (like cars in the present Odd-Even system). This can certainly lead to much higher reduction in congestion and pollution levels in the city. It is expected that through congestion pricing, public transport will improve and attract more people as there will be a clear discouragement to use private vehicles. Contrary to the Odd-even scheme, the congestion pricing scheme can work throughout the year and provide year-long benefits of lower congestion and pollution levels and savings on fuel. The congestion pricing scheme can be tried out in different ways, including a) all across congestion pricing; b) identification of low emission zones; 3) road-wise congestion pricing, etc. To start with, low emission zones can be identified and the commuters plying with lower occupancies can be made to pay congestion prices. Electronic automatic systems will need to be in place to implement congestion charges and public acceptance will need to be built, which has already been initiated due to the
appreciation for reduced congestion during the Odd-Even scheme period. With the congestion pricing scheme, public transport needs to be improved immensely.

Road map to achieve air quality standards in Delhi-NCR
The recent source apportionment study has pointed out several important sources contributing significantly to the pollution in Delhi. On the one hand, there are sources within the city limits which almost immediately impact the residents; on the other hand pollution is also transported towards Delhi from the outside regions. The in-house sources include vehicles both private (two-wheelers and cars), and commercial vehicles like auto-rickshaws, buses, trucks, etc. Trucks which ply in Delhi are still of BS-III standards, despite the fact that Delhi has moved to BS-IV vehicular standards. While industries have been moved out of Delhi, they still run and use coal outside the city limits in the districts of Panipat, Rohtak, Faridabad, Ghaziabad, Gurgaon, Gautam Budh Nagar, etc. There are coal-based power plants in NCR, which use low-grade coal and contribute significantly to the emissions. Several residential apartments and shopping malls have opened up in the surrounding towns of Delhi, which use diesel generator sets to combat frequent power cuts and hence, contribute to pollution. Agricultural residues are burnt in specific seasons, which contribute to increase in background concentrations entering the city of Delhi and affecting its quality. Burning of refuse is another activity which adds significantly to the pollution load and needs to be controlled.

Conclusively, there are several measures that need to be taken for improvement in air quality in Delhi and nearby regions, which include:

a) Immediate measures
- Congestion pricing
- Ensuring earliest possible introduction of BS-VI vehicle and fuel quality norms
- Real-time continuous monitoring and reporting of industrial stacks
- Enhanced LPG penetration in NCR
- Complete ban on refuse burning and use of technology for reporting of violations

b) Medium term measures
- Strengthening of existing I&M system, retrofitment (with tail-pipe diesel filters) of old vehicles and fleet modernization schemes
- Enhancement of public transportation systems and non-motorised options
- Enhancement of E-mobility and demand control measures
- Maintenance of stack emission control devices
- Exploring industrial emission trading schemes and fiscal measures
- Standards for NOx and other important pollutants for industrial establishments
- Ensuring 24x7 power supply in NCR to cut down the DG set use
- Business model for waste to energy conversion of agricultural wastes using biomass gasification technologies
c) Research and planning

- Regular source apportionment studies to ascertain the changing contribution of different sources in pollution to take specific actions
- Strengthen monitoring networks, reporting and development, and maintenance of database of emission inventories.
- Enhance capacities of air quality simulation and future predictions.
- Comprehensive air quality management plan for whole NCR consisting of strategies for air pollution control in different sectors. These plans should be based on scientific studies and will need to be updated every 3–5 years, in a rapidly changing scenario as in the NCR.
- Based on the plans, air quality targets needs to be defined for each year and strategies are to be enforced to achieve them.

Acknowledgements
We acknowledge the data received from DPCC (Delhi Pollution Control Committee) and CPCB (Central Pollution Control Board) websites for air quality analysis. We especially thank Dr D. Saha and Mr A. Pathak from CPCB for providing mixing height information. We thank TERI colleagues for important discussions and inputs during the analysis.
Annexure-I  Air quality trends in Delhi during Odd-Even scheme phase-II