Where and when do electric vehicles have the largest environmental benefit?

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Abstract

Electric vehicles have the important advantage that pollution resulting from energy conversion is not emitted in the same place where the vehicle is driven. Given that urban PM10 concentrations often overshoot European air quality targets, it may be a good idea to keep these emissions away from busy and populated areas.

In this paper we take this concept one step further by looking at the time when pollutants are emitted. When electric energy can be locally stored, it can be used whenever it is most useful, not just from a technical but also from an urban air quality perspective.

Specific types of vehicles are preferentially used outside rush hours and the timing of specific activities (e.g. collecting garbage or deliveries to urban shops) is adjusted to avoid congestion. We demonstrate that shifting the emission of pollutants to the late evening or early morning, when the atmosphere is relatively more stable can cause an unwanted increase in air pollution even when emissions are constant.

Electric vehicles can therefore be much more efficient in reducing environmental impacts at night, when impacts of both noise and air pollution are much more important, but electricity is cheap. The environmental benefits of electric driving is much more important at night than during daytime. From an environmental perspective vehicles that are predominantly operated before sunset or after sunrise should preferentially be substituted by electric or hybrid versions.

Keywords: pollution, emissions, environment, modeling, efficiency

1 Introduction

Many densely populated regions in the world face severe air pollution and congestion problems due to the fast growth of road transport. A popular idea to reduce congestion is to spread traffic more evenly over the day. Specific policy measures nowadays ban goods vehicles from the rush hours or even promote driving at night.

Avoiding congestion is beneficial because of the reduction of time losses from private cars and trucks queuing during the day. In addition congestion dramatically increases the amount of exhaust emissions contributing to air pollution. Avoiding congestion is therefore widely seen as an environmental benefit. On the other hand it is evident that people driving outside rush hours or even at night, obviously have negative impacts related to noise exposure and possibly accidents. Unfortunately the environmental external costs are not explicitly taken into account in the decision process because they are implicitly assumed to be much lower than the external congestion costs.

In the forthcoming discussion on road pricing in the Benelux countries it is important to have good estimates for both external congestion costs and environmental externalities disaggregated by time of day at the same resolution. This would in general increase the relevance and environmental performance of electric vehicles.

2 Objectives

In this paper we discuss the results of a simple modelling scheme to demonstrate that changing the intra-day timing of traffic also has effects on the dispersion of the exhaust gases. Shifting the emission of pollutants to the late evening or early morning, when the atmosphere is relatively more stable can cause an unwanted increase in air pollution even when emissions are constant. Such an effect is easy to demonstrate, but has been overlooked by researchers because the focus of most studies has been either on episodes of severe air pollution or on estimating the annual average concentrations for exposure and analysis of health effects. Up to now no specific environmental external costs for different hours of the day have been published.

These figures are highly relevant to the evaluation of environmental benefits. Especially the evaluation of electric and hybrid vehicles should take into account that the local benefits before sunrise and after sunset are much higher than what can be deduced from widely available annual averages.

3 Methodology

3.1 1D Gaussian dispersion model

Using a simple 1-dimensional Gaussian plume model, we studied the effect of shifting the timing of the emissions from day to night. Equation (1) was applied [1].

$$C(x,y,z) = \frac{10^6}{3600.2\pi}.\frac{Q}{u_h\sigma_y\sigma_z}.\exp\left[\frac{-y^2}{2\sigma_y^2}\right]\left[\exp\left[\frac{-(z-h)^2}{2\sigma_z^2}\right]+\exp\left[\frac{-(z+h)^2}{2\sigma_z^2}\right]\right]$$

x,y,z (in m) are the Cartesian coordinates that indicate the location where the concentration is estimated, in the direction of dispersion (x), horizontal (y) and vertical (z) to the dispersion direction

C(x,y,z) (in mg/m^3) is the mass concentration of the air pollutant at the coordinates x, y, z

Q (in kg/h) is the emission mass stream from the emission source

z (in m) is the height above the ground where the concentration is calculated

h (in m) is the actual height of the exhaust pipe

σ_y, σ_z (in m) are the horizontal and vertical dispersion parameters

u_h (in m/s) is the wind speed

This simple model is valid for the calculation of concentrations when chemical transformation can be ignored and local deposition velocities are small. Both these conditions are met for the dispersion of fine particles under generalized local conditions. Our aim is to estimate effects of emissions on concentrations at short distances from the emission source, which are typical for fine PM and gaseous pollution associated with road transport.

3.2 10 minute meteo data

In this study we have used high resolution meteorological data on a 10 minute basis for an entire year. Information about wind speed, wind direction and temperature was provided for different measuring heights at a measuring point in the city of Mol. Every 10 minute the stability of the meteorological situation was determined based on wind speed and temperature information and a stability class was determined for every 10-minute record, ranging from 1 (= very stable situation) to 7 (= very unstable situation). Based on this information, the dispersion parameters (see equation above) could be calculated as:

$\sigma_y = A.x^a$ and $\sigma_z = B.x^b$

with x: distance from the source (in m)

The coefficients A and B and the exponents a and b in these equations are subject to the stability class and derived from the following Table 1.

Table 1: Coefficients and exponents to calculate dispersion parameters (Vlarem II, 2005)

Stability class	Description	A	a	B	b
E1	Very stable	0.235	0.796	0.311	0.711
E2	Stable	0.297	0.796	0.382	0.711
E3	Neutral	0.418	0.796	0.520	0.711
E4	Slightly unstable	0.586	0.796	0.700	0.711
E5	Unstable	0.826	0.796	0.950	0.711
E6	Very unstable	0.946	0.796	1.321	0.711
E7	High wind speed	1.043	0.698	0.819	0.669

4 Results

4.1 Emission estimates

Wind speed and atmospheric stability classes at 10 minute time resolution were used to calculate the effect of emissions on pollutant concentrations at different distances from the road. A generic line source with a constant emission strength of 1 kg/hour was used. This emission is constant and may represent any particular or gaseous non-reactive pollutant over short distances. We have derived concentrations for receptor points at a distance of 10 meters, 100 meters and 1 km from the emission source. The general result is presented in Figure 1. Concentrations given in µg/m^3 for a generic pollutant.

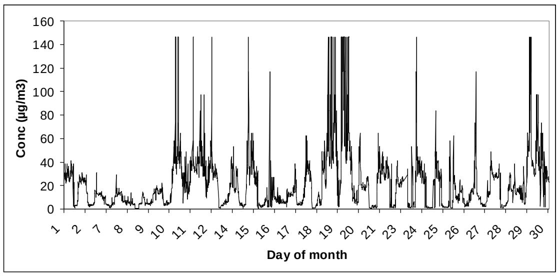

Figure 1: Predicted concentrations for a receptor at a distance of 100 meters from the source (based on a continuous emission source strength and 1 month of high resolution meteo data, April 2005

Obviously meteorological conditions are very prone to changes and the differences in concentrations resulting from a constant emission source is about an order of magnitude. We have therefore averaged the time-series to obtain a mean concentration for each 10 minute interval of a twenty-four hours' period (based on 30 results, 1 for each day of the month). An example of the results is shown in Figure 2 using meteo data for the month of April.

It is clear that a constant source of emission causes concentrations that are higher at night than during the day for the same receptor. The effect is most pronounced at short distances from the road. At a distance of 10 meters, local concentrations will be up to four times higher during the night than during the day although the emissions are the same (e.g. assuming equal speed and traffic dynamics). A distance of 10 meters is a typical distance between the center of a major road and the facades of buildings around it.

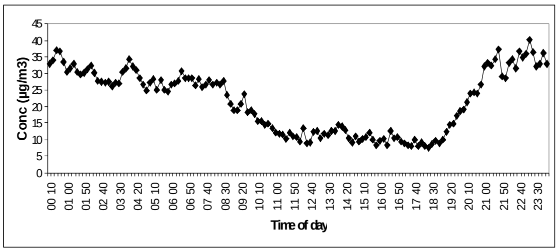

Figure 2: Average concentration for all 10-minute intervals (meteo data for April 2005, constant emission source at a distance of 100 meter).

At a distance of 100 meter from the road average night time concentrations equaled 30 µg/m3 (21:00h-8:30h). Concentrations resulting from the same emissions source (constant strength of 1 kg per hour) are only about 10 µg/m3 during the afternoon (12:00h – 18:00h).

The resulting concentrations at a distance of 1000 meters are an order of magnitude smaller. Hence any relative difference in concentration will be negligible in absolute concentrations. These results are therefore more useful for urban traffic then for highway driving.

4.2 Seasonal effects

We have repeated calculations for different months of the year, as far as high resolution meteorological data was available in the correct format. Because of the importance of average wind speed and atmospheric stability on the results, we show the results for the months of January and April, for receptor points at a distance of 10 meters (Figure 3). Differences between daytime and nighttime concentrations are clearly more distinct in April than in January.

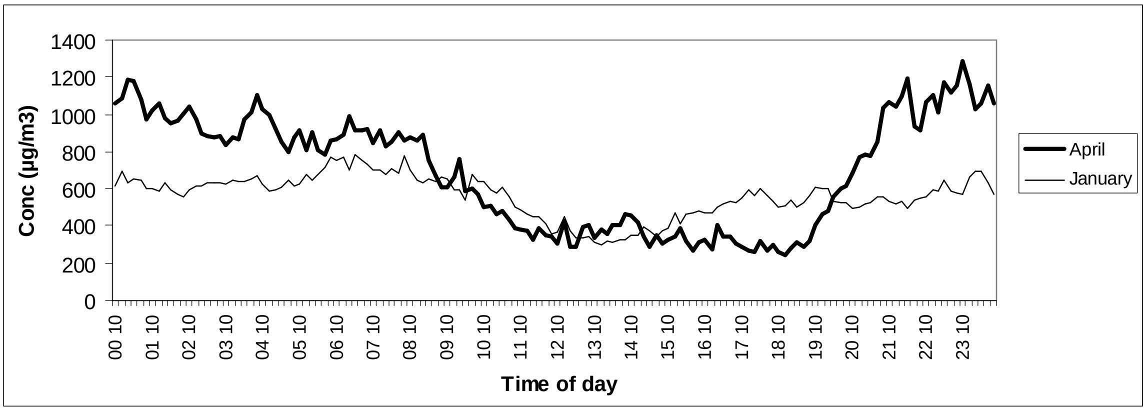

Figure 3: Average concentration for all 10-minute intervals (meteo data for January 2006 and April 2005, constant emission source at a distance of 10 meter).

5 Discussion

In this paper we demonstrate that identical emissions will cause local effects on air quality that are higher at night than during the day. The magnitude of the difference is a factor of about three.

At first glance this result seems strange because anyone familiar with air quality measurements and time series knows that concentrations of primary pollutants are far lower at night than during the day (see Figure 1). Peaks are usually seen during peak hours and concentration time-series follow the general daily pattern of the traffic flows, especially when measuring near busy roads.

In this study we have deliberately discarded the effect of changing traffic volumes to focus on the characteristics of local dispersion. We have taken this approach because we are interested in the marginal effect of one unit of pollutant emitted at different times during the day.

Our results can easily be explained by differences in average wind speed and atmospheric stability at different times of the day. Meteorological conditions certainly appear quite random, but on average, there are important differences. Average wind speeds follow the same general pattern as the concentrations data during 10 minute time intervals, corresponding to the concentrations shown in Figure 2. Lower wind speeds at night result in higher concentrations whereas higher wind speeds (more likely during the day) dilute concentrations. In January variations in wind speed are rather small compared to the wind speed variability in April, resulting in more concentration variability in April.

We cannot possibly capture the whole phenomenon of atmospheric dispersion in one model and some comments or objections to our simplified approach can be made. Emissions (even from the same vehicle) may well be different because of different speeds or different driving behaviour (e.g. less congestion) during the night. We have also neglected the possible effects of lower night time temperatures on the engines and differences in the use of headlights, heating and air-conditioning. But keeping the emission strength constant allowed us to focus on the diurnal changes in local dispersion.

On the other hand we may even have underestimated the effect because the highest concentrations are likely to occur during calm episodes with no wind at all. Unfortunately the dispersion under such conditions cannot be modeled with a Gaussian dispersion model.

The result presented in this paper has important implications for air quality and transport policy. PM air quality targets prove very hard to comply with in areas affected by residential ribbon development. It has been shown that PM concentrations in 2010 will not meet air quality standards in many urban areas in Europe and in the vicinity of important roads. Our results imply that the exposure of people from an identical amount of pollution is higher if this amount is emitted at night, which could have important implications for health impact assessments. One could argue that people are more likely to be indoors at night, but people only spend a fraction of their time outdoors during the day as well. Gaseous pollutants and the finest primary combustion particles readily enter modern houses. Although the exact indoor/outdoor ratio depends on a number of factors such as ventilation rates, the concentrations in the house typically follow outdoor concentrations [2]. Activity levels (sleeping, resting, working, driving, …) could be an important modifier.

If a policy causes a change or a spontaneous shift occurs in the timing of road transport emissions from day to night, this may likely offset whatever benefits are gained from improved traffic flows. The unexpected magnitude of this difference in dispersion dwarfs recent improvements in

European PM emissions standards for heavy duty vehicles and the effect is also large enough to offset remaining differences in PM emissions between advanced diesel cars and petrol fueled cars [3].

In addition our results also highlight the fact that annual average impacts (e.g. annual exposure of urban populations routinely used for health impact assessment) may hide important seasonal differences between summer months when days are long and winter time. In winter, both rush hours occur either before sunrise or after sunset and impacts on air quality may be different. Such aspects need to be studied in much more detail before the environmental consequences of specific transport policy measures can be assessed. At this point we can only speculate what the impact of this effect is for the exposure of people living near busy roads. In many countries a significant fraction of the population lives next to a busy road and distances of 10 meter between the central axis of the road and the facades of the houses are common.

Passenger cars, delivery vans and lorries frequently drive at night (before sunrise or after sunset). The most recognized inconvenient effect is noise exposure and a significant fraction of the urban population complains about excessive noise levels caused by (urban) road traffic. In this study we add air pollution as a second factor that is more important at night than during the day.

There are several policy options (technical and traffic management) that can help solve these environmental concerns. In some German regions stricter speed limits apply at night to combat noise exposure and these will have a similar effect on emissions of e.g. PM10 and NO_x.
Another option is to allow trucks to load/unload at night but restrict driving to motorways. This would reduce emissions resulting from motorway congestion while preventing a disproportionate increase in urban concentrations.

In urban areas much more attention should be given to electric or hybrid vehicles. Their benefits for air pollution may have been underestimated because traditional travel demand models mainly focus on peak hour information. This implies that only peak emissions and concentrations can be modeled accurately. To overcome this problem standard distributions of traffic intensity over the day are generally used, although new travel demand models have been developed to obtain hourly trip information.

In some cases vehicles do not follow the general daily traffic pattern. This is the case for e.g. delivery vans and small trucks that are used to deliver goods to stores in cities and e.g. trucks used for garbage collection, street cleaning etc.. These vehicles are often used at night, experience dynamic loads on the engine and hence they have a proportionally larger environmental impact. Based on the results presented here, these are the vehicles that should be targeted by local policy makers and be replaced by electric vehicles. Likewise plug-in hybrid electric vehicles could be loaded at night and operated fully on electricity in the early morning hours even though the capacity is not sufficient to last all day.

Gasoline fueled motorcycles and especially mopeds are among the worst polluting vehicles both for air and noise pollution. Electric versions are available and electrically assisted bicycles have recently become popular. Infrastructure planning should favor them by providing safe conditions to drive after dark

6 Conclusions

The time of day at which a specific emission takes place is very important for its impact on local air quality and exposure.

Environmental impacts of exhaust emissions may be up to 3 or 4 times higher after sunset and before sunrise than during the day.

The diurnal effect may be stronger in summer than in winter.

Environmental benefits of replacing conventional vehicles by electric and hybrid versions are much higher at night than during the day.

The intention to increase night-time traffic (emissions) should be weighed against the negative effect on air quality and noise or compensated by increasing the number of electric vehicles in the fleet, especially in urban areas.

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References

[1] Vlarem II (Flemish environmental legislation) *Bijlagen bij het besluit van de Vlaamse regering van 1 juni 1995 houdende algemene en sectorale bepalingen inzake milieuhygiëne.* Gecoördinated version 31 august 2005, 75-80 (in Dutch)

[2] Q.Y. Meng, B.J. Turpin, J.H. Lee, A. Polidori, C.P. Weisel, M. Morandi, S. Colome, J. Zhang, T. Stock, A. Winer *How does infiltration behaviour modify the composition of ambient PM2.5 in indoor spaces? An analysis of RIOPA data,* Environ. Sci. Techn., 41 (2007) 7315-7321.

[3] L. Int Panis, L. De Nocker, I. De Vlieger, R. Torfs (2001) *Trends and uncertainty in air pollution impacts and external costs of Belgian passenger car traffic,* International Journal of Vehicle Design, 27 (1-4)(2001), 183-194

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