New Directions: From biofuels to wood stoves: the modern and ancient air quality challenges in the megacity of São Paulo

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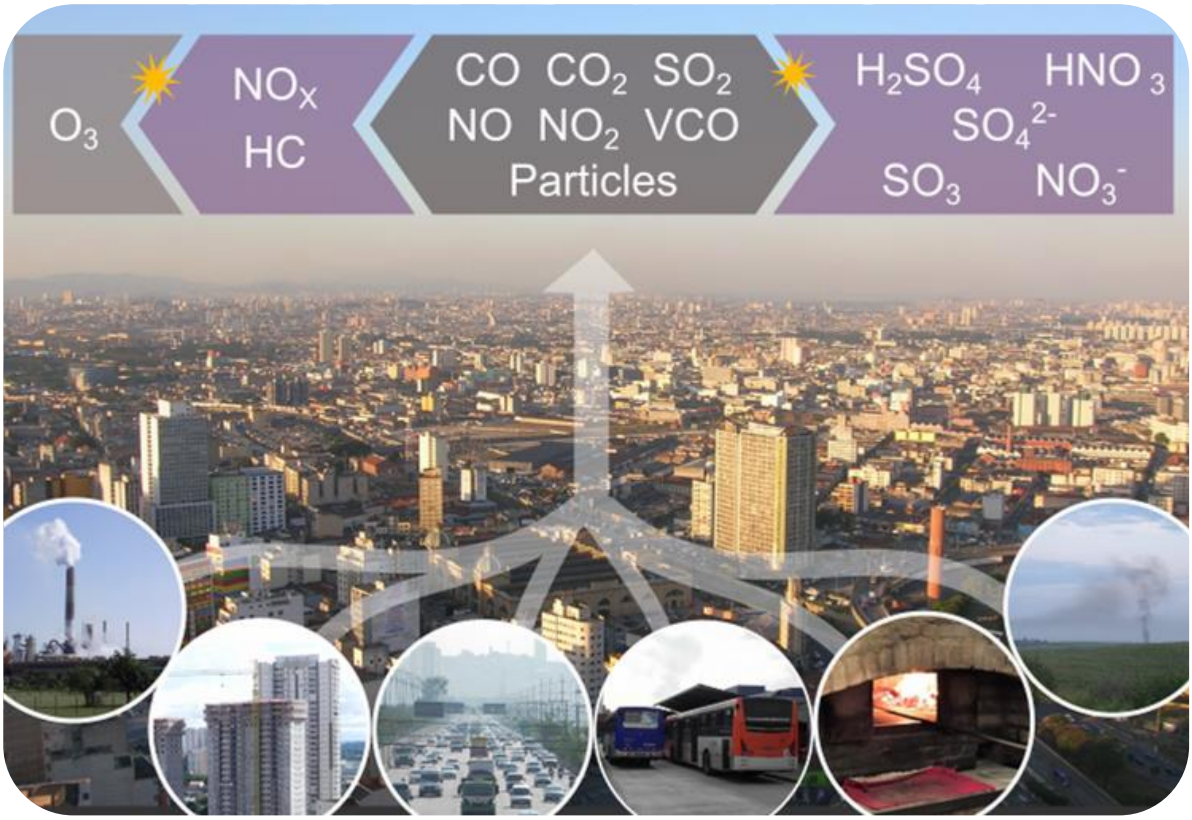
Graphical abstract



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Main Text

A megacity typically refers to a metropolitan area with more than 10 million people. The number of megacities worldwide has increased from 8 in 1970 to 34 in 2016 with their total population exceeding 650 million (City Population, 2016). Air pollution, a consequence of increased population and urbanisation, is a common concern in megacities. Here we focus on the Metropolitan Area of São Paulo (MASP), which is the 5th most populous urban region in the world and the second most populated region in Latin America (UN, 2014), making up ~10% of the total population of Brazil. With 21 million inhabitants and 8511 km^2 area (Fig. 1a), the MASP includes 38 metropolitan areas surrounding the city of São Paulo that has a population of 12 million (IBGE, 2016). What makes São Paulo distinctly different from all other megacities in the world is that its vehicle fleet operates exclusively on biofuel blends (sugarcane ethanol and soya diesel) in diesel, making it a unique biofuel-driven megacity. Yet, São Paulo's air quality face challenges to meet its national standards, which are relatively relaxed compared with the megacities of Asia (e.g., Delhi) or Europe (e.g., London). While the events of highly elevated concentrations of particulate matter (PM) are similarly common as in other megacities, the underlining factors responsible for them are unique to São Paulo and the questions are: (i) how can the air quality be improved considering that numerous interventions have already been taken in controlling emissions from vehicular fleet? (ii) how can the transportation system be transformed to make it emission-neutral? (iii) how the emissions from the main emitters such as the diesel trucks and buses can be reduced? and (iv) how the changes in the content of biofuel in diesel have influenced the exceedances and ozone formation? The aim of this paper is to propose answers to the above questions in the context of distinctness in the vehicle fleet, hitherto overlooked sources, underlining causes for pollution exceedances, and to suggest future directions and research needs to better understand and manage air quality of this unique megacity.

Unique vehicle fleet and fuels it operates on: The MASP includes more than 7 million of road vehicles, with an average of 0.34 vehicles per inhabitant (CETESB, 2015). Light duty vehicles (LDVs), including private cars and taxis, dominate the traffic fleet with 85% share, followed by motorcycles (12%) and heavy duty vehicles (HDVs; 3%) (CETESB, 2013). The fleet of LDV, HDV and motorcycle have increased by 12.7, 10 and 9.6% between 2009 and 2012, respectively. The proportion of flex-fuel vehicles that can run on ethanol or gasohol (gasoline with 25-27% ethanol) is increasing in MASP every day as 94% of vehicles sold in 2013 were flex-fuel (Posada and Façanha, 2015). Currently, the proportion of gasohol-driven LDVs is 55%, followed by flex-fuel vehicles (38%), ethanol (4%) and diesel (2%) (CETESB, 2012). To enable comparison, the relevant characteristics of the five world's largest megacities (London, Los Angeles (LA), Delhi, Beijing and São Paulo) are summarised (see Supplementary Information, SI, Table S1). Unlike other megacities such as Delhi or London where public vehicles run on compressed natural gas (CNG) or diesel (Kumar et al., 2015), all the passenger cars, whether they are public taxis or privately-owned, in São Paulo run on either pure ethanol or gasohol and CNG (mainly used by some taxis). The situation is, however, different regarding buses and trucks that run on S10 (mandatory for diesel power manufactured after 2012) or older vehicles using S500, which are fuels with the maximum sulphur content of 10 and 500 mg kg^{-1}, respectively. All types of diesel have a mandatory 7% biodiesel blend (BLN, 2014). The new diesel vehicles (>3.5 tons) have to use the S10 diesel because they are either equipped with the selective catalytic reduction or exhaust gas recirculation systems. These technologies were applied to reduce the emissions of NOx and black smoke. The use of non-S10 diesel can deteriorate the catalytic system but the price of S10 diesel is higher than the S500, determining its preferential use by old vehicles. By comparison, buses operate on CNG while trucks on S50 (sulphur content 50 mg kg^{-1}) diesel in megacities like Delhi (Kumar et al., 2013). Sulphur content in diesel in MASP has since 2013 been mandated to 10 ppm, in line with cities like London. This reduction in sulphur contents used in vehicular and industrial fuels has led to significant reductions in atmospheric sulphur dioxide (SO_2) concentration.

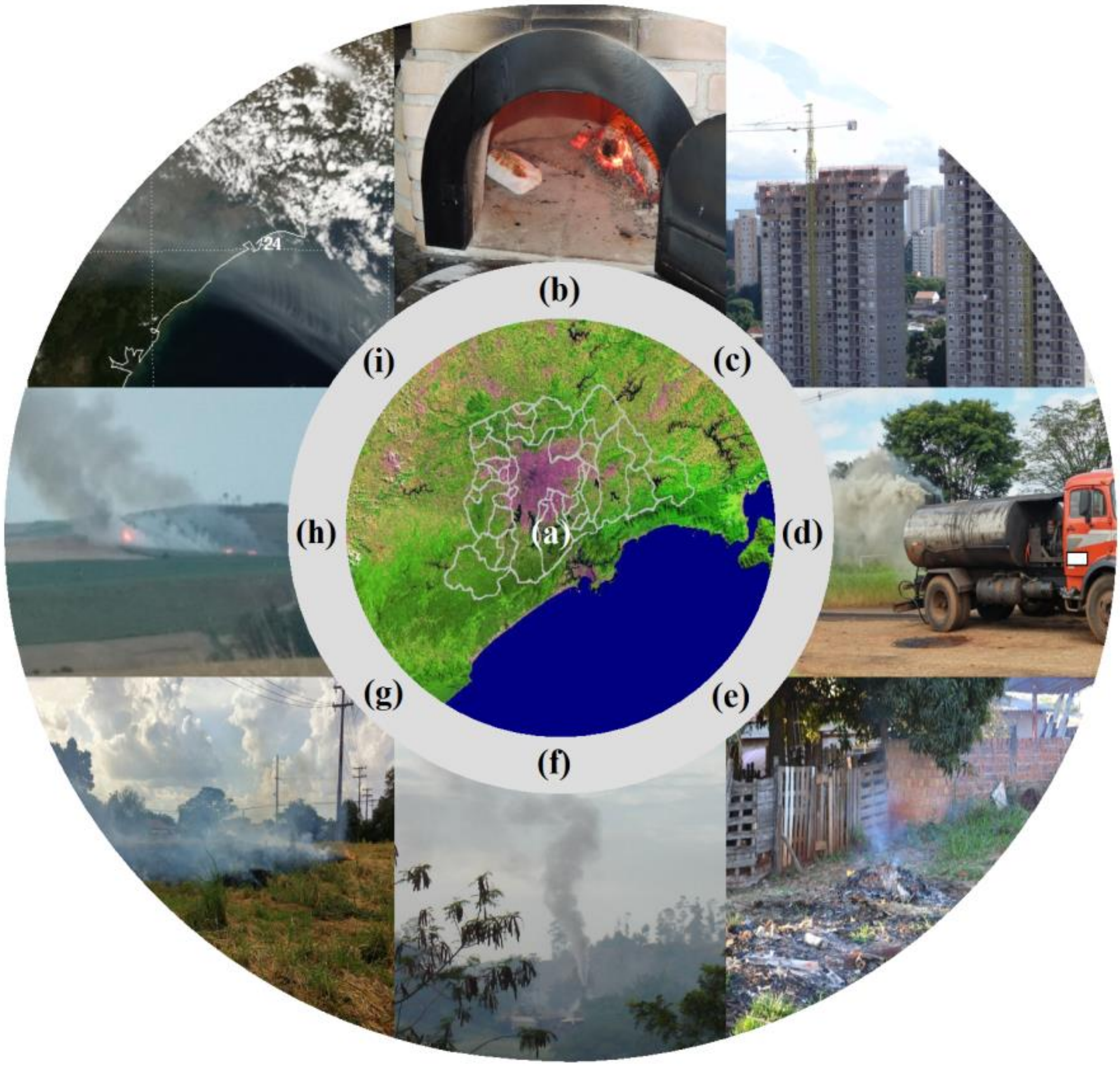

Figure 1. *Description of (a) MASP area and some unaccounted sources in current emission inventories (representation of Landsat 8, acquired on 1 September 2013, NASA Earth Observatory images by Robert Simmon), (b) wood burning emissions from pizzerias and steakhouses, (c) construction and demolition, (d) recovery and maintenance of outdoor road surfaces, (e) domestic waste burning, (f) transport of pollutants from outside industrial activities, (g) biomass burning in peripheral urban area, (h) sugarcane burning, and (i) long-range transport of smoke, especially from Amazon and sugarcane burning (http://modis-atmos.gsfc.nasa.gov/IMAGES/index.html).*

Energy sources, energy consumption and its impact on pollution emissions: To understand the emissions, considering the sources of energy for the city and how the energy is consumed within it is important (Kumar and Saroj, 2014). One of the distinctive features of the MASP is its supply of electric energy, 100% of which comes from hydropower plants that are outside the metropolitan area. Total energy consumption by stationary and mobile sources in São Paulo had grown by ~38% from 2001 levels to 575,582 TJ in 2011. However, in the same period, a much higher growth of ~57% took place in Delhi, to 230,222 TJ in 2011 (Kennedy et al., 2015). Yet, per capita energy consumption of 29 GJ hab^{-1} in São Paulo is twice as much as in Delhi (~14 GJ hab^{-1}). With the limited growth of new industries, vehicle fleet remains the main source of pollutant emissions in MASP. The number of on-road vehicles and the corresponding sales in fuel in MASP have increased substantially over the past 10 years, however, the total emissions have decreased due to the legislations imposing restrictions on emissions (DENATRAN, 2015; Pérez-Martínez et al., 2015). The dominant sources for PM_{10} and $PM_{2.5}$ (mass concentration of particles with diameters ≤10 μm and ≤2.5 μm, respectively) are road vehicles and secondary formation, respectively; these sources contribute to about 40 and 60% of total PM_{10} and $PM_{2.5}$, respectively (CETESB, 2015). Recent reports suggested contributions from the mobile and stationary sources of ~165, 46, 71, 5 and 10 ($\times 10^6$) kg yr^{-1} of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), PM, and sulphur oxides (SO_x), respectively (CETESB, 2015). Out of which, vehicular fleet contribute to 97% of CO, 82% of HC, 78% of NO_x, 43% of SO_x and 40% of PM emissions in MASP (CETESB, 2015). The LDVs are responsible for the majority of the CO and HC emissions while the diesel fleet is a dominant source of NO_x and $PM_{2.5}$. Refuelling of the vehicles is an important source, accounting for 33% of the HC emitted in MASP. Per capita emissions in 2014 of CO, HC, NO_x, PM_{10} and SO_x in MASP were 8000, 2000, 3000, 70 and 200 kg yr^{-1}, respectively. In the future, the diesel fleet is expected to contribute fewer emissions, particularly of NO_x, since the vehicles produced from 2012 onwards have to incorporate new technologies to meet the requirements of the Brazilian Program for Controlling of Vehicular Emission, PROCONVE (Pérez-Martínez et al., 2015). The Program has already led to the decrease of 90% and 80% in emissions by LDVs and HDVs in 2009 from 1996 levels, respectively (Carvalho et al., 2015).

With about 2.4 million and 12% share of vehicle fleet (Pérez-Martínez et al., 2015), motorcycles are a popular mode of transport in MASP, as is also the case for megacities of other developing countries. In Delhi, for example, motorcycles make almost half of total vehicle fleet (Nagpure et al., 2016), account for over one-third of total vehicle kilometre travelled (Kumar et al., 2011) and up to 51 and 73% of HC emissions, respectively (Nagpure et al., 2016). The motorcycles in MASP run on biofuel (sugar cane ethanol, gasohol or a mixture of both) and are responsible for 12 and 22% of the total emission of HC and CO, respectively (CETESB, 2015). Recognising their importance as a pollution source, PROMOT (program for controlling the motorcycles emission) was launched to impose emission standards from the motorcycles. Clearly, this is a transport mode which needs a special focus to make it emission-neutral. In this respect, an exemplary case is the single largest adoption of alternative fuel vehicles in the history of e-bikes in Chinese cities such as Beijing (Ji et al., 2012).

Relaxed air quality standards: The national Brazilian and the local standards of the states vary according to the approaches adopted for balancing health risks, technological feasibility, economic considerations and various political and social factors, which in turn depend on the level of development and capability in air quality management of different states. Concentration limits are non-uniform across Brazil, are more relaxed than in the São Paulo State and remain unchanged even after more than 25 years since their implementation. Other states in Brazil are planning to make their air quality standards stricter, in line with these of São Paulo state. When it comes to comparison with international standards or guidelines, even the São Paulo has relaxed standards compared to the WHO guidelines (SI Table S2). For example, 24 h limit value of $PM_{2.5}$ in São Paulo and WHO is 60 and 20 µg m^{-3}, respectively. These air quality standards will be tightened towards to the WHO guidelines through a three-phase implementation plan.

At this point PM concentrations are high, and as an example, the 24 h mean standards in 2014 for PM_{10} and $PM_{2.5}$ were exceeded on numerous occasions at 6 and 8 stations (out of total 24 in São Paulo), respectively. In addition to the emissions, climatic conditions are major contributors to exceedances of PM, especially during winter (June to September) when the typical ambient temperature is low (16 ^{o}C in August) and the precipitation is also low (35 mm in August), resulting in stable atmospheric conditions that inhibit the dispersion of pollutants. Regardless of the differences in vehicle fleet and fuel types used in São Paulo, and in Delhi for example, the major source of PM_{10} in these cities is considered to be dust resuspension, followed by exhaust from road vehicles, and secondary particle formation, while of $PM_{2.5}$, exhaust emissions. This shows that the problems in relation to PM_{10} and $PM_{2.5}$ are similar in both cities, yet addressing them requires localised strategies.

Recent studies indicate significant health effects associated with the air pollution, reporting 9.7 thousand deaths per year due to excess $PM_{2.5}$ concentrations above the WHO limits for the São Paulo city between 2007 and 2008 (Miranda et al., 2011). In 2013, about 6 and 9% of hospital admissions for cardiopulmonary and lung cancer diseases were attributed to exceedances of WHO limits for $PM_{2.5}$ (Wikuats et al., 2014). The limits established by WHO are not fully safe and may have health effects even below the guideline values, as pointed out in relation to PM_{10} by Martins et al. (2009) in a case study set in MASP. These indicate clearly a need to tighten the emission standards and the need to understand the underlining sources and associated conditions contributing to the elevated concentrations.

Ozone pollution from ethanol fuel: As for other pollutants, 8 h O_3 concentration limit of 140 µg m^{-3} in MASP is higher than the WHO guideline value of 100 µg m^{-3}. Before 2013, the 1 h limit was 160 µg m^{-3}. However, elevated levels of O_3 and the role the use of ethanol plays in the formation of O_3 are unique challenges for São Paulo to address. While the annual mean values of gaseous pollutants show a decreasing tendency, this is not the cases in relation to O_3 (Carvalho et al., 2015). The highest O_3 concentrations occur during spring and summer months (September to January) when the meteorological conditions are favourable for O_3 formation (Carvalho et al., 2015; Perez-Martinez et al., 2015). The reasons for the O_3 exceedances are not fully understood but VOCs from ethanol combustion emission could be responsible for this pattern. The VOC/NO_X ratio has been changing in São Paulo, and was on an average 6.6±3 during 1996-2005, compared with the most recent value of 12±5 in 2013. It is considered that the chemical regime remains VOC-limited (Martins and Andrade, 2008a; Sánchez-Ccoyllo et al., 2006). Recent studies suggested that O_3 concentrations can be reduced in MASP by shifting from ethanol to gasohol by flex-fuel cars (Martins and Andrade, 2008b), which has in fact been promoted by an increase of ethanol price in 2010 (Salvo and Geiger, 2014).

Unregulated sources polluting the air of São Paulo: The air quality in São Paulo is influenced by both *within* and *outside* the city sources. The *within the city* sources include those which are regulated, such as road vehicles and industries, besides numerous unregulated sources such as gas stations, bakeries, restaurants and pizzerias (Fig. 1b), burning of coal during barbecues, and the civil construction activities (residential and commercial construction and renovation; Fig.1c). There are for example 8000 pizza shops in São Paulo and about 80% of them use wood (mainly Eucalyptus) (Lima, 2015). The average quantity of wood used by each pizzeria is 48 tonnes/year, amounting to a total of 307200 tonnes of wood burned each year that results in ~321 kg day^{-1} of $PM_{2.5}$ (Lima, 2015). More than 7.5 hectares of Eucalyptus forest are being burned in MASP every month by pizzerias and steakhouses (Vieira-Filho et al., 2013). This means that there is a continuous local source of biomass burning within the city. Less work has been conducted to quantify emissions from coal burning by barbecues and wood from restaurants, and consequently, these emissions have not been considered in emission inventories. By contrast, in Delhi, it is proposed that all restaurants of sitting capacity more than 10 people should shift from coal to electric or gas-based appliances. This is expected to result in ~67% reduction in PM_{10} (2142 kg day^{-1}) and $PM_{2.5}$ (1083 kg day^{-1}) emissions (TIE, 2016). Since the emissions from pizzeria chimneys and barbecues are released close to the ground level, all year round, the effect of such emissions can be expected to be much higher, especially during cold months with stable atmospheric conditions, than those from industrial emissions having much taller chimneys. However, studies apportioning their contributions to the total emissions, and their impact on people's personal exposure are unavailable, which calls for focused efforts to close this gap in knowledge. The above listed are not the only unaccounted sources, and examples of other such sources include recovery and maintenance of outdoor street surfaces (Fig. 1d) and domestic waste and biomass burning in the peripheral urban area (Figs. 1e and 1g).

Influence of outside sources: The ambient air quality of every city is also affected by the pollutants originated outside the city and transported to its airshed. Outside sources such as sugarcane and forest burning upwind of the MASP during certain months of the year might contribute to the city pollution episodes (Fig. 1h). Brazil is the world's largest producer of sugarcane, producing ~490 ($\times 10^6$) kg yr^{-1} in an area of 7.8 million hectares, which is 2.3% of the arable land in the country. Burning of sugarcane residues during the period of May to–October has clear effects on PM chemical composition in the MASP and thus their influence on local air quality (Allen et al., 2009; Souza et al., 2014; Vasconcellos et al., 2010). A number of dedicated field campaigns such as AMAZE-08 (Martin et al., 2010) and GoAmazon2014/5 (Martin et al., 2015) have been carried out to quantify the impact of biomass burning on air quality and climate in the Amazonian region and downwind of it. These studies concluded that emissions from biomass burning from the southern edge of the forest can be transported south and southeast across the Atlantic coast of Brazil (Fig. 1i) and have to be included in quantitative assessments of the city air pollution.

Interventions: Numerous interventions have been adopted in the MASP to combat pollution, and along with the Brazilian regulations, to utilise agricultural waste from sugarcane cultivation. Firstly, the sulphur content in solid and liquid fuels has been regulated since the end of the 1970s, with the enforcement of reduction of sulphur in combustion oil used in boilers. It was firstly applied to industries and later the regulations were applied to vehicles to restrict S10 diesel in 2014. This is much more progressive than the current regulations in Delhi, which still allow for 50 ppm sulphur in diesel, but in line with London where ultra-low sulphur fuel with 10 ppm level is mandatory (Kumar et al., 2014). Secondly, cars using gasoline with *lead* were banned in 1980's and the use of gasoline with *ethanol* (called gasohol) started. Cars running on hydrated ethanol (95% ethanol, 5% water) started to be manufactured and the first car using ethanol was sold in 1982. Flex fuel vehicles was an initiative that started in 2003, allowing any blend of hydrous ethanol and gasoline as a fuel in cars. At present, all cars use hydrated ethanol, or gasohol, or a mix of both. This is a step of its first kind for any megacity in the world. Thirdly, National Environmental Council implemented the PROCONVE in 1986. After its first phase in 1992, the regulated pollutants showed a reduction of ~70% in emissions. The reduction in the sulphur content of diesel fuel, for instance, was also implemented through PROCONVE. On average, the registered decrease in ambient CO, NO_x, PM_{10} and SO_2 concentrations were –0.09 ppm yr^{-1}, –1.82 µg m^{-3} yr^{-1}, –1.97 µg m^{-3} yr^{-1} and –0.82 µg m^{-3} yr^{-1} during 1996-2009, respectively. In particular, maximum CO concentration decreased from 8 ppm to 3 ppm during the 1996-2009 period (Carvalho et al., 2015). In 2003, PROMOT programme was implemented to target motorcycles, which was an important step in controlling their emissions. Fourthly, a biodiesel program was designed in Brazil to gradually converge on market mechanisms by means of incentives, which provide for the inclusion of producers in the poorest regions into the supply chain for this fuel, through incentives based on supply and demand. In this respect, Federal Law No. 11907 was passed on 13 January 2005 that defines biodiesel as a new fuel in Brazil's energy mix, and as of January 2008, required a 2% biodiesel component blended to 98% diesel oil, known as B2. After 2013, the mixing requirement increased to 5% (B5), with possibilities for higher blend percentages all the way up to pure biodiesel (B100), which is given regulatory and fiscal control by that same law over production and sale of biofuels (Rodrigues and Accarini, 2005). In 2014, the Brazilian government increased the amount of biodiesel that was blended into diesel to 7% (biodiesel that comes mainly from soybeans). Although the use of biodiesel has contributed to an increase in the fraction of ultrafine particles (Martins et al., 2011), leaving a challenge to control them in future (Kumar et al., 2010). Fifthly, 'rodizio' came in place in 1997 to reduce pollution peaks of CO, which implies that the cars with different ending letter of number plates are not allowed to run one day a week between 0700 and 1000 h (local time), and between 1700 and 2000 h during the weekdays. One effect of 'rodizio' was the spread of commuting hours, which started at 0600 h (to avoid the 'rodizio' in the morning hours) and at night extending to 2100 h. Since there was no improvement in the availability of public transport, many households bought a second (older) car to use on the days of 'rodízio'. Thus, this intervention not necessarily had an impact on reducing air pollution, but it has partially helped to reduce congestion during peak hours and encourage people to use public transport (Jacobi et al., 1999). Sixthly, another restriction on vehicular use came in the form of prohibiting the circulation of heavy-duty trucks in the central part of the city since 2008, and only allowing the use of small trucks, coaches, and vans. Lastly, the buses have dedicated lanes, which are of the total length of ~493 km, as a step to decrease the time of travel, improve the public transportation and air quality in MASP (CET, 2016). However, heavy duty trucks are still the notable contributors to air pollution, due to being run on S10/500 diesel and with emission control (diesel particulate filter and catalytic converter) applied only for the new vehicles available since 2013. An initiative has recently started to replace the existing diesel buses by hybrid, electric, bus trails or powered with biofuel. The plan is to replace 100% of the MASP fleet by 2018, but it seems to be far behind the target as only 2% busses to date have been replaced by electric buses (Silva et al., 2015).

Future outlook: Use of public transportation and encouraging shift from private to public transportation are keys to reducing the number of on-road vehicles and hence cutting the emissions and exposure levels. The cities like London have very well-connected underground train network. In São Paulo, the total length of metro rail is about 78 km compared with 402 km in London. In 2007, 31% of the trips in the MASP were performed by walking, 28% by bus, 28% by passenger cars, 10% by subway and train, 2% by motorcycles, 0.6% bicycle and only 0.3% by taxi (Metro, 2013). There is clearly a need to further expand the underground network and also the over-ground cross-municipalities train services so that more key locations in the MASP are connected and the current share of people using it could be increased. Electricity supplied in MASP is produced by hydropower and is 'green', and, therefore, increasing the currently limited share of electric buses by replacing old diesel buses will help cut the emissions. Old vehicles are not scrapped in São Paulo except the buses going off the road after 5 years, despite the fact that half of the total emissions (CO, HC, NO_x) are from those that are more than 10 years old vehicles. Obvious steps in this regard are to scrap old vehicles in line with the established practices in most megacities, after about 10-15 years of their useable age. Promoting healthy life using bike lanes is another measure for more people to cycle and reduce fuel consumption. Centralisation of services and promoting flexibility of work from home, as in many academic institutions in countries like the UK and U.S. will certainly reduce the number of on-road vehicles and emissions. Lastly, steps are needed to control emissions from bakeries and pizzerias using wood or coal along with the schemes allowing the public to participate in controlling emissions and exposure at their sources.

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Supplementary Information

New Directions: From biofuels to wood stoves: the modern and ancient air quality challenges in the megacity of São Paulo

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Table S1. Characteristics of representative megacities in the world.

	São Paulo	London	Los Angeles	Delhi	Beijing
Population (annual rate of change, %)[1]	21 Million (1.4%)	10.2 Million (1.2%)	12.3 Million (0.2%)	25 Million (3.2%)	20 Million (4.6%)
Prosperity[1]	Solid	Very solid	Very solid	Moderate	Solid
Geography	Near the coast Moderate-high plains	Near the coast Low plains	Coastal zone Most low plains	Inland Low plains	Near the coast Low plains
Climate[2]	19 °C, 1500 mm, moderate seasonality	11°C, 600 mm, low seasonality	17°C, 300 mm, moderate seasonality	25°C, 800 mm, strong seasonality	12°C, 600 mm, strong seasonality
Local sources	Transportation	Transportation construction and demolition[3]	Transportation industries[4]	Transportation power plants, industry[5]	Industry, residential, power plant, transportation[6]
External sources	Outdoor biomass burning, long range transport	Airport, long-range transport, biomass burning for heating and decentralised energy sources	Long range transport from Asia[11]	Industry, outdoor biomass burning, crustal dust	Agriculture outdoor biomass burning, dust, and long range transport[7]
Major Interventions	Controlling emissions from, vehicles since 1986	Low emission zone; controlling emission of smoke, improvement on vehicles, fuel and public transportation system[10]	Smog alerts since the 1950s; health advisories for O_3 since 1990; it has a more stringent criteria pollutant standards than the U.S. federal standards[9]	Reduction sulphur content in fuel and controlling emissions from biomass burning; CNG driven public transport[5]	Controlling emissions from coal burning, industries, vehicles, and fugitive dust since 1998[8]

[1]UN-HABITAT (2012); [2]NOAA (2016); [3]Charron and Harrison (2005); [4]Fruin et al. (2008); [5]Kumar et al. (2015); [6]Li et al. (2015); [7]Wang et al. (2008); [8]Hao and Wang (2005); [9]Jacobson (2012); [10]Kilbane-Dawe and Clement (2015); [11]Yienger et al. (2000)

Table S2. National and São Paulo State Air Quality Standards and WHO Guidelines. Please note that current São Paulo State Air Quality Standard is showed in red colour.

			$PM_{2.5}$ [$\mu g\ m^{-3}$]	PM_{10} [$\mu g\ m^{-3}$]	TPS [$\mu g\ m^{-3}$]	SO_2 [$\mu g\ m^{-3}$]	NO_2 [$\mu g\ m^{-3}$]	O_3 [$\mu g\ m^{-3}$]	CO [$\mu g\ m^{-3}$]	Pb [$\mu g\ m^{-3}$]	Smoke [$\mu g\ m^{-3}$]
National Air Quality Standard (CONAMA No 03/90)	Short Exposure	Primary	-	150[a] (24h)	240[a] (24h)	365[a] (24h)	320 (1h)	160[a] (1h)	10.000[a] (8h) 40.000[a] (1h)	-	150[a] (24h)
		Secundary	-	150[a] (24h)	150[a] (24h)	100[a] (24h)	190 (1h)	160[a] (1h)	10.000 [a] (8h) 40.000 [a] (1h)	-	100[a] (24h)
	Long Exposure	Primary	-	50 (year[b])	80 (year[c])	80 (Ano[b])	100 (year[b])	-	-	-	60 (year[b])
		Secondary	-	50 (year[b])	60 (year[c])	40 (year[b])	100 (year[b])	-	-	-	40 (year[b])
State Standard Air Quality and Interim Targets (Decreto No 59113-2013)	Short Exposure	Interim Target (IT)1	**60** (24h)	**120** (24h)	-	**60** (24h)	**260** (1h)	**140** (8h)	-	-	**120** (24h)
		Interim Target (IT)2	50 (24h)	100 (24h)	-	40 (24h)	240 (1h)	130 (8h)	-	-	100 (24h)
		Interim Target (IT)3	37 (24h)	75 (24h)	-	30 (24h)	220 (1h)	120 (8h)	-	-	75 (24h)
		Final Interim Target	25 (24h)	50 (24h)	**240** (24h)	20 (24h)	200 (1h)	100 (8h)	**9 ppm** (8h)	-	50 (24h)
	Long Exposure	IT. 1	**20** (year[b])	**40** (year[b])		**40** (year[b])	**60** (year[b])	-	-	-	**40** (year[b])
		IT. 2	17 (year[b])	35 (year[b])		30 (year[b])	50 (year[b])	-	-	-	35 (year[b])
		IT. 3	15 (year[b])	30 (year[b])		20 (year[b])	45 (year[b])	-	-	-	30 (year[b])
		Final IT.	10 (year[b])	20 (year[b])	**80** (year[c])	-	40 (year[c])	-	-	0.5 (year[b])	20 (year[b])
WHO Guidelines	Short Exposure		25 (24h)	50 (24h)	-	20 (24h) 500 (10min)	200 (1h)	100 (8h)	10.000 (8h) 30.000 (1h)	-	-

Long Exposure	10 (year[b])	20 (year[b])	-	-	40 (year[b])	-	-	-	-

[a]Not to be exceeded more than once per year; [b]Arithmetic Annual Mean; [c]Geometric Annual Mean

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