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1 **Evaluation of anthropogenic air pollutant emission inventories for South America at**  
2 **national and city scale**

3  
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35

## 36 Abstract

37 The changing composition of the atmosphere, driven by anthropogenic emissions, is the  
38 cause of anthropogenic climate change as well as deteriorating air quality. Emission  
39 inventories are essential to understand the contribution of various human activities, model  
40 and predict the changing atmospheric composition, and design cost-effective mitigation  
41 measures. At present, national emission inventories in South America (SA) focus on  
42 Greenhouse Gases (GHG) as part of their obligations to the United Nations Framework  
43 Convention for Climate Change (UNFCCC) within the framework of their national  
44 communications. Emission inventories other than for GHG in SA focus mainly on growing  
45 urban areas and megacities. Therefore, studies examining air quality at national, regional or  
46 continental scales in SA depend on (down-scaled) global emission inventories. This paper  
47 examines the emission estimates of air pollutants from various global inventories for five  
48 SA countries, namely Argentina, Brazil, Chile, Colombia and Peru. A more detailed  
49 analysis is conducted for the EDGAR and ECLIPSE emission inventories, in particular  
50 against local city-scale inventories of a major city in each country. Although total emissions  
51 between down-scaled global inventories and local city inventories are often comparable,  
52 large discrepancies exist between the sectoral contributions. This is critical as the  
53 mitigation of poor air quality will depend on addressing the right sources. Potential sources  
54 of discrepancies between global and local inventories include the spatial distribution  
55 proxies, difference in emission factors used and/or the use of generic statistical country data  
56 when estimating emissions. This highlights the importance of using local information when  
57 generating national emission inventories, especially for air quality modeling and  
58 development of effective mitigation measures. This work represents a first step towards an  
59 increased understanding of the strength and weaknesses of emissions information in SA.

60 Key words;

61 South America, anthropogenic emissions, air pollutants, Argentina, Brazil, Chile,  
62 Colombia, Peru, city emission inventories

## 63 1 Introduction and Rationale

64 Over the last decades, environmental problems such as acidification, eutrophication,  
65 air pollution and climate change have caused significant adverse impacts on the  
66 environment, human health and vegetation (Steffen et al, 2015; HTAP, 2010;  
67 Schneidemesser et al., 2015). These environmental problems are directly related to the  
68 atmospheric emissions of greenhouse gases (GHG), air pollutants and their precursors.  
69 Reliable emission inventories are a prerequisite to understand these environmental issues  
70 including the impact of anthropogenic activity on air quality and climate, and to develop  
71 effective mitigation options. Furthermore, emission knowledge of GHG and air pollutants  
72 are key in the development of integrated policies addressing climate change and/or air  
73 quality (AQ) and reducing unintended consequences (Melamed et al., 2016; Schmale et al.,  
74 2014; Reis et al., 2012).

75 Emission inventories developed in different South American (SA) countries at  
76 national level typically focus on GHGs as part of the obligations of the Parties to the United  
77 Nations Framework Convention on Climate Change (UNFCCC) within the framework of  
78 their national communications (Baumgardner et al., 2018). Emission inventories other than  
79 for GHG in SA focus mainly on megacities in an effort to understand the interactions and  
80 feedback mechanisms between emissions, AQ and public health (Alonso et al., 2010;  
81 Gallardo et al., 2012a). Except for Argentina (Castesana et al., 2018; Puliafito et. Al.,  
82 2015; 2017), no national emission inventory for air pollutants is available with the spatial  
83 and temporal detail needed for AQ modelling, analysis and policy support. Therefore, the  
84 emission inventories currently used for national, regional or continental scale AQ  
85 assessments in SA are derived from global data sets (e.g. Longo et al., 2013; Rosario et al.,  
86 2013; Kumar et al., 2016; UNEP/CCAC, 2018).

87 South America is a continent that spans over the northern and the southern  
88 hemisphere, from the very cold Tierra del Fuego, close to Antarctica, to the equator and

89 beyond to the Caribbean Sea. Its climate exhibits tropical, subtropical as well as  
90 extratropical features (Garreaud et al., 2009). It includes the world's largest rainforest, what  
91 is considered the driest desert outside polar regions (Rondanelli et al. 2015) and the Andes  
92 mountain range peaking well above 6000 meters, introducing east-west climate  
93 asymmetries (Garreaud et al., 2009). In short, a very diverse collections of ecosystems,  
94 physical landscapes and climate zones. While SA countries experienced similar population  
95 growth in the last 20 years, there have been large differences in economic development.  
96 Emissions sources of air pollutants dominating impact on air quality also vary largely from  
97 country to country from residential combustion in central and southern Chile (Saide et al.,  
98 2016; Mazzeo et al., 2018) to transport in Colombia (Gonzalez et al., 2017; Pachon et al.,  
99 2018). Furthermore, emission conditions also vary largely, in particular among main  
100 metropolitan areas; while pollutants are emitted at sea level in Buenos Aires (Argentina),  
101 those in La Paz (Bolivia) are emitted at approximately 3600 m above sea level. This  
102 altitude can have an important impact on vehicle emissions with different emissions due to  
103 altitude (He et al., 2011; Ni et al., 2014; Szedlmayer and Kweon, 2016; Wang et al., 2018).

104 The available global emission inventories for selected countries are analyzed by  
105 source-sector in this paper. These countries are highly urbanized, except for Peru,  
106 urbanization is above 80% and more than 50% of the urban population of these countries  
107 live in cities larger than 300.000 inhabitants (UN, 2018). Air quality in the SA cities is a  
108 major problem. Measurements of particulate matter of 2.5 microns or less (PM<sub>2.5</sub>) are  
109 available for 37 cities in these countries, 35 of them (representing approximately 15% of  
110 SA population) experience annual averaged concentrations exceeding the level  
111 recommended by the World Health Organization (WHO, 2017).

112 This paper seeks to evaluate, give guidance and provide insight into the differences  
113 and similarities among emissions inventories for five selected SA countries, and possible  
114 reasons for such discrepancies. This analysis focuses foremost on air pollutants. The global  
115 emission inventories and local emission inventories for selected cities in the five SA  
116 countries together with the sources considered are presented in section 2. Sections 3 and 4  
117 present a comparative analysis of the estimated emissions between the five countries

118 investigating the reasons for discrepancies. A discussion of the main results is presented in  
119 section 5 followed by conclusions in section 6.

120

## 121 2 Methods and data

### 122 2.1 General country information and data

123 South America has an area of 17,840,000 km<sup>2</sup> and its population in 2010 is estimated  
124 at 395 Million (UN PD, 2017) (Table 1). The five countries selected in this study for  
125 analysis of the available emissions data are Argentina, Brazil, Chile, Colombia and Peru.  
126 They cover 80% of the land area, and 84% of the population of South America (Table 1).

127

Country	ISO3 code	Area ( km <sup>2</sup> ) <sup>a)</sup>	Total Population (10 <sup>6</sup> ) <sup>b)</sup>	Urban Population [%] <sup>c)</sup>
Argentina	ARG	2736690	41.2	92
Brazil	BRA	8459420	196.8	87
Chile	CHL	743800	17	88
Colombia	COL	1109500	45.9	81
Peru	PER	1280000	29.4	78
Sum of 5 countries		14329410	330.3	86
Total South America		17840000	395.3	84

128 **Table 1:** Selected generic data of the selected five countries in South America

129 <sup>a)</sup> Source FAOstat accessed through <https://unstats.un.org/>

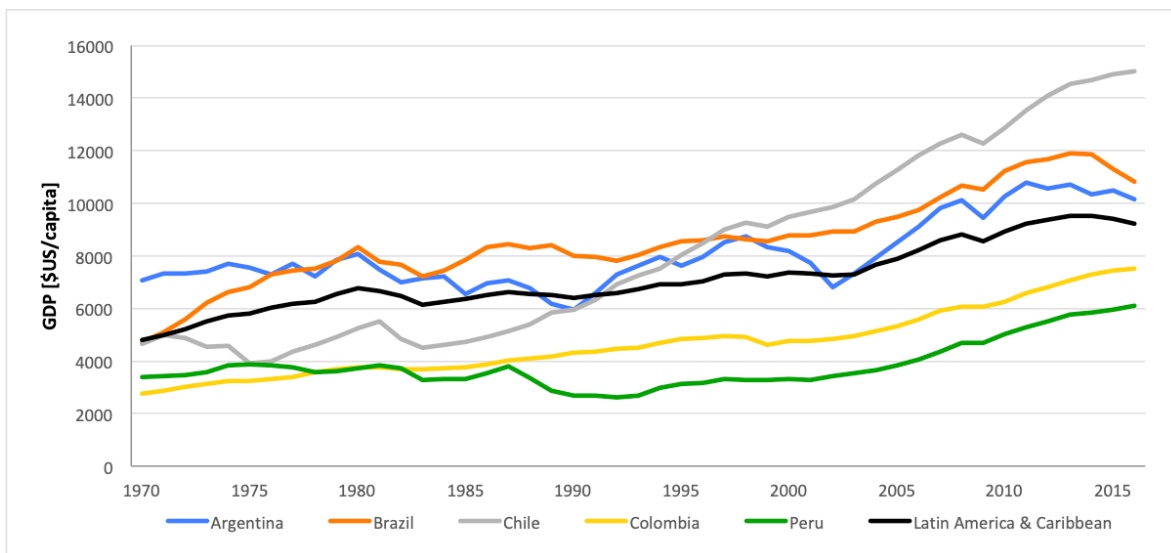
130 <sup>b)</sup> UN PD (2017)

131 <sup>c)</sup> UN PD (2018)

132

133 The population of the selected countries is estimated at 330 million in 2010. The  
134 demographic development of the countries is similar, in all five countries the population  
135 doubled since 1970. When we focus on the last 20 years (1995-2015), the population has  
136 grown by about 30% and again the pattern for the 5 countries is similar. The development  
137 in gross domestic product (GDP), however, has been less similar and less gradual (Figure  
138 1). Since Brazil is by far the largest country, its GDP follows the average rather closely but  
139 Colombia and Peru are clearly below the average GDP, while Chile and Argentina are

140 above the average. Moreover, while the GDP for Chile has mostly increased since  
141 beginning of the 1980's, Argentina experienced a decrease in GDP from 1998 until 2003  
142 and Peru mostly shows an increase in the last decade. A common feature for all SA  
143 countries is the pervasive inequity (e.g., Solimano and Schaper, 2015; PNUD, 2017), which  
144 is also relevant when considering consumption, emission and exposure patterns (e.g.,  
145 Gallardo et al, 2012b; Carpenter and Quispe-Agnoli, 2015).  
146



147  
148 **Figure 1:** Gross Domestic Product (GDP) per capita (\$US/capita in constant 2010 prices)  
149 for the same five selected countries in SA. In addition, the GDP corresponding to Latin  
150 America and the Carribbean is also included.  
151

## 152 2.2 Global emission data

153 Emission inventories providing data for SA countries from 1970 to present are collected  
154 and compared for the pollutants of primary concern: nitrogen oxides (NO<sub>x</sub>), sulfur dioxide  
155 (SO<sub>2</sub>), Black Carbon (BC), particulate Organic Carbon (OC), particulate matter of 10  
156 microns or less (PM<sub>10</sub>), particulate matter of 2.5 microns or less (PM<sub>2.5</sub>), carbon monoxide  
157 (CO), and ammonia (NH<sub>3</sub>). Methane (CH<sub>4</sub>) is important in atmospheric chemistry (e.g.,  
158 ozone formation) but this pollutant is explicitly included in the GHG emission inventories  
159 and is therefore not discussed in this study. A comparison of the data from the various  
160 inventories by pollutant and by country for the time period of 1970 to 2010 is given in  
161 section 3.1.  
162

163 Although the total number of (global) emission inventories that provide information on SA  
 164 is substantial (Table 2), a more in-depth analysis is made for a selection of few recent  
 165 inventories. The selection of inventories is based on;

- 166 1. Inventories need to include the recent period 2000-2010 for comparison with other local  
 167 data sources such as SA city inventories
- 168 2. From every “family” of EIs we take the latest version at the time of the start of our  
 169 investigation; e.g. we look in detail to EDGAR 4.3 and not version 4.2.
- 170 3. The inventory needs to have sectorial emissions information.

171

172 Based on these criteria our further analysis focuses on EDGAR 4.3.1, ECLIPSE v5,  
 173 CEDSv3 and MACCity. The MACCity inventory for years after 2000 is a projection based  
 174 on the RCP8.5 projection by Riahi et al. (2007). As it was used in several studies in support  
 175 of IPCC AR5 analysis, we include it for reference but will not analyze the implied emission  
 176 factors or discrepancies in trends compared to the other bottom-up inventories. A brief  
 177 introduction to the selected inventories is provided below; we refer to the provided  
 178 references for more details. The emission inventories are accessible through the ECCAD  
 179 server (<https://eccad.aeris-data.fr/>)

180

181

Acronym	Period	Reference and/or website
MACCity	1980-2010	Granier et al., 2011 <a href="http://eccad.aeris-data.fr/">http://eccad.aeris-data.fr/</a>
ACCMIP	1980-2010	Lamarque et al., 2010 <a href="http://eccad.aeris-data.fr/">http://eccad.aeris-data.fr/</a>
RCPs	2000-2010	Van Vuuren et al., 2011 <a href="http://www.iiasa.ac.at/web-apps/tnt/RcpDb">http://www.iiasa.ac.at/web-apps/tnt/RcpDb</a>
EDGAR v4.2	1970-2008	Janssens-Maenhout et al., 2013 <a href="http://edgar.jrc.europa.eu/">http://edgar.jrc.europa.eu/</a>
EDGAR v4.3.1	1970 and 2010	Crippa et al., 2016 <a href="http://edgar.jrc.europa.eu/os">http://edgar.jrc.europa.eu/os</a>
HTAPv2	2008 and 2010	Janssens-Maenhout et al., 2015 <a href="http://edgar.jrc.europa.eu/htap_v2">http://edgar.jrc.europa.eu/htap_v2</a>
ECLIPSE v4a	2005-2010	Stohl et al., 2015 <a href="http://eclipse.nilu.no">http://eclipse.nilu.no</a> <a href="http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv4a.html">http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv4a.html</a>



ECLIPSE v5	1990-2010	Klimont et al., 2017 <a href="http://eclipse.nilu.no">http://eclipse.nilu.no</a> <a href="http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html">http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html</a>
Junker&Liousse	1860-1997	Junker and Liousse, 2008
PKU	2002-2013	Huang et al., 2014 <a href="http://inventory.pku.edu.cn">http://inventory.pku.edu.cn</a>
CEDS	1950-2014	Hoesly et al., 2018 <a href="http://www.globalchange.umd.edu/ceds/">http://www.globalchange.umd.edu/ceds/</a>

182 **Table 2:** Overview of selected global emission data sets containing data for anthropogenic emissions for  
183 South America.  
184

### 185 2.2.1 EDGAR v4.3.1 (January 2016)

186 The Emissions Database for Global Atmospheric Research (EDGAR) provides global  
187 historic anthropogenic emissions of GHG and air pollutants by country, and sector.  
188 EDGAR uses a bottom-up methodology with international activity data and emission  
189 factors (Janssens-Maenhout et al., 2017; Crippa et al., 2018). The estimated national  
190 emissions by sector are distributed on a 0.1°x0.1° grid using geospatial proxy data.. In  
191 EDGARv4.3.1 emissions are calculated for gaseous and particulate air pollutants per sector  
192 and country for the time series 1970-2010. This version v4.3.1 is the official release of the  
193 EDGAR database used for PEGASOS scenarios (Crippa et al., 2016). Source sector  
194 specification follows the IPCC 1996 code, as was also done for EDGAR v4.2).

195

### 196 2.2.2 Eclipsev5

197 The ECLIPSE emission data set was created with the GAINS (Greenhouse gas – Air  
198 pollution Interactions and Synergies; <http://gains.iiasa.ac.at>) model (Amann et al., 2011),  
199 which calculates emissions of air pollutants and Kyoto greenhouse gases in a consistent  
200 framework. The GAINS model holds essential information about key sources of emissions,  
201 environmental policies, and further mitigation opportunities for 170 country-regions. The  
202 model relies on international and national statistics of activity data for energy use, industrial  
203 production, and agricultural activities for which it distinguishes key emission sources and  
204 related control measures. Several hundred technologies to control air pollutant and  
205 greenhouse gases emissions are represented allowing simulation of implemented air quality  
206 legislation. Recently the regional resolution of the global GAINS model has been improved  
207 by distinguishing more countries in Latin America where five regions were replaced with

208 13 regions in version V5a, including most countries of South America (UNEP/CCAC.  
209 2018). For more details we refer to Klimont et al. (2017).

210

### 211 2.2.3 CEDSV3 (as of March 2017)

212 The Community Emissions Database System (CEDSV) is an open source data system that  
213 produces global, historical (1750 - present) estimates of anthropogenic acidifying gases  
214 (Hoesly et al., 2018). Emissions are estimated annually and resolved by country, sector, and  
215 fuel, and then gridded by year and sector with monthly seasonality. CEDSV estimates rely on  
216 existing energy consumption data sets and regional and country-specific inventories to  
217 produce emission trends over recent decades. A historical emissions dataset was released in  
218 2016 for use in research, including CMIP6. For more detailed information see  
219 [www.globalchange.umd.edu/CEDSV](http://www.globalchange.umd.edu/CEDSV)

220

### 221 2.2.4 MACCity

222 The MACCity emissions dataset is based on the ACCMIP (Atmospheric Chemistry and  
223 Climate - Model Intercomparison Project) historical emissions dataset developed by  
224 Lamarque et al. (2010) and combined with the IPCC AR5 future emissions scenarios called  
225 RCPs (Representation Concentration Pathways, Van Vuuren et al., 2011). The ACCMIP  
226 and the RCPs emissions dataset have been adapted and extended on a yearly basis for the  
227 period 1990-2010. Anthropogenic emissions were interpolated on a yearly basis between  
228 the base years 1990, 2000, 2005 and 2010. For the years 2005 and 2010, the RCP 8.5  
229 emissions scenario was chosen. For biomass burning emissions, the ACCMIP dataset was  
230 extended as well on a monthly basis.. Best reference to the data set is Lamarque et al  
231 (2010).

232

## 233 2.3 City emission data in South America

234 Local emission inventories are compiled for megacities in South America to address  
235 deteriorated air quality and implement measures to reduce concentration of air pollutants in  
236 these cities (D'Angiola et al., 2010; Gallardo et al., 2012a).

237 For each of the five countries, one city was selected to evaluate the local inventory  
 238 against emissions from down-scaled global inventories. A city inventory contains the  
 239 emissions occurring within the territory of the city (Table 3) and therefore the  
 240 corresponding emissions from global inventories are extracted based on the squared area  
 241 surrounding each city. To assess the impact of the choice of the area surrounding the city,  
 242 two domains are considered when extracting the city emissions from global inventories; a  
 243 small relatively tight domain following the city limits and a somewhat larger one to test if  
 244 potential sources that in fact belong to the city are not included in the smaller domain. This  
 245 method is rather crude and may introduce errors in the estimate, which are discussed in  
 246 section 4.  
 247

City	Country	Year (s)	Sectors	Pollutants	Reference
Buenos Aires	Argentina	1970-2012	Transport	PM <sub>10</sub> , NO <sub>x</sub> , SO <sub>2</sub> , CO, VOC	D'Angiola, et al., 2010
Bogota	Colombia	2012	Transport & Industry	PM <sub>10</sub> , NO <sub>x</sub> , SO <sub>x</sub> , CO, CO <sub>2</sub> , VOC	Rojas & Peñalosa, 2012; Pachón et al., 2018
Lima	Peru	2014	Transport, Residential, Industry	PM <sub>2.5</sub> , PM <sub>10</sub> , NO <sub>x</sub> , SO <sub>x</sub> , CO, CO <sub>2</sub> , VOC	Reátegui et al., 2018
Santiago	Chile	2012	Transport, Industry, Residential, Agriculture, Construction, Total	PM <sub>2.5</sub> , PM <sub>10</sub> , NO <sub>x</sub> , SO <sub>x</sub> , CO, CO <sub>2</sub> , VOC, CH <sub>4</sub> , NH <sub>3</sub>	USACH, 2014
Rio de Janeiro	Brazil	2013	Transport	TSP, NO <sub>x</sub> , SO <sub>x</sub> , CO	GQA, 2016

248 **Table 3:** Overview of cities data (city, year(s), pollutants, reference) – see section 3.1 (Please add reference to  
 249 each inventory)  
 250

## 251 2.4 Source sector definitions

252 The various global inventories used in this paper do not all share the same source sector  
 253 definitions. Therefore, we have aggregated several sectors to come to a common sector  
 254 breakdown (Table 4). This implies that individual inventories may have a more detailed

255 sector breakdown than we use here. For example, EDGAR provides emission data for 12  
 256 IPCC 1996 main source categories whereas we aggregate the data into 8 different sectors.  
 257

<i>Source sector</i>	Description
Agriculture	Agriculture
Power	Power generation, transformation industry and refineries
Industry	Combustion and process emissions from industry
FF_prod	Fossil Fuel production, exploration and transmission
Residential Combustion	Residential and small commercial stationary combustion
Waste	Solid waste disposal and waste incineration (without energy/heat production)
Transportation	Transport excluding international shipping and excluding international non-LTO <sup>a)</sup> aviation
Solvents	Use of solvents

258 **Table 4:** The aggregated source sectors used for intercomparison of selected inventories and city inventories.  
 259 Note that in this work, Agriculture does not include savanna burning, but does include agricultural waste  
 260 burning. Furthermore, CEDS includes agriculture waste burning under Waste – not under agriculture;  
 261 ECLIPSE includes flaring emissions.

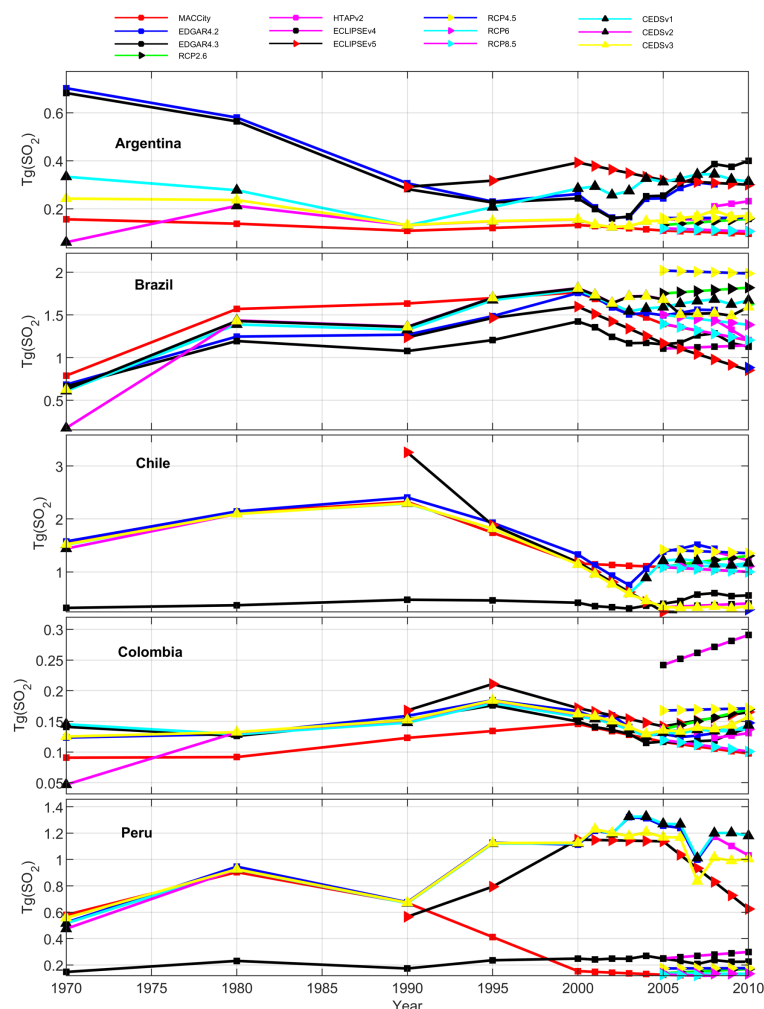
262 <sup>a)</sup> Landing and take off

## 263 3 Results

### 264 3.1 Emission inventories by pollutant and by country

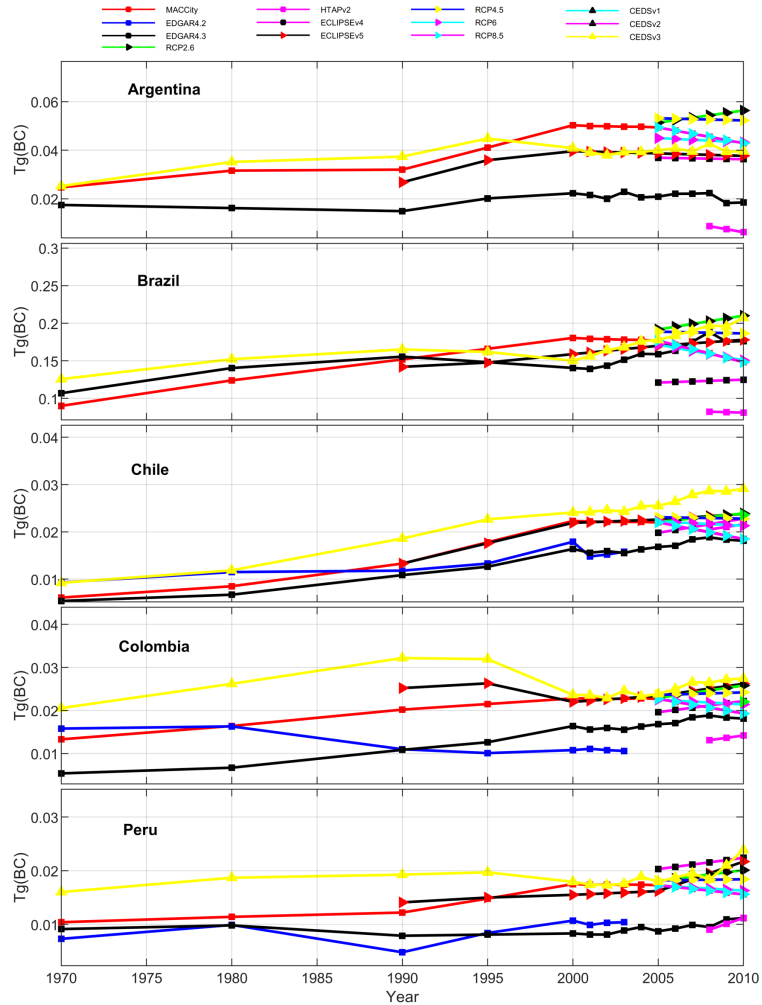
265 The SO<sub>2</sub> and BC emissions from the different global emission inventories (**Table 2**) for the  
 266 five SA countries are plotted as a function of time (Fig 2, Fig 3, respectively). Similar  
 267 figures for other pollutants are presented in Supplement material section 1 (Figures S01 to  
 268 S06). The main observation is that emission estimates from different inventories widely  
 269 vary and do not show a trend to converge. For some countries the early years vary widely  
 270 (e.g. Argentina SO<sub>2</sub>), while for others the discrepancy increases with time (e.g. Peru SO<sub>2</sub>).  
 271 Overall, discrepancies of a factor 2-3 are present for all countries and pollutants. Some of  
 272 the inventories shown in **Table 2** and Fig 2 and Fig. 3 are no longer considered up to date

273 but the overall overview is useful because these inventories were used in important global  
 274 assessments and it is not unlikely that those results may be sensitive to such differences in  
 275 emission data. We will not discuss all these discrepancies in detail. In general, it can be  
 276 stated that discrepancies between the emission inventories have multiple reasons including:  
 277 1. Emission factors may have been updated and improved over time.  
 278 2. Activity data may have been updated and improved over time.  
 279 3. New sources may have been identified over time.  
 280 4. The definition of which sources to be included in the inventory may differ between  
 281 inventories.



282  
 283  
 284  
 285  
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 287

**Figure 2:** Total annual sulphur dioxide (SO<sub>2</sub>) emissions [Tg/yr] for the period 1970 to 2010 for global emission inventories: MACCity, EDGARv2, EDGARv3, HTAPv2, ECLIPSEv4, ECLIPSEv5, RCP2.6, RCP4.5, RCP6, RCP8.5, CEDSv1, CEDSv2 and CEDSv3. See figure legend for colours and symbols associated to each inventory.



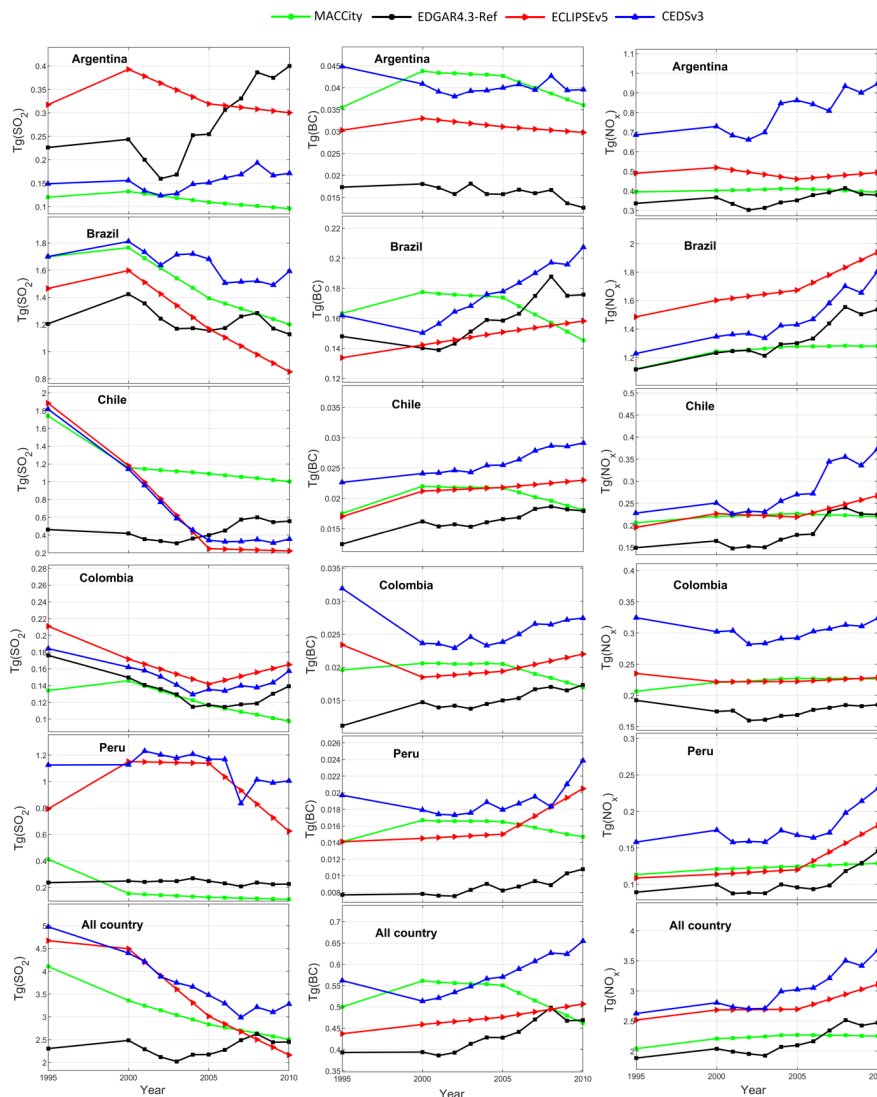
288

289 **Figure 3:** Same as Figure 2 but for black carbon (BC) and global inventories:  
 290 MACCity, PKU, Junker-Liousse, HTAPv2, ECLIPSEv4, ECLIPSEv5, RCP2.6, RCP4.5,  
 291 RCP6, RCP8.5, EDGARv3 and CEDSV3.

292

293 Based on the criteria outlined in section 2.3 we focus a further analysis on 4 recent  
 294 emission inventories; EDGAR 4.3.1, ECLIPSEv5, CEDSV3 and MACCity and restrict the  
 295 analysis only to the years 1995 to 2010. Subsequent versions of emission inventories can  
 296 differ substantially because of some of the reasons outlined above. Compare for example  
 297 Eclipse v4 and v5; CEDSV1 and v3 in Figure 2 and Figure 3. Klimont et al. (2017)  
 298 document that the major change between their ECLIPSE v5 and previous ECLIPSE  
 299 versions is that IEA and FAO statistical data were reimported for the period 1990-2010,  
 300 international shipping was included and that their global BC numbers are higher than  
 301 previously published owing primarily to inclusion of new sources. Another, often

302 overlooked issue is the inclusion or exclusion of semi-anthropogenic sources like forest  
 303 fires or agricultural waste burning. Compare for example HTAPv2.2 and EDGARv4.3.1 in  
 304 Figure 3 for Brazil. The emissions for all source sectors are equal but HTAPv2.2 excludes  
 305 agricultural waste burning, and EDGARv4.3 includes it. In SA this is a relevant source and  
 306 therefore HTAPv2.2 and EDGARv4.3.1 appear different inventories but the difference is  
 307 simply a result of inclusion or exclusion of agricultural waste burning. Out of simplicity,  
 308 the version of each inventory will be omitted henceforth and thus inventories will be  
 309 referred to as EDGAR, ECLIPSE and CEDS.



310

311 **Figure 4:** Total annual emissions of SO<sub>2</sub> (left), BC (centre) and NO<sub>x</sub> (right) [Tg/yr]  
 312 for global inventories MACCity (green), EDGAR4.3 (black), ECLIPSEv5 (red) and  
 313 CEDSv3 (blue) for the period 1995 to 2010.

314 It is also important to note that emission inventories may show comparable patterns  
315 for one country and significantly diverse patterns for another country. Differences are seen  
316 in terms of trend and/or magnitude and this will be mostly related to different key source  
317 contributions in different countries. For SO<sub>2</sub> these differences are seen both in terms of  
318 trends for Argentina and magnitude for Colombia and Peru (Figure 4). Whereas for NO<sub>x</sub>  
319 and BC, differences are mostly in terms of magnitude; see for example Argentina and  
320 Colombia for NO<sub>x</sub> and Brazil and Chile for BC (Figure 4) (See figures S7 to S10 for  
321 equivalent figures of the other pollutants considered in this work). We highlight that for  
322 most species the SA year-to-year variability (lower panels) is dominated by emissions in  
323 Brazil except for SO<sub>2</sub> and NO<sub>x</sub>. For SO<sub>2</sub> annual variability is also determined by emissions  
324 in Chile and Peru resulting from their mining activities. Argentina also contributes to the  
325 SA year-to-year variability for NO<sub>x</sub> emissions.

326 In addition to the spread in total emissions presented above, the EIs also differ in the  
327 relative contribution of each sector (Table S1 in supplement material). While the diversity  
328 between the emission inventories is small for SO<sub>2</sub> and NH<sub>3</sub> it is considerable for the other  
329 species. A more detailed description of this diversity in sectorial emissions between  
330 inventories is provided in the supplement material.

331

### 332 3.2 Particulate matter emissions

333 Particulate matter and its components, BC and OC are important species for air quality,  
334 health and climate change (Bond et al, 2013; IPCC, 2018). Next to BC and OC, PM<sub>2.5</sub>  
335 and/or PM<sub>10</sub> can contain other components like sulphates, nitrates and mineral particles but  
336 in combustion emissions the bulk is BC + OC. Therefore, looking at BC+OC in relation to  
337 PM provides information on the type of emission factors used. Moreover, theoretically  
338 BC+OC cannot exceed PM<sub>2.5</sub> as BC and OC emissions are smaller than 2.5 µm. The  
339 contribution of BC and BC+OC to PM<sub>2.5</sub> as well as the contribution of PM<sub>2.5</sub> to PM<sub>10</sub> is  
340 analysed in more detail in Table 5. In addition, we pay attention to the ratio of CO to NO<sub>x</sub>  
341 (Table 5), which may provide insights into the role of traffic emissions (Monks et al, 2015;  
342 Gallardo et al, 2012a; Vivanco and Andrade, 2006). Note that the present analysis and  
343 Table 5 are only for Transport emissions.



344 EDGAR has in general larger BC content in PM<sub>2.5</sub> than ECLIPSE except for Chile. In  
345 both inventories this contribution increases from 1995 to 2010 except for Argentina, and  
346 this increase is larger in ECLIPSE than EDGAR. Although BC is the product of incomplete  
347 combustion, such a trend can be explained by better combustion at higher temperatures,  
348 which first causes less particulate OC formation, and in a later, further advanced stage may  
349 also reduce the formation of BC. For the fraction of BC+OC in PM<sub>2.5</sub>, EDGAR presents the  
350 same features as for BC; decreasing trend in Argentina and increasing one in the other  
351 countries and the largest increase in Chile. This similarity between both ratios is likely due  
352 to the use of the same drivers to estimate the emissions. However, ECLIPSE does not seem  
353 to use the same drivers to estimate BC and OC emissions; while for the ratio BC/PM<sub>2.5</sub> the  
354 country with the largest growth was Colombia, for the ratio (BC + OC)/PM<sub>2.5</sub> Chile and  
355 Peru presented the largest increase. We note that both, Argentina and Peru, have unrealistic  
356 fractions larger than 1 in EDGAR (Table 5)<sup>1</sup> The use of independent OC emission factors  
357 in EDGAR (that is, independent from PM<sub>2.5</sub>) could explain these unrealistic values and  
358 allow BC+OC to be larger than PM<sub>2.5</sub>. In addition, EDGAR considers that all emitted PM<sub>10</sub>  
359 for road transport is also PM<sub>2.5</sub> while ECLIPSE estimates the coarse PM fraction (PM<sub>10</sub>-  
360 PM<sub>2.5</sub>) to be approximately 10%, and gradually increasing over time from approximately  
361 8% to 11%. Finally, the CO/NO<sub>x</sub> ratio decreases over time with a comparable decrease in  
362 both inventories. When comparing the ratios CO/NO<sub>x</sub> by country and across the years we  
363 see a consistent lower CO/NO<sub>x</sub> ratio for ECLIPSE compared to EDGAR. Yet, while in  
364 EDGAR, both Argentina and Chile show an increasing trend since 2005; in ECLIPSE only  
365 Chile presents this trend. The CO/NO<sub>x</sub> emission ratios are important for atmospheric  
366 chemistry and composition. If better national data would be available, this discrepancy  
367 should be analysed and reconciled or at least better understood as it highlights a  
368 fundamental difference.

369

370

371

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<sup>1</sup> This is now corrected in version EDGARv4.3.2 where the PM<sub>2.5</sub>biofuel, PM<sub>2.5</sub>fossil and BC and OC have been revised and a ratio smaller than 1 is guaranteed for the sum of BC and OC over the sum of PM<sub>2.5</sub>fossil and PM<sub>2.5</sub>biofuel.

Transp.	EDGAR4.3.1-Ref			ECLIPSEv5			EDGAR4.3.1-Ref	ECLIPSEv5
1995	BC/PM2.5 (BC+OC)/ PM2.5/PM10 PM2.5			BC/PM2.5 (BC+OC)/ PM2.5/PM10 PM2.5			CO/NOx	CO/NOx
Argentina	0.71	1.18	1.00	0.45	0.82	0.94	14.28	5.51
Brazil	0.52	0.86	1.00	0.45	0.82	0.93	9.57	6.31
Chile	0.38	0.63	1.00	0.44	0.84	0.91	16.77	7.76
Colombia	0.48	0.80	1.00	0.20	0.78	0.91	28.71	12.26
Peru	0.65	1.08	1.00	0.36	0.81	0.92	12.57	5.88
<b>2000</b>								
Argentina	0.69	1.14	1.00	0.48	0.84	0.94	9.70	4.01
Brazil	0.53	0.89	1.00	0.48	0.84	0.92	8.86	5.51
Chile	0.51	0.81	1.00	0.48	0.87	0.90	17.87	6.76
Colombia	0.48	0.79	1.00	0.33	0.80	0.89	23.14	10.17
Peru	0.63	1.04	1.00	0.44	0.85	0.92	10.43	5.46
<b>2005</b>								
Argentina	0.67	1.09	1.00	0.50	0.83	0.93	8.16	3.28
Brazil	0.50	0.83	1.00	0.50	0.84	0.91	7.22	4.81
Chile	0.46	0.73	1.00	0.54	0.90	0.89	11.36	5.08
Colombia	0.52	0.84	1.00	0.39	0.81	0.89	17.66	8.13
Peru	0.71	1.15	1.00	0.48	0.86	0.91	9.27	4.55
<b>2010</b>								
Argentina	0.69	1.13	1.00	0.53	0.85	0.92	13.02	3.13
Brazil	0.54	0.88	1.00	0.53	0.87	0.90	6.11	3.56
Chile	0.50	0.79	1.00	0.57	0.93	0.86	12.01	5.42
Colombia	0.52	0.84	1.00	0.46	0.82	0.89	11.51	5.88
Peru	0.84	1.32	1.00	0.51	0.88	0.89	7.52	3.74

372 **Table 5:** Road transport emission fraction of BC in PM2.5, BC+OC in PM2.5, fraction of PM2.5 in PM10  
373 and CO/NOx ratio for EDGAR and ECLIPSE.

374 Note: the color scale only applies to CO/NOx one can see that it becomes lighter from 1995 to 2010 and that  
375 EDGAR CO/NOx ratio tends to be higher than ECLIPSE

376

### 377 3.3 Comparison of city emission data with global inventories

378 Emission estimates from local and global inventories are intercompared for total  
379 emission as well as individual source sectors (Transport, Industry and Residential)

380 whenever available. To keep the comparison transparent only EDGAR and ECLIPSE are  
381 considered in this analysis because CEDS partly relies on EDGAR and other inventories.  
382 One city per country was selected; namely Bogota, Buenos Aires, Lima, Rio de Janeiro and  
383 Santiago (Table 3). Unfortunately, the local city inventories differ substantially in terms of  
384 sectors included, period and pollutants considered (Table 3). Furthermore, while both  
385 global EIs are available for the year 2010, the local city EIs are only available for specific  
386 years and the year nearest to 2010 was selected (Table 3). The corresponding emission  
387 from the global EIs for a given city was derived by considering emissions within a squared  
388 domain surrounding the city. To assess the sensitivity of the method, two domains are  
389 considered; a small one with its limits in the vicinity of the city and a larger one  
390 considering potential sources excluded in the smaller domain. Maps illustrating each  
391 domain as well as the emissions included in each one are provided in the supplement  
392 material (Figure S11 to S13).

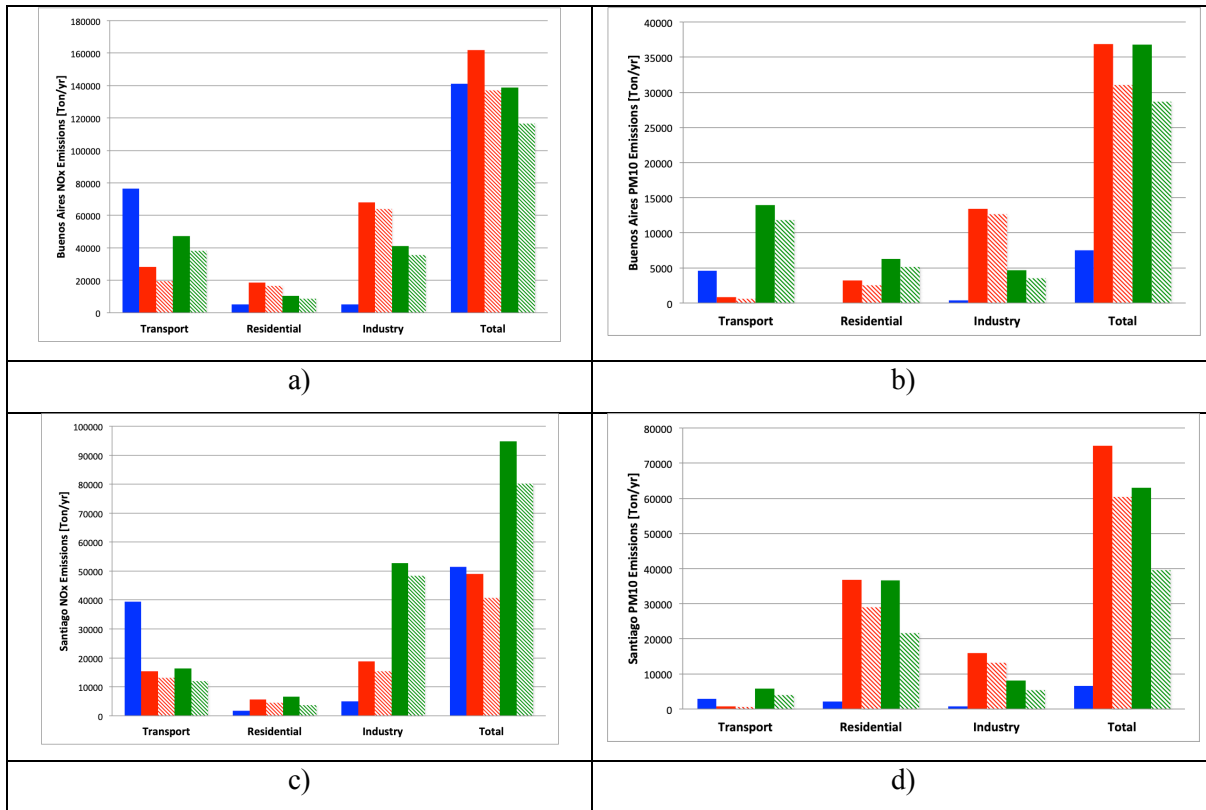
393 The total emissions from Santiago and Buenos Aires (the only two cities with  
394 emission estimates for all sectors) will be analyzed first and then the analysis will be  
395 extended to sectorial emissions for the remaining cities. We focus on two pollutants; NO<sub>x</sub>  
396 and PM<sub>10</sub>, since the goal of this analysis is not to validate either inventory but to highlight  
397 differences between them and identify the impact of local information in the estimate. In  
398 **Table 6** an overview is given for the cut-out from EDGAR and ECLIPSE that represents the  
399 Santiago and Buenos Aires metropolitan areas by sector and how it relates to national total  
400 emissions. Knowing that over 1/3 of Argentina's and Chile's population live in their  
401 corresponding capitals (Buenos Aires and Santiago, respectively) their share of Transport  
402 emissions appears small but an in-depth analysis by inventory would be needed to fully  
403 understand this. Furthermore, regardless of the domain considered, ECLIPSE attributes a  
404 larger fraction of the total national transport emissions to both cities than EDGAR while the  
405 opposite occurs for industrial emissions. For residential and total emissions, percentages  
406 between both inventories and for both domains are comparable. In terms of NO<sub>x</sub> emissions,  
407 for Buenos Aires both inventories assign comparable percentages of the total emissions to  
408 transport but differ for residential and industrial emissions. In spite of these differences,  
409 both inventories allocate comparable fractions of the national total emissions to Buenos  
410 Aires. On the contrary, for Santiago both inventories present comparable percentages for

411 transport and industrial emissions but differ in residential and total emissions. Detailed,  
412 spatial explicit national inventories for Argentina and Chile would be extremely useful to  
413 elucidate the reasons for the discrepancies highlighted above. For EDGAR the geospatial  
414 proxy data have been disclosed in Janssens-Maenhout et al. (2017) for the sake of  
415 transparency but exactly why higher or lower shares of emissions are attributed to the city  
416 remains unclear.

417         The relative magnitude of total NO<sub>x</sub> emissions for both cities depend on the domain  
418 or regions considered to estimate the city emission from global inventories. EDGAR  
419 presents for Buenos Aires comparable emissions to the local inventory when the smaller  
420 domain is considered and larger emissions when using the larger domain, whereas the  
421 contrary is observed for Santiago where the estimate based on the larger domain is  
422 comparable to the local inventory and the one based on the smaller domain presents smaller  
423 emissions than the local one (Figure 5). Spatial distribution of the emission in each city  
424 explains this opposite behavior; while for Buenos Aires most of the city NO<sub>x</sub> emissions are  
425 distributed within the city domain enclosed by the smaller domain, for Santiago the  
426 emissions are distributed beyond the city limits and fall thus outside of the smaller domain  
427 but are captured by the larger one (Figure S12e and S12n in the supplement material).  
428 Contrary to EDGAR for Santiago, ECLIPSE presents larger emissions than the local  
429 inventory regardless of the domain used to estimate the city emissions. For Buenos Aires  
430 however, the estimate based on the larger domain is comparable to the local inventory  
431 while the estimate based on the smaller domain is smaller than the local inventory. The  
432 local inventories in both cities estimate smaller emissions for the Transport sector (Figure  
433 5). The contrasting estimates between Transport sector and the Residential and Industrial  
434 sectors between the Global EIs and the local city EIs may be partly related to the  
435 distribution proxies used in the global inventories but the impact on total emissions  
436 attributed to the cities is large (Figure 5).

437         Except for Transport, both EIs (and regardless of the domain used to estimate the city  
438 emissions) present larger PM<sub>10</sub> emissions than local inventories for both cities. Finally, for  
439 total emissions both inventories present comparable emissions for Buenos Aires whereas  
440 for Santiago EDGAR presents larger emissions than ECLIPSE per domain.

441



442 **Figure 5:** Total and sector emissions (Transport, Residential and Industry) of NOx  
 443 and PM10 for Buenos Aires (a and b, respectively) and Santiago (c and d, respectively)  
 444 from local EIs (blue) as well as global EIs EDGAR (red) and ECLIPSE (green). Estimates  
 445 for a large (filled) and small (shaded) domain are included for each global EI. See figure  
 446 S01 for limits of each domain and city boundaries.  
 447

448 The analysis is extended to all selected cities for the Industrial, Residential and  
 449 Transport sector. Emissions from both global inventories are presented only when a local  
 450 inventory is available for comparison (Figure S14 in supplement material). The analysis  
 451 focuses on cities not analyzed before, namely Bogota and Lima. Residential and Industrial  
 452 emissions present the same features for both pollutants; global inventories are mostly larger  
 453 than the local ones. While in general EDGAR emissions are larger than ECLIPSE ones for  
 454 both sectors in Bogota the opposite is seen for Lima where ECLIPSE is larger than  
 455 EDGAR. We note that for Lima, estimates for each inventory between both approaches are  
 456 mostly the same indicating that allocation of the sources are confined within the city  
 457 included in the smaller domain. The opposite of Residential and Industrial emissions is  
 458 seen in the Transport sector for NOx where the local inventories are mostly larger than the  
 459 global ones (probably due to the geospatial allocation of roads x population into the city).

460 Exception to this is Rio de Janeiro where based on the domain considered for the estimate  
 461 the estimates are either larger (EDGAR based no large domain), smaller (ECLIPSE based  
 462 on small domain) or comparable to the local inventory. For PM10 emissions from the  
 463 Transport sector, EDGAR mostly estimates smaller emissions than the local inventory  
 464 whereas ECLIPSE in general estimates larger emissions with the exception of Lima where  
 465 they are comparable with the local inventory.

466 Although the magnitude of the estimated emissions from the global inventories for  
 467 each city depends on the region considered, the results with respect to the local inventories  
 468 are in general independent of the selected domain.

469

	EDGAR				ECLIPSE			
	Transport	RCO	Industry	All sectors	Transport	RCO	Industry	All sectors
<b>PM10</b>								
(tons/yr)								
Buenos Aires	580 (868)	2491 (3192)	12643 (13424)	<b>31020</b> <b>(36836)</b>	11805 (13943)	5146 (6295)	3553 (4647)	<b>28655</b> <b>(36814)</b>
Percentage of national total	6% (8%)	26% (33%)	28% (30%)	<b>8%</b> <b>(9%)</b>	24% (29%)	31% (38%)	8% (11%)	<b>11%</b> <b>(15%)</b>
Santiago	618 (751)	28976 (36834)	13170 (15989)	<b>60396</b> <b>(74994)</b>	3994 (5842)	21635 (36640)	5398 (8182)	<b>39611</b> <b>(62920)</b>
Percentage of national total	4% (5%)	31% (39%)	38% (47%)	<b>25%</b> <b>(31%)</b>	27% (39%)	25% (43%)	10% (15%)	<b>21%</b> <b>(34%)</b>
<b>NOx (tons/yr)</b>								
Buenos Aires	19386 (28285)	16664 (18545)	64053 (68106)	137160 (161879)	38348 (47182)	8760 (10442)	35508 (41205)	116671 (138942)
Percentage of national total	10% (15%)	68% (75%)	75% (80%)	29% (34%)	12% (14%)	45% (54%)	51% (59%)	23% (28%)
Santiago	13125 (15299)	4420 (5564)	15398 (18769)	40774 (49008)	12005 (16360)	3644 (6546)	48420 (52740)	80195 (94801)
Percentage of national total	13% (15%)	51% (64%)	47% (57%)	17% (21%)	9% (13%)	39% (70%)	53% (58%)	30% (35%)

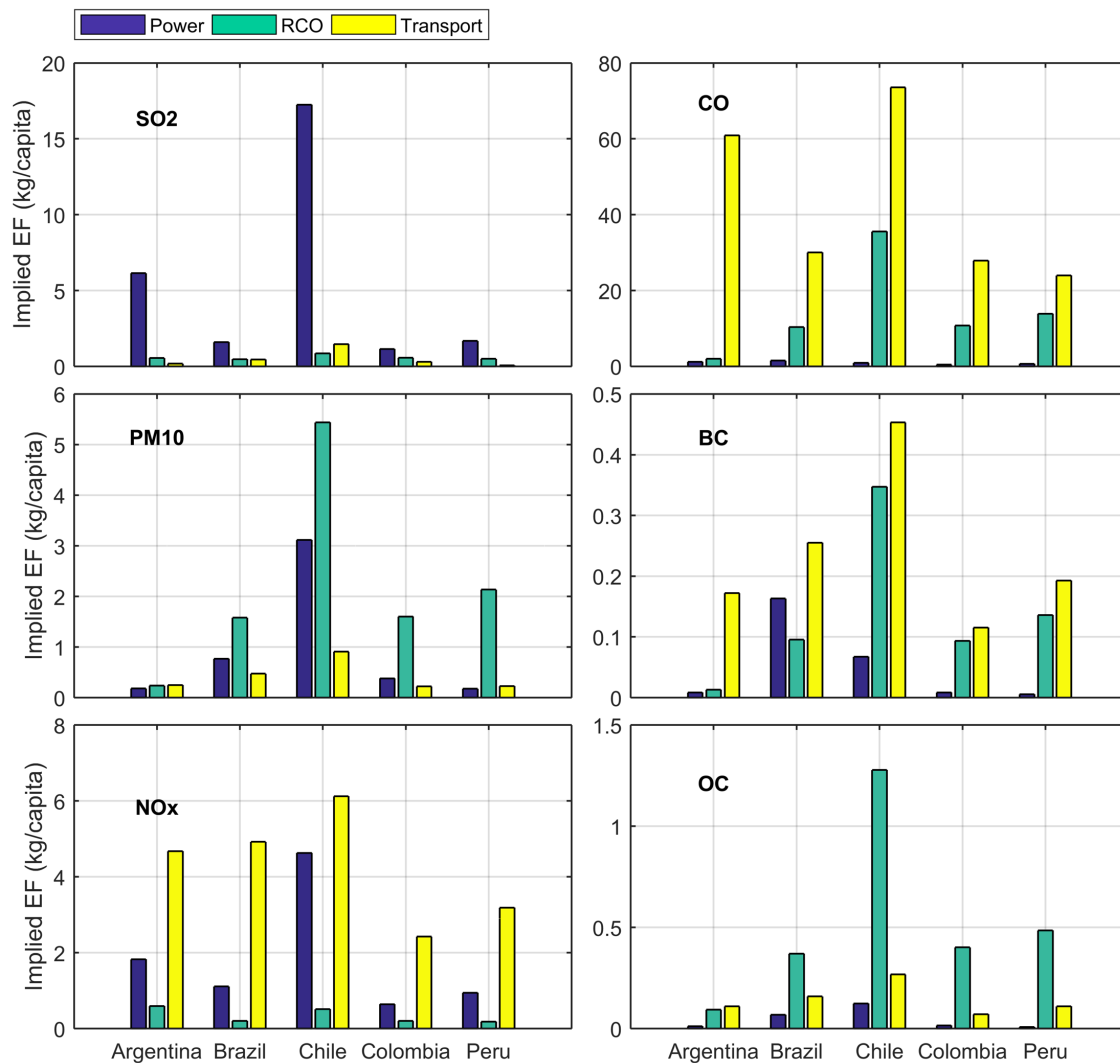
470 **Table 6:** Extracted city domain emissions of small (large) domain for Buenos Aires and Santiago for PM10  
 471 and NOx in 2010 and the fraction of national total emissions located in the city domain for 2010  
 472

## 473 4 Discussion.

474 Brazil is the largest emitter of all analyzed species, except for SO<sub>2</sub> where its  
 475 emissions are comparable with those from Chile and Peru. This is not surprising as it is the  
 476 largest and most populated country in SA. However, when emissions are considered per  
 477 capita, i.e. they are normalized by population, this domination of Brazil disappears (Figure

478 6 and 7). To limit the amount of data, we only present normalized data for the inventories  
479 ECLIPSE and EDGAR, including more inventories would not give significantly different  
480 insights. We only normalize sectors by population if population has a direct link with  
481 activities causing emissions, such as heating of houses (residential), commuting (transport)  
482 and industrial heat/power use. For sectors like agriculture and industry, population is not a  
483 good proxy to normalize emissions. Normalization by population of EDGAR emissions  
484 reveals that Chile is, in general, the country with the largest emissions per capita among  
485 these five countries. Chile stands out as the largest emitter per capita for SO<sub>2</sub>, PM<sub>10</sub> and OC  
486 mostly related to the residential sector and power generation (Figure 6). For BC, Chile is  
487 also dominating due to transport and residential emissions. Finally, emissions of CO and  
488 NO<sub>x</sub> are dominated by the transport sector where again Chile has the largest emissions per  
489 capita, but those from Argentina and Brazil follow with smaller differences than for the  
490 other species. Normalization of ECLIPSE emissions by population presents similar figures  
491 as EDGAR for the power and residential sector with larger implied emission factors (EF)  
492 for EDGAR in the power sector but in general, smaller ones in the residential sector (Figure  
493 7). Largest differences between both inventories are seen in the transport sector. While  
494 Chile is the largest emitter per capita for PM<sub>10</sub>, BC, OC and NO<sub>x</sub> according to EDGAR, the  
495 largest emitter according to ECLIPSE is Argentina. Part of the differences can be  
496 understood from geographical data. Chile is the country with a substantial amount of the  
497 population living in the South with cold winters and residential emission will be much  
498 higher in a cold climate, hence higher per capita emissions for residential sector. Another  
499 explaining factor is the economic development, in a relatively affluent country like Chile  
500 (see Fig 1) more people will own a car or have access to transportation and as a result more  
501 vehicle km (vkm) and transport emissions per person can be expected. This, however,  
502 already becomes more difficult to generalize because a more affluent country will have a  
503 more modern car fleet with less emission per vkm, but more vkm still create more  
504 emissions. So, while per capita transport emissions in Chile rank high (Figure 6 and 7), per  
505 vkm they would probably be lower than some of the other countries. The data for power are  
506 most difficult to interpret. For SO<sub>2</sub> it is related to the S content in the fuel used but more  
507 important we may have to correct for (small) industrial power use and we lack the data to  
508 properly do this. Also climatic differences may play a role. In general the normalization in

509 Figure 6 and 7 suggests we may expect that per capita emissions from Colombia and Peru  
 510 will still grow.  
 511

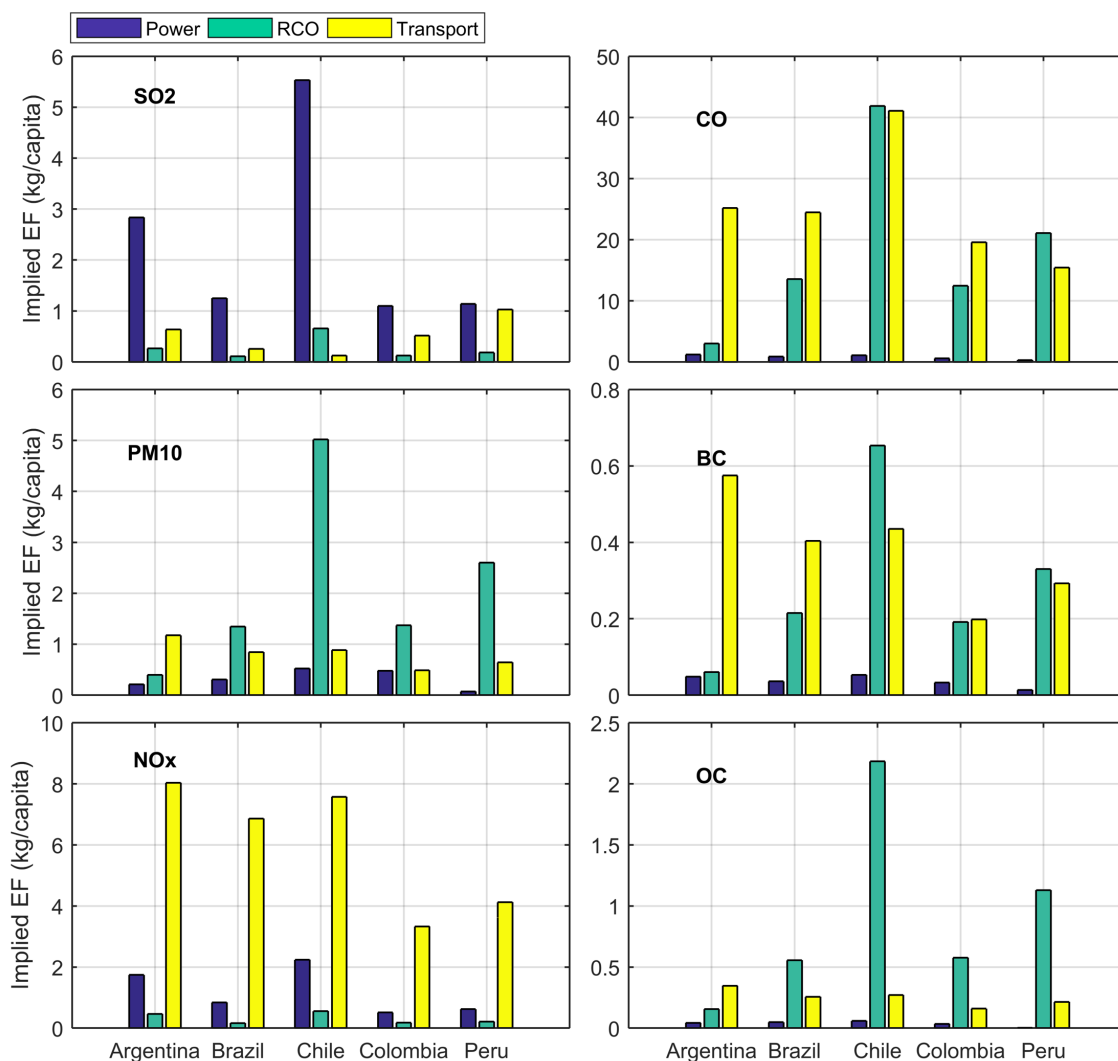


512  
 513 **Figure 6:** Normalized (by population) national emissions of SO<sub>2</sub>, CO, PM<sub>10</sub>, BC,  
 514 NO<sub>x</sub> and OC from the global inventory EDGAR for Transport (yellow), RCO (green) and  
 515 Power (blue) sector for the five selected countries (Argentina, Brazil, Chile, Colombia and  
 516 Peru).

517  
 518 Global Inventories use generic statistical country data to estimate emissions by  
 519 combining for example transportation fuel sales data with emissions factors (e.g. Klimont et  
 520 al. 2017, Crippa et al., 2018). Using road transport as an example, it is known that he



521 emission factors are strongly dependent on the engine technology, type of fuel and fuel  
522 quality. The latter is highly variable and rapidly changing in SA. Global scale inventories  
523 try to capture this change over time but can only do so in a rather generic way, at best for  
524 individual countries but often by grouping multiple countries in similar “stage of  
525 technology development” classes. However, for air quality modelling and exposure in  
526 major cities the patterns in, and within, individual countries are important. This is  
527 illustrated with diesel fuel in Argentina as an example (Table 7). Argentina has three grades  
528 of diesel; Grade 1 (Agrodiesel or Gasoil Agro), is intended mainly for agricultural  
529 equipment. Grade 2 (Gasoil Común; common diesel fuel), is intended for the bulk of diesel  
530 fuelled vehicles and the sulphur limit of 500 ppm is not strictly enforced. Grade 3 diesel  
531 fuel, also known as Gasoil Ultra, is the highest quality diesel fuel. Another complication is  
532 that a policy or resolution may be accepted but the delay in implementation can be  
533 substantial; as seen in Table 7; a resolution for low sulphur fuels was accepted in 2016 but  
534 availability on the market is not expected until 3 years later. This kind of details are  
535 important but often only known by local or national experts. In the supplement material we  
536 provide additional information on sulphur contents in fuel and its evolution in SA (see  
537 Table S2), illustrating the importance of national and subnational policies. However, from  
538 **Table 7** we can already see how challenging proper incorporation and spatial distribution  
539 will be for global emission inventories. Various grades may exist next to each other and  
540 will be implemented differently across the country, severely affecting the emissions in  
541 urban population centers. The example of the complex temporal and spatial implementation  
542 of the sulphur fuel standards shows the importance of working with local and national  
543 teams, especially when high resolution and spatial distribution is important to predict  
544 exposure and define mitigation measures. For global scale studies these details will be of  
545 limited importance but when understanding the air pollution in South American cities or  
546 regions it may be crucial. Also, when assessing climate impacts and mitigation options this  
547 may become increasingly important.



548

549

**Figure 7:** Same as Figure 6 but for global inventory ECLIPSE.

550

Grade	name	Sulphur limit (ppm)				
		2006	2008	2009	Current	June 2016 <sup>a)</sup>
1	Agrodiesel or Gasoil Agro	3000	2500	2000	1500	1000
2	Gasoil Comun	1500 <sup>b)/</sup> 2500	1500 <sup>b)/</sup> 2000	500 <sup>b)/</sup> 2000	500	30
3	Gasoil Ultra	500	500	50	10	10

551

**Table 7:** Stepwise changes in diesel Sulphur limits in Argentina since 2006.

552

<sup>a)</sup> Date of resolution, market availability is expected in 2019.

553

<sup>b)</sup> Sold in high population zones (more than 90,000 inhabitants, since 2008 50,000 inhabitants)

554

555 The analysis of local city emission estimates against results from global inventories  
556 for the corresponding domain strongly highlight the importance of including local  
557 information. The emission estimates are dramatically different. If emissions are to be  
558 applied to forecast air quality and/or to develop mitigation measures the results from down-  
559 scaled global inventories as compared to local city data will be entirely different. To come  
560 to more general conclusions we have calculated the ratio by source sector for the down-  
561 scaled emissions from the global inventories and the local city inventories (Table 8). In this  
562 table a value smaller than 1 indicates that the local estimate is higher (green shading), a  
563 value higher than 1 indicates the down-scaled estimate is higher (orange shading). The  
564 sectors industry and power had to be grouped because in the city inventories this is often  
565 one category. A comparison for total emissions could only be made for Santiago and  
566 Buenos Aires because other city inventories are not complete. However, for these two cities  
567 the sectors transportation, RCO and Industry and power represent  $62 \pm 10\%$  and  $79 \pm 9\%$  of  
568 the emissions for PM10 and NOx, respectively. Hence, the comparison of the other cities is  
569 likely to cover at least the most important sectors and emissions.

570 Except for Lima, for each global inventory the magnitude of the estimated emission  
571 between the two domains (large and small) is mostly different, yet the relative magnitude to  
572 the local inventory is in general independent of the selected domain with the exception of  
573 total NOx Emissions in Buenos Aires from EDGAR and transport PM10 emissions in  
574 Bogota and NOx emissions in Lima from ECLIPSE. Therefore, the following analysis will  
575 focus on the dominant features between the local inventory and the equivalent estimate  
576 from each global inventory.

577 The result show that transportation emissions are estimated to be higher in local city  
578 inventories in most of the cities, except for Rio de Janeiro where global inventories are  
579 higher than the local inventory. Sometimes the result is close to 1 (e.g. PM10 ECLIPSE for  
580 Lima) but more often the discrepancies are large up to a factor of 5 (e.g. NOx ECLIPSE for  
581 Santiago) or even up to a factor of 10 when the NOx ECLIPSE estimate for Lima based on  
582 the small domain is considered. This is remarkable because the selected cities represent a  
583 large fraction of the national population and transport emissions are assumed to be in some

584 way proportional to population, and in the case of Santiago 40% of the Chilean population  
 585 lives in the Santiago Metropolitan region.

586  
 587

City	Inventory	Transport		Residential		Industry		Total	
		PM10	NOx	PM10	NOx	PM10	NOx	PM10	NOx
Bogota	Local	1 <sup>a)</sup>	1	NA <sup>a)</sup>	NA	1	1	NA	NA
	EDGAR-S	0.44	0.19			5.5	3.1		
	EDGAR-L	0.54	0.24			8.1	4.3		
	ECLIPSE-S	0.96	0.07			1.2	3.1		
	ECLIPSE-L	2.25	0.22			3.1	3.8		
Lima	Local	1	1	1	1	1	1	NA	NA
	EDGAR-S	0.30	0.52	49	5.4	8.7	32		
	EDGAR-L	0.35	0.60	50	5.6	8.7	32		
	ECLIPSE-S	1.1	0.17	76	8.2	14.2	39		
	ECLIPSE-L	1.1	0.17	76	8.2	14.2	39		
Rio de Janeiro*	Local	1	1	NA	NA	NA	NA	NA	NA
	EDGAR-S	0.60	1.3						
	EDGAR-L	0.96	1.9						
	ECLIPSE-S	3.0	0.44						
	ECLIPSE-L	5.2	1.1						
Santiago	Local	1	1	1	1	1	1	1	1
	EDGAR-S	0.21	0.33	13	2.5	18	3.1	9.2	0.79
	EDGAR-L	0.26	0.39	17	3.1	22	3.8	11	0.95
	ECLIPSE-S	1.4	0.31	10	2.0	7.3	9.8	6.0	1.6
	ECLIPSE-L	2.0	0.42	17	3.7	11	11	9.6	1.8
Buenos Aires	Local	1	1	1	1	1	1	1	1
	EDGAR-S	0.13	0.25	6.2	3.2	32	12	4.1	0.97
	EDGAR-L	0.19	0.37	8.0	3.6	34	13	4.9	1.2
	ECLIPSE-S	2.6	0.50	13	1.7	8.9	6.7	3.8	0.83
	ECLIPSE-L	3.0	0.62	16	2.0	12	7.7	4.9	0.98

588 **Table 8:** Ratio of city domain inventory over local city inventory for PM10 and NOx emissions for transport,  
 589 RCO and industry & power. A comparison of total emissions could only be done for Santiago and Buenos  
 590 Aires.

591 <sup>a)</sup> NA = Not Available; A ratio of 1 for the local inventory indicates the source sector is estimated, if no sector  
 592 estimate is available in the local inventory, a ratio for EDGAR or ECLIPSE could not be calculated.

593 \*PM as TSP in local

594

595 In contrast with the emissions from the transportation sector, the emissions from other  
 596 sectors (Residential and Industry & Power) are overwhelmingly larger in the downscaled  
 597 global inventories. The discrepancies can easily amount to a factor 10 or more with an

598 extreme of a factor 70 for ECLIPSE PM10 from the Residential sector in Lima. An  
599 overestimation in down-scaled global inventories for RCO emissions is not surprising as  
600 they are likely to use population density as a proxy, whereas national or cities information  
601 may have better data on which fuels are used where in the country; e.g. more in rural or  
602 colder mountainous areas. As a result the ratio for the total emission (Table 8, right  
603 column) comes again closer to 1 but the unbalance in individual sectors suggests that this is  
604 a case of a better fit for the wrong reasons. Moreover, for air quality modelling emission  
605 height and emission timing which vary by source sector are important and for mitigation  
606 measures the sector information is crucial. While we highlight that the local information is  
607 crucial, it should be acknowledged that this is often lacking (only 2 cities provide a  
608 complete inventory) and the use of downscaled global inventories is the only option. A  
609 deeper understanding is further hampered by the scarcity of national total emission  
610 inventories. For example if the national total emission for transport between EDGAR or  
611 ECLIPSE and a national inventory would be similar but the ratio for the major city would  
612 be really different, we would know that this is due to spatial distribution and much less  
613 likely a fundamental difference in activity and emission factors used. So, national country  
614 wide emission inventories are not only needed to model air quality on the national scale but  
615 also to place city emissions in perspective. Such an analysis was made by Puliafito et al.  
616 (2017) for Argentina by comparing their national inventory (GEAA) with EDGAR.  
617 Although the estimated CO<sub>2</sub> emissions were very close (within 1%), large differences were  
618 found for the air pollutants with the national inventory being 1.7, 1.1, 1.4 higher for NO<sub>x</sub>,  
619 PM10 and PM2.5 but only 0.4 times the EDGAR estimate for SO<sub>2</sub>. In line with our results  
620 in Table 8, the attribution to source sectors was often dramatically different partly masking  
621 the difference in the totals. Moreover, Puliafito et al. (2017) conclude that the spatial  
622 distribution by EDGAR was not adequate for Argentina, especially for transport and  
623 residential sectors, leading to an overestimation in rural areas and an underestimation in  
624 urban areas. We refer to Puliafito et al. (2017), for a more detailed analysis.

625 In addition to the differences of the fraction of national emissions allocated to the  
626 different cities in the global inventories, we note that the spatial distribution of these  
627 emissions vary largely not only between the inventories but also with respect to the  
628 physical location of the actual city (Figure S12 and S13 in the Supplement material). For

629 example, ECLIPSE locates most of the emissions of Santiago outside the city limits  
630 extending even over the Andes to the border with Argentina. Similarly, EDGAR although  
631 partially distributes the emissions within the city, they are centred on the northern border  
632 and an important fraction is outside the city limits.

633

## 634 5 Conclusions

635

636 Air quality modeling and exposure assessment needs, next to a validated chemistry  
637 transport model, two critical inputs; meteorological data and emissions data. National  
638 emission inventories in South America have focused on GHG as part of their obligations to  
639 the UNFCCC. Only for Argentina a national emission inventory of air pollutants has recently  
640 been released (Castesana et al., 2018; Puliafito et al., 2015, 2017). Hence, studies assessing  
641 air quality at national, regional or continental scale in SA have been relying on global  
642 emission data sets. Several global emission inventories provide estimates for the selected  
643 SA countries (Argentina, Brazil, Chile, Colombia and Peru) for the past and present. These  
644 have been compiled and compared here with a further analysis focusing on three recent  
645 inventories (EDGAR 4.3.1, ECLIPSEv5, and CEDSv3) as they include data at least up to  
646 2010 and can be compared with recent national or city scale emissions estimates.  
647 Emissions from these global inventories are compared against available city-scale  
648 inventories for a major city in each country by selecting the spatial domain from the  
649 gridded data of the global inventory. Large discrepancies are found both between the global  
650 datasets as well as when comparing downscaled global emissions data with local/national  
651 city emissions data for the same domain. A direct conclusion of these discrepancies is that  
652 it is not recommended to use a global emission inventory to derive city emission as input  
653 for AQ modelling. The local situation appears to be not properly represented and the results  
654 of air quality modelling will significantly depend on the choice of inventory. Moreover a  
655 ranking of potential efficient mitigation measures would also depend on the choice of  
656 emission inventory. Without more detailed national emission data, a clear conclusion on the  
657 origin of discrepancies cannot be made although we have given several suggestions in the  
658 discussion. In some cases it is clear that emission factors differ substantially and this may

659 need further attention in the future. At the same time spatial allocation can be another cause  
660 for large discrepancies. Simply said, the lack of consistent national inventories prohibits a  
661 further analysis. Efforts to create such national gridded inventories in South America are  
662 urgently needed.

663 The emissions analysed in this study, although limited to five countries out of the 12  
664 existing countries in SA, are representative of most of the territory of South America as  
665 well as most of its population. This work seeks to increase the understanding of strength  
666 and weaknesses of emissions data available for South America by focusing on these five  
667 countries. The intention for the future is to include other countries not only from South  
668 America but also Central America and the Caribbean.

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## 676 References

- 677 Alonso, M. F., Longo, K. M., Freitas, S. R., Mello da Fonseca, R., Marécal, V., Pirre, M.,  
678 & Klenner, L. G. (2010). An urban emissions inventory for South America and its  
679 application in numerical modeling of atmospheric chemical composition at local and  
680 regional scales. *Atmospheric Environment*, 44(39), 5072–5083.  
681 <http://doi.org/http://dx.doi.org/10.1016/j.atmosenv.2010.09.013>.
- 682 Amann, M., et al. (2011), Cost-effective control of air quality and greenhouses gases in  
683 Europe: Modeling and policy applications, *Environ. Modell. Softw.*, 26(12), 1489–1501,  
684 doi:10.1016/j.envsoft. 2011.07.012.
- 685 Baumgardner, D., M. de Fatima Andrade, Z. Klimont, J. Kuylenstierna, S. M. Carvalho, N.  
686 Borgford-Parnell, O. L. Mayol-Bracero, et al. “Short-Lived Climate Pollutants: Drivers,  
687 Regional Emissions and Measurements.” In *Integrated Assessment of Short-Lived  
688 Climate Pollutants in Latin America and the Caribbean: Improving Air Quality While  
689 Contributing to Climate Change Mitigation*, 18–53. Paris: United Nations Environment  
690 Programme (UNEP) and Climate and Clean Air Coalition (CCAC), 2018
- 691 Bond, T.C., E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D.G. Streets, S.

692 Fernandes, and N. Trautmann, Historical emissions of black and organic carbon aerosol  
693 from energy-related combustion, 1850-2000. *Global Biogeochemical Cycles* 21:  
694 GB2018, doi:10.1029/2006GB002840, 2007.

695 Bond, T. C., et al. (2013), Bounding the role of black carbon in the climate system: A  
696 scientific assessment, *J. Geophys. Res. Atmos.*, 118(11), 5380–5552,  
697 doi:10.1002/JGRD.50171.

698 Carpenter, A and Quispe-Agnoli, M. 2015. A Comparison of Economic and Social  
699 Implications of Rapid Urbanization in Lima and Santiago de Chile. *Perspectives on*  
700 *Global Development and Technology* 14(5): 497–518. DOI: 10.1163/15691497-  
701 12341358

702 Castesana, Paula, Dawidowski, Laura, Finster, Laura, Gómez, Darío, & Taboada, Miguel.  
703 (2018). Ammonia emissions from the agriculture sector in Argentina, 2000-2012.  
704 *Atmospheric Environment*, 178C, 293–304.

705 Crippa, Monica Greet Janssens-Maenhout, Frank Dentener, Diego Guizzardi, Katerina  
706 Sindelarova, Marilena Muntean, Rita Van Dingenen, Claire Granier: Forty years of  
707 improvements in European air quality: regional policy-industry interactions with global  
708 impacts, *Atmos. Chem. Phys.*, 16, 3825-3841, doi:10.5194/acp-16-3825-2016, 2016.  
709 EDGAR website (<http://edgar.jrc.ec.europa.eu/>)

710 Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., van Aardenne, J. A.,  
711 Monni, S., Doering, U., Olivier, J. G. J., Pagliari, V., and Janssens-Maenhout, G.:  
712 Gridded emissions of air pollutants for the period 1970–2012 within EDGAR v4.3.2,  
713 *Earth Syst. Sci. Data*, 10, 1987-2013, <https://doi.org/10.5194/essd-10-1987-2018>, 2018

714 D'Angiola, A., Dawidowski, L., Gómez, D., and Osses, M. (2010). On-road traffic  
715 emissions in a megacity. *Atmospheric Environment*, 44(4), 483–493.

716 Gallardo, L., Escribano, J., Dawidowski, L., Rojas, N., de Fátima Andrade, M., & Osses,  
717 M. (2012). Evaluation of vehicle emission inventories for carbon monoxide and nitrogen  
718 oxides for Bogotá, Buenos Aires, Santiago, and São Paulo. *Atmospheric Environment*,  
719 47, 12–19. <http://doi.org/10.1016/j.atmosenv.2011.11.051>

720 Gallardo, L, Alonso, F, Andrade, MF, Barreto-Carvalho, V, Behrentz, E, et al. 2012a.  
721 South American megacities. In: Zhu, T, Parrish, DD, Gauss, M, Doherty, S, Lawrence,  
722 M, Gallardo, L and Kanakidou, M (eds.), *The Impacts of Megacities on Air Quality and*  
723 *Climate Change: An IGAC Perspective* , 141–171. Geneva, Switzerland.

724 Garreaud, R. D., M. Vuille, R. Compagnucci, and J. Marengo (2009), Present-day South  
725 American climate, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 281(3–4), 180–195,  
726 doi:10.1016/j.palaeo.2007.10.032.

727 Gerência de Qualidade do Ar (GQA), Inventário, Emissões de Fontes Veiculares, Região  
728 Metropolitana do Rio de Janeiro, Ano-Base 2013, Rio de Janeiro, 2016.

729 Gonzalez, C.M.; Gomez, C.D.; Rojas, N.Y.; Acevedo, H.; Aristizabal, B.H. (2017),  
730 Relative impact of on-road vehicular and point-source industrial emissions of air  
731 pollutants in a medium-sized Andean city. *Atmos. Environ.*, 152, 279–289.



732 Granier, C., Bessagnet, B., Bond, T., D'Angiola, A., Denier van der Gon, H., Frost, G. J.,  
733 Heil, A., Kaiser, J. W., Kinne, S., Klimont, Z., Kloster, S., Lamarque, J.-F., Liousse, C.,  
734 Masui, T., Meleux, F., Mieville, A., Ohara, T., Raut, J.-C., Riahi, K., Schultz, M. G.,  
735 Smith, S. J., Thompson, A., Aardenne, J., Werf, G. R. and Vuuren, D. P.: Evolution of  
736 anthropogenic and biomass burning emissions of air pollutants at global and regional  
737 scales during the 1980–2010 period, *Climatic Change*, 109(1–2), 163–190,  
738 doi:10.1007/s10584-011-0154-1, 2011.

739 He, C., Ge, Y., Tan, C. M., Liu, Z., et al., "Emission Characteristics of a Heavy-Duty  
740 Diesel Engine at Simulated High Altitudes," *Science of the Total Environment*, Vol.  
741 409, pp. 3138-3143, 2011

742 Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T.,  
743 Seibert, J. J., Vu, L., Andres, R. J., Bolt, R. M., Bond, T. C., Dawidowski, L., Kholod,  
744 N., Kurokawa, J.-I., Li, M., Liu, L., Lu, Z., Moura, M. C. P., O'Rourke, P. R., and  
745 Zhang, Q.: Historical (1750–2014) anthropogenic emissions of reactive gases and  
746 aerosols from the Community Emissions Data System (CEDS), *Geosci. Model Dev.*, 11,  
747 369–408, <https://doi.org/10.5194/gmd-11-369-2018>, 2018.

748 HTAP: Hemispheric Transport of Air Pollution 2010 – Part A: Ozone and Particulate  
749 Matter, *Air Pollution Studies No. 17*, edited by: Dentener, F., Keating, T., and Akimoto,  
750 H., United Nations, New York and Geneva, 2010.

751 Huang, Y. H. Shen, H. Chen, R. Wang, Y. Zhang, S. Su, Y. Chen, N. Lin, S. Zhuo, Q.  
752 Zhong, X. Wang, J. Liu, B. Li, W. Liu, and S. Tao, Quantification of global primary  
753 emissions of PM<sub>2.5</sub>, PM<sub>10</sub>, and TSP from combustion and industrial process sources,  
754 *Environ. Sci. Technol.*, 48, 23, 13834–13843, 2014.

755 Infineum, Worldwide winter diesel fuel quality survey 2002, <http://www.infineum.com/>  
756 Infineum Worldwide Winter Diesel Fuel Quality Survey 2014  
757 Infineum Worldwide Winter Diesel Fuel Quality Survey 2016

758 IPCC, 2018: Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special  
759 Report on the impacts of global warming of 1.5°C above pre-industrial levels and related  
760 global greenhouse gas emission pathways, in the context of strengthening the global  
761 response to the threat of climate change, sustainable development, and efforts to  
762 eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.  
763 R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R.  
764 Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T.  
765 Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp

766 Janssens-Maenhout, G., Pagliari, V., Guizzardi, D., and Muntean, M.: Global emission  
767 inventories in the Emission Database for Global Atmospheric Research (EDGAR) –  
768 Manual (I): Gridding: EDGAR emissions distribution on global gridmaps, JRC Report,  
769 EUR 25785 EN, ISBN 978-92-79-28283-6, doi:10.2788/81454, 2013.

770 Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Dentener, F., Muntean, M., Pouliot, G.,  
771 Keating, T., Zhang, Q., Kurokawa, J., Wankmüller, R., Denier van der Gon, H., Kuenen,  
772 J. J. P., Klimont, Z., Frost, G., Darras, S., Koffi, B., and Li, M.: HTAP\_v2.2: a mosaic of

773 regional and global emission grid maps for 2008 and 2010 to study hemispheric  
774 transport of air pollution, *Atmos. Chem. Phys.*, 15, 11411-11432, doi:10.5194/acp-15-  
775 11411-2015, 2015.

776 Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F.,  
777 Bergamaschi, P., Pagliari, V., Olivier, J. G. J., Peters, J. A. H. W., van Aardenne, J. A.,  
778 Monni, S., Doering, U., and Petrescu, A. M. R.: EDGAR v4.3.2 Global Atlas of the  
779 three major Greenhouse Gas Emissions for the period 1970–2012, *Earth Syst. Sci. Data*  
780 *Discuss.*, <https://doi.org/10.5194/essd-2017-79>, 2017.

781 Junker, C. and Lioussé, C.: A global emission inventory of carbonaceous aerosol from  
782 historic records of fossil fuel and biofuel consumption for the period 1860-1997, *Atmos.*  
783 *Chem. Phys.*, 8, 1195-1207, doi:10.5194/acp-8-1195-2008, 2008.

784 Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., Borken-Kleefeld,  
785 J., and Schöpp, W.: Global anthropogenic emissions of particulate matter including  
786 black carbon, *Atmos. Chem. Phys.*, 17, 8681-8723, [https://doi.org/10.5194/acp-17-8681-](https://doi.org/10.5194/acp-17-8681-2017)  
787 2017, 2017.

788 Kumar Rodrigo and Belalcázar, Luis Carlos and Roja, Néstor Y., A. and J. (2016).  
789 Application of WRF-Chem Model to Simulate PM10 Concentration over Bogota.  
790 *Aerosol and Air Quality Research*, 16(5), 1206–1221.  
791 <http://doi.org/10.4209/aaqr.2015.05.0318>

792 Lamarque, JF et al. Historical (1850-2000) gridded anthropogenic and biomass burning  
793 emissions of reactive gases and aerosols: methodology and application, *Atmospheric*  
794 *Chemistry and Physics*, 2010 (ACP-2010-67) UNdata, United Nations Statistics  
795 Division, <http://data.un.org/>, accessed June 2017

796 Longo, K. M., Freitas, S. R., Pirre, M., Marécal, V., Rodrigues, L. F., Panetta, J., ... Bela,  
797 M. (2013). The Chemistry CATT-BRAMS model (CCATT-BRAMS 4.5): a regional  
798 atmospheric model system for integrated air quality and weather forecasting and  
799 research. *Geosci. Model Dev.*, 6(5), 1389–1405. [http://doi.org/10.5194/gmd-6-1389-](http://doi.org/10.5194/gmd-6-1389-2013)  
800 2013

801 Mazzeo, A., Huneus, N., Ordoñez, C., Orfanoz-Chequela, A., Menut, L., Mailler, S.,  
802 Valari, M., Denier van der Gon, H., Gallardo, L., Muñoz, R., Donoso, R., Galleguillos,  
803 M., Osses, M., and Tolvett, S., (2018). Impact of residential combustion and transport  
804 emissions on air pollution in Santiago during winter. *Atmospheric Environment*, 190,  
805 195–208. <http://doi.org/https://doi.org/10.1016/j.atmosenv.2018.06.043>

806 Melamed, M. L., Schmale, J., & von Schneidmesser, E. (2016). Sustainable policy—key  
807 considerations for air quality and climate change. *Current Opinion in Environmental*  
808 *Sustainability*, 23, 85–91. <http://doi.org/http://dx.doi.org/10.1016/j.cosust.2016.12.003>

809 Monks, P. S., Archibald, A. T., Colette, A., Cooper, O., Coyle, M., Derwent, R., ...  
810 Williams, M. L. (2015). Tropospheric ozone and its precursors from the urban to the  
811 global scale from air quality to short-lived climate forcer. *Atmospheric Chemistry and*  
812 *Physics*, 15(15), 8889–8973. <https://doi.org/10.5194/acp-15-8889-2015>.

813 Ni, H., Zhao, W., Liu, L., Li, M., Fu, T. and Wang, Y., "A research of the effects of altitude  
814 on the emissions and fuel consumption of a gasoline vehicle", 2014, *Automotive*  
815 *Engineering* 36(10):1205-1209 and 1179.

816 Reis, S., P. Grennfelt, Z. Klimont, M. Amann, H. ApSimon, J.-P. Hettelingh, M. Holland,  
817 et al. "From Acid Rain to Climate Change." *Science* 338, no. 6111 (November 30,  
818 2012): 1153–54. <https://doi.org/10.1126/science.1226514>

819 Pachón, J., Galvis, B, Lombana, O., Carmona, L., Fajardo, S., Rincón, A., Meneses,  
820 S., Chaparro, R., Nedbor-Gross, R., Henderson, B., 2018, Development and evaluation  
821 of a comprehensive atmospheric emission inventory for air quality modeling in the  
822 megacity of Bogotá, *Atmosphere*, 9 (2) (2018), p. 49, 10.3390/atmos9020049.

823 PNUD. 2017. Desiguales: Orígenes, cambios y desafíos de la brecha social en Chile.  
824 Santiago, Chile: Ograma Impresores , 411. 978-956-7469-86-4. Available at:  
825 <https://www.desiguales.org/>.

826 Puliafito, S. Enrique; Allende, David G., Castesana, Paula S., Ruggeri, María F. (2017):  
827 High-resolution atmospheric emission inventory of the argentine energy sector.  
828 Comparison with Edgar global emission database. *Heliyon* 3, e00489.  
829 <http://doi:10.1016/j.heliyon.2017.e00489>

830 Puliafito, S.E., Allende, D., Pinto, S., Castesana, P. (2015): High resolution inventory of  
831 GHG emissions of the road transport sector in Argentina, *Atmospheric Environment*  
832 101, 303-311. <http://doi:10.1016/j.atmosenv.2014.11.040>

833 Reátegui, W., Sánchez-Ccoyllo, O., Andrade, M., & Moya, A. (2018). PM2.5 Estimation  
834 with the WRF/Chem Model, Produced by Vehicular Flow in the Lima Metropolitan  
835 Area. *Open Journal of Air Pollution*, 215-243.

836 Riahi, K., Grübler, A., & Nakicenovic, N. (2007). Scenarios of long-term socio-economic  
837 and environmental development under climate stabilization. *Technological Forecasting*  
838 *and Social Change*, 74(7), 887–935.  
839 <http://doi.org/http://dx.doi.org/10.1016/j.techfore.2006.05.026>

840 Rojas, N.Y., Peñaloza, N.E.. Desagregación de inventarios de emisiones. Bogotá como caso  
841 de estudio. *Editorial Académica Española* (2012-05-02). ISBN: 978-3-659-00796-5.

842 Rondanelli, R., Molina, A., and Falvey, M. (2015). The Atacama Surface Solar Maximum.  
843 *Bulletin of the American Meteorological Society*, 96(3), 405–418.  
844 <http://doi.org/10.1175/BAMS-D-13-00175.1>.

845 Rosário, N. E., K. M. Longo, S. R. Freitas, M. A. Yamasoe, and R. M. Fonseca. 2013.  
846 "Modeling the South American regional smoke plume: aerosol optical depth variability  
847 and surface shortwave flux perturbation." *Atmos. Chem. Phys.*, **13 (6)**: 2923-2938  
848 [10.5194/acp-13-2923-2013].

849 Saide, P.E., Mena-Carrasco, M., Tolvett, S., Hernandez, P., Carmichael, G.R., 2016. Air  
850 quality forecasting for winter-time PM2.5 episodes occurring in multiple cities in central  
851 and southern Chile. *J. Geophys. Res.: Atmosphere* 121 (1), 558–575.

852 Schneidemesser, Erika von, Paul S. Monks, James D. Allan, Lori Bruhwiler, Piers Forster,  
853 David Fowler, Axel Lauer, et al. "Chemistry and the Linkages between Air Quality and

854 Climate Change.” *Chemical Reviews* 115, no. 10 (May 27, 2015): 3856–97.  
855 <https://doi.org/10.1021/acs.chemrev.5b00089>

856 Schmale, J., Shindell, D., Von Schneidemesser, E., Chabay, I., and Lawrence, M. (2014).  
857 Air pollution: Clean up our skies. *Nature* 515, 335–337. doi:10.1038/515335a.

858 Schultz, M., S. Rast, M. van het Bolscher, T. Pulles, R. Brand, J. Pereira, B. Mota, A.  
859 Spessa, S. Dalsøren, T. van Noije, S. Szopa, Emission data sets and methodologies for  
860 estimating emissions, Report of the RETRO European project, EU-Contract No. EVK2-  
861 CT-2002-00170, available at: [http://retro-archive.iek.fz-](http://retro-archive.iek.fz-juelich.de/data/documents/reports/)  
862 [juelich.de/data/documents/reports/](http://retro-archive.iek.fz-juelich.de/data/documents/reports/), 2007.

863 Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, et al. 2015. Planetary  
864 boundaries: Guiding human development on a changing planet. *Science* 347(6223):  
865 1259855.

866 Solimano, A and Schaper, M. 2015. The Paradoxes of Chilean Economic Development:  
867 Growth, Inequality, De-industrialization and Sustainability Risks. In: Hansen,  
868 AaUW (ed.), *Emerging Economies and Challenges to Sustainability Theories,*  
869 *strategies and local realities.* London, New York: Routledge.

870 Stohl, A., Aamaas, B., Amann, M., Baker, L. H., Bellouin, N., Berntsen, T. K., Boucher,  
871 O., Cherian, R., Collins, W., Daskalakis, N., Dusinska, M., Eckhardt, S.,  
872 Fuglestvedt, J. S., Harju, M., Heyes, C., Hodnebrog, Ø., Hao, J., Im, U., Kanakidou,  
873 M., Klimont, Z., Kupiainen, K., Law, K. S., Lund, M. T., Maas, R., MacIntosh, C.  
874 R., Myhre, G., Myriokefalitakis, S., Olivie, D., Quaas, J., Quennehen, B., Raut, J.-  
875 C., Rumbold, S. T., Samset, B. H., Schulz, M., Seland, Ø., Shine, K. P., Skeie, R.  
876 B., Wang, S., Yttri, K. E., and Zhu, T.: Evaluating the climate and air quality  
877 impacts of short-lived pollutants, *Atmos. Chem. Phys.*, 15, 10529-10566,  
878 doi:10.5194/acp-15-10529-2015, 2015.

879 Szedlmayer, M. and Kweon, C., "Effect of Altitude Conditions on Combustion and  
880 Performance of a Multi-Cylinder Turbocharged Direct-Injection Diesel Engine," SAE  
881 Technical Paper 2016-01-0742, 2016, <https://doi.org/10.4271/2016-01-0742>.

882 United Nations Population Division, Department of Economic and Social Affairs, World  
883 Population Prospects: The 2017 Revision, New York: United Nations, 2017. Available  
884 at <https://population.un.org/wpp/Download/Standard/Population/>

885 United Nations, Department of Economic and Social Affairs, Population Division (2018).  
886 World Urbanization Prospects: The 2018 Revision, custom data acquired via website.  
887 Available at <https://population.un.org/wup/Download/>

888 UNEP, Status of Fuel Quality and Vehicle Emission Standards Latin America and the  
889 Caribbean, 2016  
890 [http://staging.unep.org/transport/New/PCFV/pdf/Maps\\_Matrices/LAC/matrix/LAC\\_Fue-](http://staging.unep.org/transport/New/PCFV/pdf/Maps_Matrices/LAC/matrix/LAC_FuelsVeh_November2016.pdf)  
891 [lsVeh\\_November2016.pdf](http://staging.unep.org/transport/New/PCFV/pdf/Maps_Matrices/LAC/matrix/LAC_FuelsVeh_November2016.pdf) accessed April 2017

892 UNEP/CCAC (2018). Integrated Assessment of Short-Lived Climate Pollutants in Latin  
893 America and the Caribbean: Improving Air Quality While Contributing to Climate  
894 Change Mitigation, Paris: United Nations Environment Programme (UNEP) and  
895 Climate and Clean Air Coalition (CCAC);

896 [http://ccacoalition.org/en/resources/integrated-assessment-short-lived-climate-](http://ccacoalition.org/en/resources/integrated-assessment-short-lived-climate-pollutants-latin-america-and-caribbean)  
897 [pollutants-latin-america-and-caribbean](http://ccacoalition.org/en/resources/integrated-assessment-short-lived-climate-pollutants-latin-america-and-caribbean)  
898 USACH, 2014. Informe final: Actualizacion y sistematizacion del inventario de emisiones  
899 de contaminantes at mosfericos en la region metropolitana. Universidad de Santiago de  
900 Chile.  
901 van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C.  
902 Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic,  
903 S.J. Smith, and S.K. Rose, The representative concentration pathways: an overview,  
904 Climatic Change, 109, 5-31, DOI: 10.1007/s10584-011-0148-z, 2011.  
905 Vivanco, M.G., Andrade, M.F., 2006. Validation of the emission inventory in the São  
906 Paulo metropolitan area of Brazil based on ambient concentrations ratios of CO, NMOG  
907 and NOx and on a photochemical model. Atmospheric Environment 40,1189 – 1198.  
908 Wang, H., Ge, Y., Hao, L., Xu, X., Tan, J., Li, J., Wu, L., Yang, J., Yang, D., Peng, J.,  
909 Yang, J., Yang., R., 2018, The real driving emission characteristics of light-duty diesel  
910 vehicle at various altitudes, Atmos. Env., 191, 126-131.  
911 <https://doi.org/10.1016/j.atmosenv.2018.07.060>  
912 WHO (World Health Organization), 2017, Evolution of WHO air quality guidelines: past,  
913 present and future (2017), vi + 32 pages, ISBN 978 92 890 5230 6  
914 World bank, World Development Indicators, 2017, accessed June 6, 2017.  
915 <http://data.worldbank.org/indicator/SP.POP.TOTL>,  
916  
917  
918  
919  
920  
921  
922