High-resolution atmospheric emission inventory of the argentine energy sector. Comparison with edgar global emission database

S. Enrique Puliafito\textsuperscript{a,b,*}, David G. Allende\textsuperscript{a,b}, Paula S. Castesana\textsuperscript{b,c}, Maria F. Ruggeri\textsuperscript{a}

\textsuperscript{a}Facultad Regional Mendoza, Universidad Tecnológica Nacional/CONICET Rodríguez 273, Mendoza 5500, Argentina
\textsuperscript{b}Facultad Regional Buenos Aires, Universidad Tecnológica Nacional, Medrano 951, Buenos Aires 1179, Argentina
\textsuperscript{c}Instituto de Investigación en Ingeniería Ambiental, Universidad Nacional de San Martín, 25 de Mayo 1401, 1650 Buenos Aires, Argentina

* Corresponding author.
E-mail address: epuliafito@frm.utn.edu.ar (S. E. Puliafito).

Abstract

This study presents a 2014 high-resolution spatially disaggregated emission inventory (0.025° × 0.025° horizontal resolution), of the main activities in the energy sector in Argentina. The sub-sectors considered are public generation of electricity, oil refineries, cement production, transport (maritime, air, rail and road), residential and commercial. The following pollutants were included: greenhouse gases (CO\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}O), ozone precursors (CO, NO\textsubscript{x}, VOC) and other specific air quality indicators such as SO\textsubscript{2}, PM\textsubscript{10}, and PM\textsubscript{2.5}. This work could contribute to a better geographical allocation of the pollutant sources through census based population maps. Considering the sources of greenhouse gas emissions, the total amount is 144 Tg CO\textsubscript{2}eq, from which the transportation sector emits 57.8 Tg (40%); followed by electricity generation, with 40.9 Tg (28%); residential + commercial, with 31.24 Tg (22%); and cement and refinery production, with 14.3 Tg (10%). This inventory shows that 49% of the total...
emissions occur in rural areas: 31% in rural areas of medium population density, 13% in intermediate urban areas and 7% in densely populated urban areas. However, if emissions are analyzed by extension (per square km), the largest impact is observed in medium and densely populated urban areas, reaching more than 20.3 Gg per square km of greenhouse gases, 297 Mg/km² of ozone precursors gases and 11.5 Mg/km² of other air quality emissions. A comparison with the EDGAR global emission database shows that, although the total country emissions are similar for several sub sectors and pollutants, its spatial distribution is not applicable to Argentina. The road and residential transport emissions represented by EDGAR result in an overestimation of emissions in rural areas and an underestimation in urban areas, especially in more densely populated areas. EDGAR underestimates 60 Gg of methane emissions from road transport sector and fugitive emissions from refining activities.

Keywords: Energy, Environmental science, Atmospheric science, Earth sciences

1. Introduction

Atmospheric emission inventories (AEIs) are used to determine the national balances of greenhouse gas (GHGs) emissions, to estimate air quality in urban areas or to evaluate the environmental impact of a new facility, among other applications. They are also basic inputs of air quality models, such as: WRF/Chem (Grell et al., 2005), CMAQ (Binkowski and Roselle, 2003), CALPUFF (Scire et al., 2000) or AERMOD (Cimorelli et al., 1998). An example of global data collection is the EDGAR database (EDGAR, 2016; Crippa et al., 2016) (Emissions Database for Global Atmospheric Research) compiled by the European Commission and Joint Research Center (JRC) and the Netherlands Organization for Applied Scientific Research. In its most recent format, EDGAR is an AEI in the form of a grid of 0.1° longitude × 0.1° latitude resolution. Among the regional or continental databases, we can mention EMEP (European Monitoring and Evaluation Program), which covers Europe (EMEP, 2016) or REAS (Regional Emissions Inventory in Asia), which covers Asia with a resolution of 0.25° longitude × 0.25° latitude (Kurokawa et al., 2013), among others. At national level, the US Environmental Agency, has disaggregated its national atmospheric emission inventory (NEI) by geographical division (provincial states, or regions or cities), pollutants (including PM10, CO, NOx, SO₂), productive sector (agriculture, energy, industrial processes, etc.), and sources type (point, area, mobile) (NEI, 2016). Similarly, other countries such as the United Kingdom have their own national databases, which compiles relevant information for the estimation of emissions affecting air quality as well as GHGs (UK NAEI, 2016). China has developed several emission inventories, including the Multi-resolution Emission Inventory for China, compiled by Tsinghua University, Beijing, China (MEIC, 2016).
There are no complete regional inventories for South America, except for those compiled by global databases such as EDGAR. Alonso et al. (2010) have presented a vehicle emission inventory for South America based on local inventories of 9 cities, extrapolating socio-economic data of the region and associating it with high resolution satellite data. Gallardo et al. (2012) have presented a vehicle emission inventory for four megacities in South America (Bogotá, Santiago, Buenos Aires and Sao Paulo). Brazil has several biomass burning emission inventories (Brazilian Biomass Burning Emission Model) (Longo et al., 2013; Pereira et al., 2009) as well as urban activity inventories in the south of Brazil (Andrade et al., 2004; Vivanco and Andrade, 2006). Puliafito et al. (2015) presented a vehicle activity and emissions inventory with a resolution of 9 km × 9 km for Argentina.

Despite the efforts to improve inventory resolution and level of detail, there are still significant uncertainties and discrepancies among various authors, (Ferreira et al., 2013; Poulit et al., 2012; Saikawa et al., 2011; Granier et al., 2011; Gurjar et al., 2008; Butler et al., 2008; Garg et al., 2006). Many of these studies agree on the fact that the possible explanations for the differences among inventories include the use of different criteria for compiling data, different resolutions and spatial disaggregation methods, and differences in the population distribution taken as baseline data.

Emission inventories are mainly estimated using “top-down” methods by collecting activity data at the regional or national level and then spatially distributing them based on ancillary data. Certain sources, such as transportation, are however not well represented, as it will be discussed below. Therefore, simple, but also accurate methods for assessing the spatial distribution of these emissions are needed in order to account for the current situation in urban areas. Moreover, in order to make the inventory systems reliable, mainly for key categories, it is indispensable to check their internal consistency and to assure their accuracy to be conducive to the reduction of uncertainties as far as practicable.

This study seeks to provide documentation to support the employment of more sophisticated methodologies, country-defined parameters and improvement in the spatial resolution of the primary databases to produce improvements in the geographical distribution of the sources of emissions compared to the existing AEIs. That is the reason why we present a high-resolution inventory of 0.025° longitude × 0.025° latitude (or approximately 2.5 × 2.5 km, for the middle latitudes) for the energy sector of Argentina, built through a methodological approach to ensure the accuracy, consistency and transparency of the estimations.

This new inventory is compared to the EDGAR database and the emissions estimated in the Argentine Third National Communication to the United Nations Framework Convention on Climate Change (ATNC, 2015).
A further aim of this work is to provide the community stakeholders with an updated map of emissions from the main activities described and to offer a methodological framework that could be extrapolated to other areas of interest for which high-resolution inventories have not yet been developed. Finally, the use of this inventory may improve air quality or pollutant transport models in Argentina, using regional or local numerical models.

2. Methodology

This work presents the development of AEIs for the following activities:

1. Thermoelectric power generation plants.
2. Emissions from large point sources: refineries and cement production plants.
3. Residential and commercial consumption of natural gas, liquefied petroleum gas (LPG) and biomass.
4. Transportation activity: road, railroad, inland navigation and aviation.
5. Fugitive emissions from refineries due to product processing and fuel loading and unloading in gas stations.

In order to provide results which are comparable with different global databases, this inventory has been organized according to the categories proposed by the IPCC classification (IPCC, 2006), though focused on air quality research. Table 1 shows the pollutants included in this study and Table 2 lists the fuels considered for each source.

2.1. Study area and baseline grid

The Argentine Republic has two main hierarchical political divisions: 24 Provinces, divided in turn by Departments (554 in total) (Fig. 1), which cover a continental area of 2,778,000 km². It should be noted that some Departments have very large extensions (their average area is 5,700 km², with a minimum of 3.55 km² and a maximum of 63,700 km²), containing both urban and rural areas and, as a result, the average information does not account for its spatial distribution accurately. Most energy consumption sources and users related to water networks, sewage availability, etc., are disaggregated into these two main geographic divisions.

Recently, the Argentine Statistics Office (INDEC) published a new database based on the 2010 census (INDEC, 2016), with information on population and number of dwellings at the level of census tract. A census tract (or census radii) is the minimum geographical unit used by census workers consisting of an average of 300 households, but with a variable population and area. Another database recently made available by the Energy Secretary (MINEM, 2016) includes other activities,
| Code | Abr. | Sector                                      | GHGs<sup>1</sup> | Ozone precursor gases<sup>2</sup> | Acidifying gases<sup>3</sup> | Particulates<sup>4</sup> | Organic compounds<sup>5</sup> | Metals<sup>6</sup> |
|------|------|--------------------------------------------|------------------|----------------------------------|-----------------------------|----------------------|-------------------------------|------------------|
| 1A1a | PHE  | Public electricity and heat production     | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1A1b | ROP  | Oil Refining                                | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1A3a | DAV  | Domestic aviation                           | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1A3b | ROT  | Road transportation                         | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1A3c | RRT  | Rail transportation                         | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1A3d | INN  | Inland navigation                           | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1A4  | RES  | Residential and other sectors               | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 1B2  | FUG  | Fugitive emissions from oil and gas         | ●                | ●                                | ●                            | ●                    | ●                             | ●                |
| 2A1  | CEM  | Cement production                           | ●                | ●                                | ●                            | ●                    | ●                             | ●                |

<sup>1</sup>: CO2, CH4, N2O; <sup>2</sup>: CO, NOx, NMVOC; <sup>3</sup>: NH3, SO2; <sup>4</sup>: PM10, PM2.5, TSP, BC; <sup>5</sup>: Benzopyrene, Benzanthracene, Benzene, Xylenes, Toluene, Chlorobenzenes, Naphthalene, HCB; <sup>6</sup>: Se, Ni, Pb, Hg, Zn, Cu.
such as location of refueling gas stations, sale of fuels, number of natural gas users and fuel consumption in thermal power stations with variable spatial disaggregation. This newly released information enabled the building of the inventory presented here with improved spatial resolution.

Using GIS tools, the information contained in the census tract map was intersected with a baseline grid map (EPGS 4326, WGS84 cartography) with cells of 0.025° longitude × 0.025° latitude resolution in an area ranging from 21° to 55° South latitude and 53° to 73° West longitude. Thus, the study area is made up of 700,000 cells corresponding to the continental and coastal maritime sector of Argentina. Fig. 1 shows the different scales associated to the mapping process of the available information.

### 2.2. Spatial disaggregation

Depending on the spatial extent, an industrial source or refueling gas station can easily be associated with a geographical point; residential consumption to an area source, whereas transport emissions are associated with a line which may range from hundreds of meters to hundreds of kilometers. To be used in an air quality model, these different source types are reorganized into a single database in the form of a grid map. The resolution of the baseline information determines the size of the grid cell (in this case 2.5 × 2.5 km). Area or line sources can be included in a single cell or not. When source sizes were greater than one cell (e.g. consumption known at the Department level) a proxy known data was selected to spatially disaggregate such variable (e.g. night-lights, population). If the variable was smaller than the cell (e.g., small census tract data in urban areas), all the sources contained in that cell were added together (Fig. 1).

| Cod. | Cod. | Sector | Liquid*1 | Natural Gas | LPG*2 | Coal | Biomass | Firewood | Crude | Refinery Gas |
|------|------|--------|----------|-------------|-------|------|---------|----------|-------|-------------|
| 1A1a | PHE  | Public electricity and heat production | ● | ● | ● | ● |
| 1A1b | ROP  | Oil Refining | ● | | | |
| 1A3a | DAV  | Domestic aviation | ● | | | |
| 1A3b | ROT  | Road transportation | ● | | | ● |
| 1A3c | RRT  | Rail transportation | ● | | | |
| 1A3d | INN  | Inland navigation | | | | |
| 1A4  | RES  | Residential and other sectors | ● | ● | ● | ● | ● |
| 1B2  | FUG  | Fugitive emissions from oil and gas | ● | ● | | ● | ● |
| 2A1  | CEM  | Cement production | ● | | | ● |

*1: Gasoline, Gas-Oil, Fuel-Oil; *2: Liquefied petroleum gas.
Night light satellite images (i.e., NOAA-NGDC, 2010) are commonly used as an indicator of residential consumption levels and population density (Oda and Maksyutov, 2011; Raupach et al., 2010). However, industrial parks, refineries, and hydrocarbon extraction wells also have many associated lights and are not always

Fig. 1. Spatial units used in the inventory. a) Argentina in South America with main rivers; b) Provinces; c) Details of Departments showing annual gasoline sales (m3); d) Details of census radii showing population e) Detailed view of the used grid (white rectangle), census tract (red polygons showing number of homes) and Departments boundaries (blue line). Rectangles show the zoom area in the subsequent figure. Geographic regions include the following Provinces: Patagonia: Neuquén, Río Negro, Chubut, Santa Cruz y Tierra del Fuego; West: La Rioja, Mendoza, San Juan, San Luis; Northwest: Catamarca, Jujuy, Salta Tucumán; Northeast: Corrientes, Chaco, Formosa, Misiones; Central: Córdoba, Entre Ríos Santiago del Estero y Santa Fe; Pampa: Buenos Aires, Ciudad de Buenos Aires y La Pampa.
in the vicinity of populations, so that these lights could lead to the estimation of a higher population density in that area.

As mentioned above, since 2016, a new high-resolution database (based on census tract) has been available in Argentina, and it has thus been possible to produce a high-resolution, fine-scale map for the geographical distribution of population. Consequently, the present map has a better geographical distribution that in Puliafito et al. (2015), where night-light map distribution was used to geographically distribute the departmental population in a 9 km × 9 km grid. Moreover, spatial operations performed with the aim to allocate the emissions derived from these preexisting databases to the highest possible spatial level are combined, when possible, with source-specific information to reduce uncertainty in the spatial allocation, also validating activity data.

2.3. General calculation approach

Atmospheric emissions were calculated as follows (EMEP, 2016):

\[ E(p) = \sum_{p,j,k} \left[ FE(p,j,k) \times A(j,k) \right] / C_{138} \]  

Where \( E(p) \) is the total emission for species or pollutant \( p \), \( FE(p,j,k) \) is the emission factor for pollutant species \( p \), the type of source \( j \) and fuel \( k \), and \( A(j,k) \) is the level of activity for source \( j \). The following subsections present detailed calculations and considerations for each subsector.

2.4. Residential and commercial emissions

The census tract map (Fig. 1 d-e) available from INDEC (2016) contains information on population structure, types of fuel used in households for cooking and heating (e.g. natural gas, LPG (in tube, cylinder or tank)), timber or electricity. The statistical database also includes a social index called Unsatisfied Basic Needs (UBN) following the description of UNDP (UNDP, 2017). This index includes, among other considerations, number of rooms, built area (square meters) and main heating type. Table 3a and Table 3b show the data structure in detail. Detailed consumption maps were built using the UBN index and other information such as percentage of homes connected to the water/drain network, natural gas, number of homes with computers or cellular phones. However, since the main goal of this inventory is for air quality purposes, the consumption calculated in this point is only includes (in situ) energy consumption by natural gas (or charcoal or wood) for cooking and heating, thus excluding electricity-use, whose emissions are considered within the electricity production at thermal power plants (see next section). Natural gas/wood/charcoal household consumption is available only at department level, which made it necessary to redistribute this information to each cell proportionally to the number of departmental users, using equation (2):
\[ R_g(x, y, k) = R_d(x, y, k) \times \left[ \frac{H_g(x, y, k)}{H_d(x, y, k)} \right] \times \left[ I_g(x, y)/I_d(y, x) \right] \]  

\( R_g \) is the residential consumption of fuel \( k \) considered in cell \((x, y)\); \( H_g \) is the number of households in the same cell consuming fuel \( k \); \( H_d \) is the total number of households in department \( d \) consuming fuel \( k \), and \( R_d \) is the consumption of fuel \( k \) in Department \( d \). This disaggregation includes each type of fuel used for cooking and heating. We further corrected the consumption by household’s income level according to the UBN index. \( I_g(x, y) = \sum [1 - UBN(x, y)/100] / N_g(x, y) \) is the average inverse UBN for a given cell and \( I_d(y, x) \) is its departmental average (all

Table 3a. a) Sample of censal tract information.

| CENSAL FRACTION | HABIT. | HOUSES | HOMES | UBN | WATER | N.GAS | DRAIN | PC | CEL. PHONES |
|-----------------|-------|--------|-------|-----|-------|-------|-------|---|------------|
| 60070101        | 479   | 213    | 178   | 1  | 100   | 86    | 0     | 41| 87         |
| 60070102        | 677   | 275    | 253   | 4  | 100   | 80    | 0     | 37| 84         |
| 60070103        | 27    | 23     | 13    | 0  | 77    | 0     | 0     | 8 | 85         |
| 60070104        | 2     | 2      | 1     | 0  | 0     | 0     | 0     | 0 | 100        |
| 60070105        | 34    | 29     | 12    | 8  | 17    | 0     | 8     | 17| 100        |
| 60070106        | 15    | 15     | 5     | 0  | 0     | 0     | 0     | 60| 100        |
| 60070107        | 216   | 97     | 64    | 2  | 97    | 69    | 6     | 44| 92         |
| 60070108        | 24    | 23     | 11    | 9  | 9     | 0     | 0     | 18| 100        |
| 60070109        | 20    | 15     | 8     | 13 | 0     | 0     | 0     | 13| 88         |

Table 3b. b) Sample of grid information.

| CENSAL FRACTION | MEN | WOMEN | POPUL | HOMES | HOUSES | FAM. HOMES | CELL ID. # |
|-----------------|-----|-------|-------|-------|--------|------------|-------------|
| 60070101        | 240 | 239   | 479   | 178   | 213    | 177        | 672273      |
| 60070102        | 324 | 353   | 677   | 253   | 275    | 251        | 672273      |
| 60070103        | 16  | 11    | 27    | 13    | 23     | 13         | 670838      |
| 60070104        | 1   | 1     | 2     | 1     | 2      | 1          | 669397      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 669391      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 676600      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 676601      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 676602      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 676603      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 676604      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 678041      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 678042      |
| 60070105        | 24  | 10    | 34    | 12    | 29     | 12         | 678043      |
grids included in a department d). \(N_g\) is the total number of household in the cell regardless of the type of fuel used.

The information on the use of timber, coal and other forms of biomass was calculated using a similar approach to the one proposed in the project FAO/WISDOM (Trossero et al., 2009). We assumed an annual consumption rate for cooking and heating per household of 2.7 \(\text{tn (dry basis)}\) for those households which only use biomass, and of 0.25 \(\text{tn}\) for the remaining households. The emissions from domestic use of fuel in each cell are calculated as follows:

\[
E_{\text{RESID}}(x, y, p) = \sum_k R_g(x, y, k) \times F_{\text{FUEL}}(k, p) \tag{3}
\]

Where \(E_{\text{RESID}}(x, y, p)\) are the emissions of pollutant \(p\) at cell grid \((x, y)\) resulting from the use of fuel consumption \(k\); and \(F_{\text{FUEL}}(k, p)\) are proper emission factors for pollutant \(p\) and fuel type \(k\). The emission factors from burning considered are those established by EMEP/EEA (EMEP, 2016) for natural gas stoves and heaters. Fig. 2 shows the relative seasonal variation of natural gas consumption for the residential sector according to geographical regions.

Commercial and business district areas, stores, large shopping centers and public buildings (hospitals, schools, and governmental offices) are mainly located in the residential urban areas. Their geographical location are known through cooperative GPS maps like Openstreetmap (https://www.openstreetmap.org); local sources like INDEC (Argentine National Statistical Office, www.indec.gov.ar) or IGN (Argentine National Geographic Institute, http://www.ign.gob.ar/); however, this information is not complete for the entire country. Nevertheless, the highest energy consumption of this sector is from electric power and, to a lesser extent, from natural gas and other biomass fuels, whose consumption is known at the departmental level. Therefore, in situ emissions from the commercial and governmental sectors (natural gas and other biomass fuels) are calculated as additional to the residential areas. Since its consumption is not known at the census fraction level, we distributed the fuel consumption proportionally to the census fraction population within the residential areas.

\[
C_g(x, y, k) = C_d(x, y, k) \times \left[ H_g(x, y, k)/H_d(x, y, k) \right] \tag{4}
\]

\(C_d(x, y, k)\) is the (natural gas, charcoal, GLP, etc.) consumption known at the department level for the commercial plus public offices. Similarly to Eq. (3), the emissions are calculated as follows:

\[
E_{\text{COM-PUB}}(x, y, p) = \sum_k C_g(x, y, k) \times F_{\text{FUEL}}(k, p) \tag{5}
\]

Fig. 3 shows the energy demand of the residential and commercial sector per household and per capita by geographical regions.
2.5. Thermal plant emissions

To estimate the emissions from large thermal plants in the electric power generation sector, we considered the equipment installed in each plant and their annual fuel consumption (MINEM, 2016). We included sixty-six natural gas-fired thermal plants, 275 diesel power plants and 6 biomass-fired power plants. Equation (1) was used, where \( E \) is the emission of pollutant \( p \) in the power plant \( j \), using fuel \( k \); \( A \) is the annual energy generated and \( FE \) is the emission factor used (EMEP, 2016).

Fig. 4 shows the annual electricity generation according to fuel type and Fig. 5 shows the electricity demand according to user type (size) and geographic region.

Fig. 2. Natural gas consumption for residential sector according to geographical regions: a) Relative seasonal variation (deviations correspond to 1993–2014 period). b) Annual variation (millions m³/year).

\[
E_{p,j,k} = A 	imes FE_{p,k}
\]
2.6. Direct and fugitive refinery emissions

This subsection considers the atmospheric emissions due to heat and electricity production in refineries and due to fugitive emissions from by-product production. The Argentine Energy Office (MINEM, 2016) compiled activity data such as sales, the refinery’s own consumption, exports and imports of fuel. The Argentine Petrochemical and Chemical Industry Manual (IPA, 2015) compiled refinery activity data.

The emissions from the refineries' own heat and electricity production were estimated from their own consumption rates:

\[ E_{\text{HREF}}(j, p) = \text{Fuel}_{\text{OWN}}(j, k) \times LHV(k) \times F_{\text{FUEL}}(k, p) \]  

(6)

![Figure 3](http://dx.doi.org/10.1016/j.heliyon.2017.e00489)

**Fig. 3.** Energy demand for the residential and commercial sector in terms of GJ/household and GJ/capita distributed according to geographical regions.

![Figure 4](http://dx.doi.org/10.1016/j.heliyon.2017.e00489)

**Fig. 4.** Electric energy generation according to fuel type.
Where $E_{\text{HREF}}$ is the emission of pollutant $p$ from the refinery's own consumption ($\text{Fuel}_{\text{OWN}}$) of fuel $k$ produced in refinery $j$, $F_{\text{FUEL}}$ is the emission factor used in Argentina’s Third National Communication (ATNC, 2015) and $L_{\text{HV}}$ is the heat value of the fuel considered. Fugitive emissions were calculated considering the annual processed products (EMEP, 2016):

$$E_{\text{FUG}_{\text{REF}}} (j, p) = \text{Oil}_{\text{PROC}} (j) \times F_{\text{FUG}} (p)$$

Where $E_{\text{FUG,REF}}$ is the emission of pollutant $p$ to the atmosphere due to the annual amount of processed crude oil ($\text{Oil}_{\text{PROC}}$) in refinery $j$, and $F_{\text{FUG}}$ is the corresponding emission factor.

### 2.7. Cement plant emissions

We included ten cement production plants and calculated the emissions from their energy consumption and from the production of Clinker (US-EPA AP-42 Manual). This activity was reported in APCMA (2016).

### 2.8. Direct transportation emissions

One of the recently available databases in MINEM (2016) is the geo-localization of refueling gas stations. This database was associated to fuel sales in each gas station. Fuel sales were aggregated in each cell of the grid.

$$\text{Fuel}_{\text{GRID}} (x, y, k) = \sum_j \text{Fuel}_{\text{STATION}} (j, x, y, k)$$

Where $\text{Fuel}_{\text{GRID}}$ is the sum of fuel $k$ sold in all the refueling gas stations located in cell $(x, y)$ ($\text{Fuel}_{\text{STATION}}$). Since not all the fuel sold in that cell is consumed in that place, a distribution of fuel consumption was made to the neighboring cells by means of a convolution function with a bi-Gaussian filter function $bg(x, y)$, normalized for the kernel filter ($bg(x_m, y_m)=1$) (Puliafito et al., 2015):

---

**Fig. 5.** Electricity demand: a) distribution by user type and b) by geographical region.
\[
bg(x, y) = \exp \left[ -\frac{(x - x_m)^2}{d} \right] \times \exp \left[ -\frac{(y - y_m)^2}{d} \right]
\]

(9)

Fuel distribution \((Fuel_{\text{CONV}})\) is:

\[
Fuel_{\text{CONV}}(x, y, k) = \frac{1}{\sum_{u,v} bg(u, v) \iint_{u_{0},v_{0}} [Fuel_{\text{GRID}}(u, v, k) \times bg(x - u, y - v)] du dv}
\]

(10)

Where \(u_0 = x - x_m; \ u_f = x + x_m; \ v_0 = y - y_m; \ v_f = y + y_m; \) the filter width is 500 km with a deviation \(d\) dependent on the type of fuel. Vehicle-kilometers travelled (VKT) was estimated in each grid using fuel consumption and efficiency \(\gamma\) by type of fuel \(k\):

\[
VKT_{\text{GRID}}(x, y, k) = Fuel_{\text{CONV}}(x, y, k) \times \gamma(k)
\]

(11)

The road transportation sector emissions \(E_{\text{RTS}}\) corresponding to cell \((x, y)\) of the grid, fuel \(k\) and pollutant \(p\) were calculated as follow:

\[
E_{\text{RTS}}(x, y, k, p) = VKT_{\text{GRID}}(x, y, k) \times F_{\text{RTS}}(k, p, v)
\]

(12)

Where \(F_{\text{RTS}}\) is an emission factor that depends on the type of vehicle \(v\), fuel \(k\) and pollutant \(p\) (EMEP, 2016).

### 2.8.1. Calibration of the VKT

VKT can be calibrated using annually mean daily flow (AMDT) at different roads, fleet composition and fuel consumption, and efficiencies. The considered vehicle fleet is mainly composed of light passenger cars (LPC); commercial light duty-load vehicles (CLD < 2 tons); light-duty truck (LDT < 2 tons); medium-duty truck (MDT < 4 tons); semi-trailer towing truck (STTT < 20 tons); heavy-duty truck (HDT >20 tons); and four-stroke motorcycles and buses. With regard to fuel type, LPC and CLD use gasoline, natural compressed gas for vehicles (NCGV) and diesel; light, medium and heavy duty trucks use mainly diesel, but a small proportion use gasoline; and motorcycles use mainly gasoline. Table 4 shows a summary of fleet composition, fuel consumption, estimated fuel efficiency and annual VKT.

According to Eq (9), the activity of each cell \(VKT_{\text{GRID}}\) is estimated from the fuel consumption assigned to each cell. The vehicle activity in a cell is performed on streets and roads included in this cell. Then \(VKT_{\text{GRID}}(x, y, k) = \sum s VKT_{\text{SEG}}(s, k)\) is the activities summation of all \(s\) segments. Moreover, the activity in each segment is \(VKT_{\text{SEG}}(s, k) = VEH_{\text{SEG}}(s, k) \times L(s); \) \(VEH_{\text{SEG}}\) being the vehicles using fuel \(k\) at the segment \(s\), and \(L\) being the length of that segment. Street segments were classified into main access, trunk and primary routes, secondary and tertiary roads. There is no information on the average daily traffic for every segment; therefore, this information must be estimated from the consumption of
the cell and the hierarchy of the routes. The activity of the segment is distributed proportionally to $VKT_{GRID}$ and weighted by the product average of the road hierarchy $J(s)$ and the length of $L(s)$ at segment $s$ for each grid.

$$VKT_{SEGM}(s, i) = VKT_{GRID}(x, y, i) \times [J(s) \times L(s)] / \left[ \sum_s J(s) \times L(s) \right]$$

(13)

We can also consider $J(s)$ as average values of vehicles fluxes for a given hierarchy or weighting factors. Coefficient $J(s)$ takes into account traffic flow, width, type, use and importance of the road, and can be estimated using measured AMDT flow points. In this case study, the following values were assumed:

Access Routes = 120000; National trunk roads = 30000; Primary roads = 9000; Provincial routes = 4000; secondary streets = 1000, tertiary streets = 250 (Table 5).

Once $VKT_{SEGM}$ is calculated, the daily average vehicle $VEH_{SEGM}$ is determined for each segment dividing $VKT_{SEGM}$ by the segment length $L(s)$. This value allows us to compare the results with existing AMDT values. The width $d$ of the bi-Gaussian function in Eq. (9) can be calculated by iterating Eq. (9, 10, 11 and 13). Fig. 6 shows the calibration results of VKT values using the AMDT fluxes measured at 1548 points for different road types in Argentina. Fig. 6b shows the correlation between calculated and measured AMDT. Fig. 6c shows an example of AMDT fluxes following an east-west direction at a national road from two main urban metropolitan areas: Buenos Aires (12 million inhab.), in the East, and Mendoza (1.8 million inhab.), in the West. Vehicular activity spreads around urban centers proportionally to population and fuel sales. It must be noted that National Road N7 starts at the west edge of Buenos Aires city and ends at the west border of Argentina.

Table 4. Average annual national activity in the year 2014.

| Variable/fuel | Units | Gasoline | Diesel Oil | NCG (*) | Total |
|---------------|-------|----------|------------|---------|-------|
| Registered number of vehicles | Thousands | 7,028 | 4,653 | 1,695 | 13,376 |
| Percentage of vehicles | % | 53% | 35% | 13% | 100% |
| Fuel consumption | Thousand m$^3$ (* million m$^3$) | 7,812 | 8,759 | 2,853 |
| Fuel efficiency | km/l (* km/Thousand m$^3$) | 11.5 | 6.9 | 7.2 |
| Annual VKT | Millions veh.-km | 89,839 | 60,434 | 20,538 | 170,811 |
| Annual traveled distance per vehicle | km | 12,783 | 12,990 | 12,115 |
| Percentage of VKT | % | 53% | 35% | 12% | 100% |
| Daily traveled distance per vehicle | km | 35 | 36 | 33 |

Ref.: VKT: Vehicle-km traveled; NCG: Natural Compressed Gas.
Table 5. Average AMDT according to segment hierarchy.

| Hierarchy and road class | Number of points | Average | Std. Dev. | Assumed  |
|--------------------------|------------------|---------|-----------|----------|
| 1. Motorways             | 55               | 112,890 | 55%       | 120,000  |
| 2. National trunk roads  | 229              | 29,961  | 38%       | 30,000   |
| 3. Primary roads         | 243              | 9,763   | 24%       | 9,000    |
| 4. Provincial roads      | 570              | 3,838   | 32%       | 4,000    |
| 5. Secondary streets     | 336              | 1,281   | 32%       | 1,000    |
| 6. Tertiary streets      | 115              | 243     | 56%       | 250      |

Ref.: AMDT: Annual mean daily traffic measuring points.

2.8.2. Civil and military aviation

Estimated emissions include civil and military aviation comprising domestic and international airport traffic (landing and take-off – LTO – and landing cycles <1,000 m) and cruise traffic (following Tier 1 in EMEP, 2016). Activity was estimated from national fuel sales statistics subdivided into national and international use (MINEM, 2016) and from the National Airport System Regulatory Organization (ORSNA, 2016).

Fig. 6. Calibration of traffic flow in main roads. a) Location of AMDT data points. b) Correlation Calculated vs measured AMDT. c) East-West cross-section of AMDT data following National Road 7 (RN 7). AMDT measuring points of RN 7 is shown in panel a) with green dots.
\[ E_{\text{FLIGHT}}(p) = \sum_{k,t} A_{\text{FLIGHT}}(k,t) \times F_{\text{FLIGHT}}(k,p) \]  

(14)

Where \( E_{\text{FLIGHT}}(p) \) is the annual emission of the pollutant \( p \) for each of the LTO and cruise phases, \( A_{\text{FLIGHT}} \) is the fuel consumption at each phase of the flight, and \( F_{\text{FLIGHT}} \) is the emission factor referred to pollutant \( p \) and fuel \( k \).

### 2.8.3. Railways

Railroad passenger activity in Argentina is based on a train system centered in the city of Buenos Aires that comprises a long-distance service and commuter trains. The railroad freight network is organized to export the production of grains and minerals through the main ports along main rivers mainly in Rosario, Santa Fe, Buenos Aires and the deep-water port in Bahía Blanca. The approach used in this inventory is based on fuel consumption, according to Equation (1) using emission factors suitable for the average technology of the locomotive fleet. The activity data and railway park data were taken from the National Transportation Commission (CNRT, 2016). Fuel use was distributed proportionally to the length of the active railways by applying a hierarchy system distinguishing between fully-operating and intermittent rail corridors.

### 2.8.4. Navigation

This category includes the exhaust emissions arising from propulsion and auxiliary engines during berthing, maneuvering in harbor and during cruise from ocean-going, in port, and inland waterway vessels. Inland navigation in Argentina is centralized in the De la Plata, Paraná, Paraguay and Uruguay rivers and the most important ports are Buenos Aires, La Plata, Rosario, Santa Fe, Campana, San Nicolás, Goya, Reconquista, Barranqueras, Formosa, Gualeguaychú, and Concepción del Uruguay.

Navigation-related emissions are a consequence of combusting fuel in an internal combustion engine. Therefore, to estimate them, a general top-down approach was employed using available statistics on fuel consumption for national and international navigation, according to the general Equation (1). Port berths and routes to and from those berths were spatially identified using existing geographic definitions of the port boundaries. GIS tools were used to describe the transit routes using navigational charts. The National Port Authority (SSPYVN, 2016) provided the activity data on every port. Cruise emissions were spatially allocated across the major shipping lines also using ship movements.
3. Results

3.1. Emissions by source type

3.1.1. Residential and commercial emissions

Population is unevenly distributed in the territory (Table 6). Densely populated areas (> 7500 inhab./km²) are distributed in 0.06% (< 190,000 ha) of the territory with 13.2 million inhabitants compared to the 42 million total inhabitants of Argentina. Medium-sized urban areas (between 2,500 and 7,500 inhab./km²) occupy 0.68% of the territory with 22.3 million inhabitants and the remaining 1.45% (580,000) are distributed in the rest of the territory (98%).

With 12 million homes, the consumption of the residential and commercial sector in 2014 was: \(11.4 \times 10^9\) m³ of natural gas, \(1.7 \times 10^6\) Mg of LPG; \(8 \times 10^6\) Mg of firewood and \(51 \times 10^6\) MWh, leading to an average of 15.64 GJ/cap and 55.48 GJ/home (Fig. 2). Natural gas provides 52% of the total energy consumed by residential and commercial sectors for cooking and heating. While the Pampean Region has 20 million inhabitants consuming 54% of the total natural gas provision (460 m³/home per year), Patagonia, with 2.2 million inhabitants and the coldest climate in the country, consumed 24% of the natural gas provision (3,700 m³/home per year), other Regions consumed the remaining 22% (Fig. 3). Emissions to the atmosphere from the use of electricity in homes and offices are estimated as emissions from thermal power plants (next section).

Table 7 shows the spatial distribution of pollutants emitted in residential and commercial areas. For example, this sector emits 13,393 Mg per year of PM10.

### Table 6. Distribution of the population in the continental territory.

| Category | Density inhab./km² | % Territory | Homes | Inhabitants | % Total Population |
|----------|--------------------|-------------|-------|-------------|--------------------|
| 1        | < 1                | 82.8%       | 4,230 | 14,305      | < 0.1%             |
| 2        | ≥ 1 < 10           | 13.6%       | 1,066 | 4,716       | < 0.1%             |
| 3        | ≥ 10 < 100         | 1.7%        | 154,527 | 609,589 | 1%                |
| 4        | ≥ 100 < 1000       | 1.03%       | 590,197 | 4,262,934 | 6%                |
| 5        | ≥ 1000 < 2500      | 0.40%       | 520,082 | 6,228,667 | 5%                |
| 6        | ≥ 2500 < 5000      | 0.20%       | 1,722,198 | 9,212,099 | 14%               |
| 7        | ≥ 5000 < 7500      | 0.08%       | 2,596,990 | 8,610,400 | 21%               |
| 8        | ≥ 7500 < 10000     | 0.04%       | 4,281,534 | 7,077,751 | 36%               |
| 9        | ≥ 10000 < 20000    | 0.02%       | 1,746,468 | 5,092,160 | 13%               |
| 10       | ≥ 20000            | 0.005%      | 588,485 | 2,124,281 | 3%                |
|          |                    | 100%        | 12,205,777 | 43,236,901 | 100%              |
From this total, 26% of the emissions are generated in rural areas (<1,000 inhab./km²), 27% are generated in urban areas (between 1,000 and 2,500 inhab./km²), 48% are emitted in medium and densely populated cities (>2,500 inhab./km²). Fifty-five percent of the total PM10 emissions are produced around big cities in the Central and Pampean Regions (Fig. 7). PM2.5 shows a similar pattern. Eighty-four percent of NOx (65,000 Mg) emissions are more concentrated in urban areas in cities with densities higher than 2,500 inhab./km².

### 3.1.2. Main point sources

Fig. 8 shows the geographical distribution of refineries, thermal power plants and cement production plants. Table 8 presents the annual production for year 2014 by geographical regions of cement plants (8.1 × 10⁶ Mg), refineries (31.7 × 10⁶ Mg of crude oil refining), and electricity generation (129 GWh). Regarding the energy production, thermal power plants generate 64%, hydroelectric plants generate 31%, and the remaining is nuclear or renewable. Considering the energy demand, the residential sector consumes 41%, the commercial sector consumes 29% and the industrial sector consumes 30%. Fig. 8 also represents, as an example, the CO₂ emissions (Gg) produced by these point sources: 40,329 Gg from power plants, 6,444 Gg from refineries’ own consumption and 4,134 Gg from cement production plants. Considering its regional distribution, 43% of carbon dioxide emissions (22,500 Gg) are emitted in the Pampean Region, followed by 24% in the Central Region (12,100 Gg); the rest of the country contributes with 32%, that is 16,350 Gg.

### Table 7. Annual emissions (Mg/year) of the residential and commercial sector according to the population density of the cells.

| Zone         | Density Inhab./km² | CO₂  | NOₓ  | CH₄  | CO   | N₂O  | NMVOC | SO₂  | PM₁₀ | PM₂.₅ |
|--------------|--------------------|------|------|------|------|------|-------|------|------|-------|
| 1            | < 1                | 12,102 | 29   | 2.0  | 56   | 0.05 | 3.23  | 0.95 | 7.17 |
| 2            | ≥ 1 < 10           | 1,445 | 1.66 | 1.88 | 52   | 0.04 | 3.09  | 0.94 | 7.81 |
| 3            | ≥ 10 < 100         | 179,407 | 349  | 102  | 2.77 | 2.1  | 165   | 48   | 408  |
| 4            | ≥ 100 < 1000       | 1,730,579 | 3,664 | 764  | 20,886 | 18.0 | 1,240 | 367  | 3,029 |
| 5            | ≥ 1000 < 2500      | 3,502,961 | 8,151 | 930  | 25,738 | 29.0 | 1,521 | 440  | 3,575 |
| 6            | ≥ 2500 < 5000      | 6,803,417 | 17,049 | 787  | 22,931 | 34.7 | 1,325 | 352  | 2,753 |
| 7            | ≥ 5000 < 7500      | 6,907,071 | 17,702 | 481  | 14,949 | 28.4 | 844   | 209  | 1,504 |
| 8            | ≥ 7500 < 10000     | 5,042,579 | 12,916 | 367  | 11,318 | 20.4 | 640   | 154  | 1,160 |
| 9            | ≥ 10000 < 20000    | 4,222,106 | 10,914 | 226  | 7,400  | 17.0 | 412   | 103  | 650  |
| 10           | ≥ 20000            | 2,491,243 | 6,472 | 112  | 3,809 | 13.0 | 212   | 71   | 298  |
| TOTAL        |                    | 30,892,910 | 77,246 | 3,774 | 109,909 | 163  | 6,365 | 1,745 | 13,393 |

From this total, 26% of the emissions are generated in rural areas (<1,000 inhab./km²), 27% are generated in urban areas (between 1,000 and 2,500 inhab./km²), 48% are emitted in medium and densely populated cities (>2,500 inhab./km²). Fifty-five percent of the total PM10 emissions are produced around big cities in the Central and Pampean Regions (Fig. 7). PM2.5 shows a similar pattern. Eighty-four percent of NOx (65,000 Mg) emissions are more concentrated in urban areas in cities with densities higher than 2,500 inhab./km².
Fig. 7. PM10 (Mg/year) emissions from residential and commercial sector: a) Geographical distribution; b) total values according to urban densities; c) total and proportional values according to geographical regions. Urban densities: i) rural (density < 100 inhab./km²), ii) urban low (densities between 100 and 5000 inhab./km²), iii) urban medium (densities between 5000 and 100000 inhab./km²), iv) Urban high (densities > 100000 inhab./km²).

Fig. 8. a) Spatial distribution of CO2 emissions (Gg/year) thermal power plants, cement and refineries by production of heat or electricity; b) total and proportional values according to geographical regions.
Table 8. Annual production (2014) in cement plants, refineries and electricity thermal power plants by regions.

| REGION   | CEMENT (Mg) | OIL REFINING (Mg) | ELECTRICITY (GWh) | FUEL USED IN THERMAL POWER PLANTS |
|----------|-------------|-------------------|-------------------|----------------------------------|
| PATAGONIA| 1,800,000   | 1,712,909         | 23,923            | NG (10^3 m^3) BD (Mg) FO (Mg) C (Mg) |
| WEST     | 137,400     | 5,850,593         | 5,969             | 756,049 37,712 147,266           |
| NORTHWEST| 780,000     | 732,507           | 13,523            | 2,703,687 37,047                 |
| NORTHEAST| 780,000     | 2,048,465         | 19,026            | 1,729,094 337,595 225,353        |
| CENTRE   | 780,000     | 2,048,465         | 19,026            | 1,729,094 337,595 225,353        |
| PAMPA    | 3,380,000   | 21,439,793        | 55,192            | 6,646,400 1,055,548 394 2,450,916 1,044,417 |
| TOTAL    | 8,114,000   | 31,784,267        | 129,312           | 14,276,572 1,584,521 394 2,823,536 1,044,417 |

NG: Natural Gas; GO: Gas oil, BD Biodiesel, FO Fuel-oil, C: Coal.
Geographic regions include the following Provinces: Patagonia: Neuquén, Río Negro, Chubut, Santa Cruz y Tierra del Fuego; West: La Rioja, Mendoza, San Juan, San Luis; Northwest: Catamarca, Jujuy, Salta Tucumán; Northeast: Corrientes, Chaco, Formosa, Misiones; Centre: Córdoba, Entre Ríos Santiago del Estero y Santa Fe; Pampa: Buenos Aires, Ciudad de Buenos Aires y La Pampa; (See also Fig. 1).

3.1.3. Emissions from the transport sector

In 2014, the transportation sector consumed $8.2 \times 10^6$ Mg of gas-oil, $7.9 \times 10^6$ Mg of gasoline and $2.8 \times 10^9$ m$^3$ of compressed natural gas mainly in road transport, $1.6 \times 10^6$ Mg of kerosene for aviation and $1.4 \times 10^6$ Mg of fuel oil for inland navigation (Table 9). The railroad freight network carried $8.9 \times 10^6$ tonne-kilometers (TKT) and transported 267 million passengers from which 13 million veh-km (VKT) used diesel engines and 99.5 million VKT used electric engines.

Fig. 9 shows the fuel sales at the refueling gas stations. It also shows the calculated VKT activity derived for the road transport sector and the respective NOx emissions for this subsector. The Pampean and Central Region concentrates 60% of the activity and emissions. Road transport produced the main NOx emissions, which has a strong impact on rural areas. Maritime and inland navigation has a significant impact on NOx, PM10 and SO$_2$ emissions due to the use of fuel oil as the main fuel.

4. Discussion

4.1. Analysis of the results

Calculated emissions are analyzed from different points of view:

A) According to the whether the pollutants affect climate change, air quality or health, they were classified as: i) greenhouse gases (CO$_2$, CH$_4$ and N$_2$O) grouped
as CO₂eq (weighted by their global potential warming); ii) ozone precursors (linear sum of CO, NOX and VOC) and iii) impacting air quality (linear sum of PM10, PM2.5 and SO₂). Greenhouse gases were calculated according to their global warming potential, converting them to CO₂eq; while emissions of ozone precursors and air quality were added in equal proportion.

B) According to the generating sector, that is, where emissions are produced, we organized the emissions in four subgroups: i) production of electricity, ii) transport, iii) residential and commercial, iv) transformation in refineries and cement production (Fig. 10a).

C) According to the demanding sector, we aggregated the emissions into three large groups: i) energy for housing: residential + commercial + 60% of the thermal emissions of the electric generation; ii) energy for transport: road + rail + navigation + aviation + 50% of refinery (its own emissions of transformation); iii) emissions from the industry: that is, only cement production and 50% from refinery. Note that in this inventory we do not include the agricultural sector or the industrial’s own process emissions, except for cement (Fig. 10b and Table 10).

D) When classifying emissions according to population density, we have formed four subgroups: i) rural (density < 100 inhab./km²), ii) urban low (densities between 100 and 5000 inhab./km²), iii) urban medium (densities between 5000 and 100000 inhab./km²), iv) Urban high (densities > 100000 inhab./km²) (Fig. 11 and Table 11).

If we focus on the sources of emissions (Fig. 10a), greenhouse gases (GHGs) are mainly produced by the transport sector (40%) followed by electricity generation (28%) and the residential + commercial sectors (22%). Moreover, for ozone precursors (OZPR), transport is also clearly the main emitter (83%). Concerning

---

### Table 9. Fuel consumption by transportation sector Mg/year by sectoral activity, year 2014.

| ARGENTINA            | AEK  | FUEL OIL | GAS OIL | GASOLINE | NCG (1000 m³) |
|----------------------|------|----------|---------|----------|---------------|
| FED. GOVERNMENT      | 410.4| -        | 9,885   | 1,006    | -             |
| PASSENGER PRIVATE TRANSPORTATION | -    | 615.4    | 6,798,979 | 5,293,381 | 2,852,517     |
| BUNKER (NATION+ INTERN.) | 1,301,024 | -        | 417,047  | 13.6     | -             |
| ROAD LOAD TRANSPORT  | -    | 2,721    | 558,190 | 18,827   | -             |
| TRAIN LOAD TRANSPORT | -    | -        | 45,990  | -        | -             |
| PASSENGER PUBLIC TRANSPORTATION | -    | -        | 752,156  | 84.6     | -             |
| TOTAL                | 1,301,435 | 3,336.4  | 8,582,249 | 5,313,313 | 2,852,517     |

Ref.: AEK: Aero kerosene and jet fuel; NCG: Natural compressed gas.
other air quality emissions (AQIMP: PM and SO2) electricity generation (33%), transport (30%) and cement production (20%) have also contributed to emissions. From the energy demand perspective, transport is responsible for an average 56% of the emissions, contributing with 85% of ozone precursors, 44% of greenhouse gases and 38% of air quality specific contaminants. Housing has an average emission impact of 29%, from which 39% are greenhouse gases, 37% are air quality pollutants, and 10% are ozone precursors.

Fig. 11 shows the contribution of each pollutant group according to population density. This shows that 49% of total emissions occur in rural areas, 31% in rural areas of medium density, 13% in intermediate urban areas and 7% in densely populated urban areas. On the other hand, when emissions are analyzed by
Fig. 10. Sectoral emissions contributions a) from the energy generation and b) from the energy demand. Ref: AVERAGE: National mean values; GHG: Greenhouse gases (CO2, CH4 and N2O); OZOPR: Ozone Precursors (CO, NOx and NMVOC); AQIMPO: Air quality impact (PM10, PM2.5 and SO2).

Table 10. Emissions (Mg/year) aggregated by the demanding sector.

| ENERGY DEMAND SECTOR | GHG     | OZOPR    | AQIMPO  |
|----------------------|---------|----------|---------|
| TRANSPORT            | 62,903,541 | 2,680,989 | 64,353   |
| HOUSING              | 55,831,675 | 310,214  | 62,130   |
| INDUSTRY             | 25,596,136 | 157,570  | 40,947   |
| TOTAL                | 144,331,351 | 3,148,773 | 167,430  |

Ref.: GHG (Greenhouse gases CO2eq): CO2, CH4, N2O; OZOPR (Ozone precursors): CO, NOx, NMVOC; AQIMP (Air quality impact): PM10, PM2.5, SO2.
extension (per square km), the largest impact is seen, as expected, in medium and densely populated urban areas (Fig. 12). They reach more than 20.3 Gg per square km (GHG), 297 Mg/k^2 of OZPR and 11.5 Mg/km^2 for AQIMP, which is approximately 300 times higher than the national average (390, 290 and 160 times, respectively). Fig. 13 shows the geographical distribution of total emissions for two primary pollutants: PM2.5 and carbon monoxide with their distributions by subsector. PM2.5 has a significant component from the residential sector (48%), especially due to fuelwood consumption in heating and cooking, followed by navigation (23%) from fuel oil use. In contrast, CO is mainly produced by the road transport sector (90%), especially gasoline cars. The maps clearly indicate the highest concentration of pollutants to the atmosphere coming from major urban centers and the impact of transport in vast rural areas.

Table 11. Emissions (Mg/year) aggregated by the source sector.

| ENERGY GENERATION | GHG        | OZOPR     | AQIMP     |
|-------------------|------------|-----------|-----------|
| ELECTRICITY       | 40,973,052 | 194,491   | 55,998    |
| TRANSPORT         | 57,830,626 | 2,623,251 | 50,173    |
| RESIDENTIAL + COMMERCIAL | 31,247,843 | 193,519   | 28,531    |
| REFINERY + CEMENT PRODUCTION | 14,279,830 | 137,512   | 32,728    |
| TOTAL             | 144,331,351| 3,148,773 | 167,430   |

Ref.: GHG (Greenhouse gases CO2eq): CO2, CH4, N2O; OZOPR (Ozone precursors): CO, NOx, NMVOC; AQIMP (Air quality impact): PM10, PM2.5, SO2.
4.2. Top-down comparison

To validate the present inventory, we compared the total results with the national inventory of greenhouse gases submitted by Argentina for the year 2012 to the UNFCC presented as the Third National Communication (ATNC, 2015) and the total values of EDGAR global database for Argentina 2010. Although it corresponds to different reference years, the average inter-annual variations of the activities do not exceed 15% between 2010 and 2014 except for the increase in domestic aviation that reached a 57% increase in kerosene sales. Table 12 (a) summarizes the calculations of this inventory (GEAA); Table 12 (b), the TNCA; and Table 12 (c), EDGAR. It is observed that while for some sectors relative differences between both inventories have a good approximation depending on pollutants (3%, electricity production; 3–6%, residential, road and rail transportation; 10–20%, oil refining and cement production) the discrepancies in other sectors are high: air navigation (CH4 325%, CO 185%) and maritime navigation are greater than 80% (i.e. SO2 300%). This difference in the navigation and aviation sector is partly due to the variation in activity between 2012 and 2014 (57% in kerosene for aviation, 15% fuel oil and 36% gas oil in sea and river navigation). In the residential sector, the differences (8–25%) arise from the uncertainty in the estimation of the consumption of fuelwood and LPG for use in kitchen and home heating. An important total difference of 60 Gg is also seen in the methane emissions comparing GEAA with EDGAR, especially for the road transport sector and the fugitive emissions from refinery. Probably, EDGAR has underestimated the use of NCGV vehicles, where Argentina has an important fleet. Another source of discrepancies is in the CH4 fugitive emissions from the refineries’ own consumption.

Fig. 12. Emissions density (Mg/km²) by pollutant and population density. Ref: GHG: Greenhouse gases (CO₂, CH₄ and N₂O); OZOPR: Ozone Precursors (CO, NOx and NMVOC); AQIMPO: Air quality impact (PM10, PM2.5 and SO₂). Urban densities: i) rural (density < 100 inhab./km²), ii) urban low (densities between 100 and 5000 inhab./km²), iii) urban medium (densities between 5000 and 100000 inhab./km²), iv) urban high (densities > 100000 inhab./km²).
4.3. Spatial comparison with EDGAR

To evaluate uncertainty in the spatial distribution, we compared the inventory here proposed (GEAA) with the EDGAR international database, which is often used in those areas for which there are not any specific national inventories.

We compared the road transportation and residential sectors since they are widely distributed in the territory. Due to different resolutions (GEAA is 4 times finer), we converted the GEAA data to the EDGAR resolution, adding 16 GEAA-cells included in each EDGAR cell (hereinafter called “low resolution”). Additionally,
Table 12. Comparison between the inventories of Argentina GEAA (2014), TCNA (2012) and EDGAR (2010) (Gg yr⁻¹).

| Inventory | CO2  | NOX  | CH4  | CO   | N2O  | VOC  | SO2  | PM10 | PM25 |
|----------|------|------|------|------|------|------|------|------|------|
| GEAA     |      |      |      |      |      |      |      |      |      |
| PHE      | 40330| 158.68| 4.58 | 29.46| 1.21 | 6.35 | 49.41| 3.81 | 2.78 |
| ROP+FUG  | 6444 | 14.35| 43.46| 4.48 | 0.04 | 96.65| 26.91| 0.72 | 0.72 |
| CEM      | 4134 | 10.06| 11.82| 0.15 | 3.03 | 0.65 | 0.69 |      |      |
| DAV      | 2224 | 9.92 | 0.06 | 6.42 | 0.07 | 0.38 | 0.70 | 0.07 | 0.07 |
| ROT      | 48851| 436.29| 16.52| 1740.44| 3.56| 368.53| 12.63| 9.66 | 9.66 |
| RRT      | 237  | 3.95 | 0.01 | 0.81 | 0.35 | 0.11 | 0.10 |      |      |
| INN      | 3976 | 49.76| 4.42 | 4.67 | 1.26 | 1.74 | 12.61| 2.39 | 2.17 |
| RES      | 30893| 77.25| 3.77 | 109.91| 0.16| 6.36 | 1.75 | 13.39| 13.39|
| T. GEAA  | 136818| 760.26| 72.82| 1908.00| 6.30| 480.51| 107.03| 30.81| 29.59|
| TNCA     |      |      |      |      |      |      |      |      |      |
| PHE      | 43840| 167.86| 4.47 | 31.22| 1.28 | 6.84 | 49.02|      |      |
| ROP+FUG  | 5953 | 13.05| 39.29| 3.98 | 0.03 | 70.12| 24.93|      |      |
| CEM      | 4446 |      |      |      |      | 3.21 |      |      |      |
| DAV      | 1125 | 3.93 | 0.01 | 1.57 | 0.03 | 0.79 | 0.71 |      |      |
| ROT      | 48259| 434.53| 16.12| 1433.99| 3.57| 377.27| 14.07|      |      |
| RRT      | 220  | 3.57 | 0.01 | 2.97 | 0.09 | 0.59 | 0.11 |      |      |
| INN      | 1359 | 27.03| 0.13 | 18.02| 0.04 | 3.60 | 1.81 |      |      |
| RES      | 28371| 75.12| 3.11 | 138.51| 0.14| 7.35 | 2.06 |      |      |
| T. TNCA  | 133573| 725.09| 63.13| 1630.26| 5.17| 466.57| 95.92|      |      |
| EDGAR    |      |      |      |      |      |      |      |      |      |
| PHE      | 41784| 106.42| 1.54 | 33.62| 0.19 | 2.76 | 240.14| 7.18 | 3.77 |
| ROP+FUG  | 16926| 9.16 | 0.86 | 15.46| 0.04 | 1.87 | 13.12| 0.26 | 0.22 |
| CEM      | 5610 |      |      |      |      |      |      |      |      |
| DAV      | 2367 | 5.66 | 0.02 | 1.87 | 0.07 | 0.56 | 0.60 | 0.10 | 0.10 |
| ROT      | 36399| 284.53| 6.49 | 2507.95| 0.95| 328.71| 3.15 | 9.15 | 9.15 |
| RRT      | 92   | 5.44 | 0.01 | 1.31 | 0.16 | 3.63 | 1.06 | 1.06 |      |
| INN      | 34329| 37.77| 4.28 | 81.88| 4.02 | 6.09 | 22.68| 9.75 | 6.77 |
| RES      |      |      |      |      |      |      |      |      |      |
| T. EDGAR | 137507| 448.99| 13.19| 2642.08| 5.27| 339.67| 283.27| 27.52| 21.08|

Ref.: PHE: Public electricity and heat production; ROP: Refinery oil products; DAV: Domestic aviation; ROT: Road transportation; RRT: Rail transportation; INN: Inland navigation; RES: Residential and commercial sectors; FUG: Fugitive emissions from oil refinery; CEM: Cement production.
the reverse conversion was done by adapting EDGAR data to the GEAA resolution, dividing each cell by 16 and repeating the same value in the 16 cells (hereinafter called “high resolution”). As can be observed in Table 12, the total values for Argentina in both inventories for these subsectors are very similar. However, the spatial distribution of these values shows important discrepancies. In Fig. 14, blue colors indicate higher EDGAR values and red colors show higher GEAA values.

In the high-resolution comparison, roads are in red color with higher values for GEAA, and a combination of positive (red) and negative (blue) values are observed in the cities, indicating an uneven distribution of main routes or residential urban zones. Fig. 15 shows the differences in low resolution, and it is observed that in the GEAA map, emissions are higher in the urban zones (red values) than in the EDGAR map. On the contrary, emissions are higher in the rural zones in the EDGAR map (blue colors), and they can reach, for example, between 5 and 90 additional annual Mg of PM10. These differences are important when it comes to computing air quality in a city by using both maps. An air quality study using EDGAR (Garcia Ferreyra et al., 2016) shows an underestimation of the measures of air quality in urban zones, which would be a reason to affirm that the GEAA map (even in the 10 × 10 km resolution) could produce better results.

Fig. 16 shows an evaluation of the emissions (of CO₂) according to the population densities of the cells. EDGAR assigns up to 45% of the emissions to cells with very low population densities mainly from road transport emissions. In residential

![Fig. 14. Difference between the GEAA and EDGAR inventories for road transport. a) Differences in high resolution (2.5 × 2.5 km). Green: no value, b) Zoom on the central zone of Argentina.](image-url)
emissions, there is also an excess of EDGAR relative to GEAA for the first 4 density categories (less than 1000 inhab./km²). It should be noted that Argentina has a very high urban population (90% resides in areas with densities higher than 1000 inhab./km²), so GEAA seems more appropriate, since it was built from smaller units of population census data. Comparing only the emissions of road transport, an excess of EDGAR relative to GEAA of 32% is observed for the cells

![Fig. 15. Difference between the GEAA and EDGAR inventories for road transport. a) Differences in low resolution (10 km x 10 km). Green: no value., b) Zoom on the central zone of Argentina.](image)

![Fig. 16. Comparison of CO2 emissions residential and road transport for both inventories based on the average population densities of the cells.](image)
with densities of less than 1 inhab./km², which corresponds to rural routes with very little vehicular traffic. In GEAA, the traffic is developed in those cells with densities greater than 1 hab./km². Fig. 17 shows an overestimation of EDGAR emissions in low density urban areas and an underestimation in densely populated cities. While total emissions are similar, residential emissions of GEAA are concentrated in medium- and high-density cities, while EDGAR allocates them to low-density areas. Fig. 18 shows a longitudinal section (60°W) of road and residential emissions (normalized to their maximum) between latitudes 30°S and 34°S for both GEAA and EDGAR inventories compared to the red channel intensity of the night light map (NOAA-NGDC, 2010) and the population map provided by INDEC (INDEC, 2016). EDGAR closely follows the red channel signal, whereas GEAA does it to the population. Note that EDGAR has a higher background level than GEAA consistent with the previous figures, which leads it to overestimate rural emissions.

Both EDGAR and GEAA emission inventories correlate emission sources with their activity in geographical terms using spatial indicators or proxies, which are defined based either on geographically resolved official statistics (e.g. population density), on GIS maps-derived data (e.g. road network) or on land cover data (departments/districts). Although EDGAR emission inventory is currently available worldwide and it has been used in regional air quality model applications, its spatial uncertainty remains very large and the representation of the sources cannot be expected to be accurate.

According to the EDGAR team (Janssens-Maenhout et al., 2012; Janssens-Maenhout et al., 2015), for the road transport sector EDGAR implements a proxy data defined as “population × road length” to improve spatial disaggregation. This
calculation applied at the grid level, requires knowing the population and length of the country road system at each cell. While the latter is well known (i.e. through GIS tool using open-source maps like openstreetmap), population data used by EDGAR is known only at the provincial or district level. Moreover, when the spatial activity level is incomplete, no additional information is used to enhance GIS data quality.

Therefore, emission distribution on grid maps in EDGAR derived from proxy data (“in-house”) leads to a poor assessment of the rural population. These uncertainties are particularly evident in large rural areas like in Patagonia or the north-east region of Argentina, where population density is close to zero. By means of this procedure, the road and residential transport emissions represented by EDGAR result in an overestimation of emissions in rural areas and an underestimation of urban areas, especially in more densely populated areas. Nevertheless, the EDGAR view is understandable since it uses a common approach to produce similar tier level proxy data for all countries in the world with very different sources and data quality.

In that context, GEAA spatially resolved emissions of the road transport sector were scaled down to the 2.5 km grid, employing a combination of a top–down approach that uses an ensemble of activity databases and high resolution digital maps. Basic information on fuel sales was obtained at point level since the location of refueling gas stations is known. The fuel consumption allocation was performed at grid and segment level and then validated using measured AMTD fluxes by means of road hierarchies and their lengths. This procedure is more likely to capture the spatial variations within the urban areas, since the road network is used to estimate the emissions at the road link level. Moreover, this method for spatial
allocation is able to produce more detailed emissions maps, even allowing the
consideration of the activity in secondary and local roads along with main roads.
Furthermore, the final gridding resolution can be improved as desired due to the
possibilities of the geospatial surrogates.

5. Conclusions

We presented a high-resolution inventory (0.025° × 0.025°) of atmospheric
emissions for the energy sector in Argentina for 2014. The main contribution of
this work is the geographic allocation of the considered sources using newly
baseline information of population data from the census tract and energy
consumption. We have organized the inventory following the categories proposed
by the IPCC for the energy sector for greenhouse gases (CO₂, CH₄, N₂O), ozone
precursors (CO, NOₓ, VOC) and other specific air quality indicators such as SO₂,
PM10, and PM2.5. Either from the energy generation or from the demand sector,
transportation is the main contributor affecting both urban and rural areas. With
regard to the sources of GHG emissions, the total amount reaches 144 Tg, from
which the transportation sector emits 57.8 Tg (40%), followed by electricity
generation with 40.9 Tg (28%), residential + commercial with 31.24 Tg (22%), and
cement and refinery production with 14.3 Tg (10%). This inventory shows that
49% of the total emissions occur in rural areas, 31% in rural areas of medium
density, 13% in intermediate urban areas and 7% in densely populated urban areas.
However, when emissions are analyzed by extension (per square km), the largest
impact is in medium and densely populated urban areas, reaching more than 20.3
Gg per square km (GHG), 297 Mg/k² of OZPR and 11.5 Mg/km² for AQIMP,
corresponding to amounts approximately 300 times higher than the national
average (390, 290 and 160 times, respectively).

From the energy demand perspective, transport accounts for an average 56% of the
emissions, contributing with 85% of ozone precursors, 44% of greenhouse gases
and 38% of air quality specific contaminants. Housing has an emission impact of
29% on average, from which 39% are greenhouse gases, 37% are air quality
pollutants, and 10% are ozone precursors.

Regarding the comparison with the EDGAR database, although EDGAR has a fine
resolution (0.1° × 0.1°) and the total emissions estimated by EDGAR and GEAA
are similar (within a 10% variation), for several subsectors the spatial distribution
of EDGAR is not adequate for Argentina. EDGAR’s road transport and residential
emissions result in an overestimation in rural areas and an underestimation of
urban areas, especially in more densely populated areas compared to GEAA.
EDGAR underestimates 60 Gg in methane emissions from the road transport sector
and fugitive emissions from refinery.
The use of this high-resolution map will allow the development of air quality models with more accurate estimates of the environmental concentrations of the pollutants present, for allocating control responsibility and for meeting an emission target in appropriate administrative sectors.

In subsequent works, the national inventory of other activities affecting air quality, such as the waste sector, agricultural activities (in preparation), biogenics and burning of biomass will be presented.

Declarations

Author contribution statement

S. Enrique Puliafito: Conceived and designed the experiments; Wrote the paper.

Paula S. Castesana, María F. Ruggeri: Analyzed and interpreted the data; Contributed analysis tools or data.

David G. Allende: Performed the experiments; Analyzed and interpreted the data.

Funding statement

This work was supported by Universidad Tecnológica Nacional (UTN IFI Projects PID 1799 and 1487, CONICET (CONICET PIP 112 201101 00673) and FONCYT (FONCYT PICT 2012-1021).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Alonso, M.F., Longo, K.M., Freitas, S.R., da Fonseca, R.M., Marécal, V., Pirre, M., Klenner, L.G., 2010. An Urban Emissions Inventory for South America and Its Application in Numerical Modeling of Atmospheric Chemical Composition at Local and Regional Scales. Atmospheric Environ. 44 (39), 5072–5083.

Andrade, M., Ynoue, R., Harley, R., Miguel, A., 2004. Air Quality Model Simulating Photochemical Formation of Pollutants: The São Paulo Metropolitan Area Brazil. Int. J. Environ. Pollut. 22 (4), 460–475.

APCMA, 2016. Argentine Portland Cement Manufacturers Association. Last access Nov 2, 2017 www.afcp.org.ar.
ATNC, 2015. Argentina Third National Greenhouse Report to UNFCCC. Last Access Nov 2, 2017 www.ambiente.gob.ar/tercera-comunicacion-nacional/.

Binkowski, F., Roselle, S., 2003. Models-3 Community Multiscale Air Quality (CMAQ) Model Aerosol Component 1. Model Description. J. Geophys. Res. Atmos. 108 (D6), 4183.

Butler, T., Lawrence, M., Gurjar, B., van Aardenne, J., Schultz, M., Lelieveld, J., 2008. The representation of emissions from megacities in global emission inventories. Atmospheric Environ. 42 (4), 703–719.

CNRT, 2016. Argentina National Transportation Commission. Last access Nov 2, 2017 www.cnrt.gob.ar/.

Cimorelli, A., Perry, S., Venkatram, A., Weil, J., Paine, R., Peters, W., 1998. AERMOD-Description of Model FormulationEnvironmental Protection Agency. Last access Nov 7, 2017 www3.epa.gov/scram001/7thconf/aermod/aermod_mfd.pdf.

Crippa, M., Janssens-Maenhout, G., Dentener, F., Guizzardi, D., Sindelarova, K., Muntean, M., Van Dingenen, R., Granier, C., 2016. Forty Years of Improvements in European Air Quality: Regional Policy-Industry Interactions with Global Impacts. Atmos. Chem. Phys. 16, 3825–3841.

EDGAR, 2016. Emissions Database for Global Atmospheric ResearchEuropean Commission - JRC Joint Research Centre IES Institute for Environment and Sustainability, Italy. Last access Nov 7, 2017 http://edgar.jrc.ec.europa.eu/.

EMEP, 2016. EMEP/EEA air pollutant emission inventory guidebook 2016 Technical guidance to prepare national emission inventories, Copenhagen Denmark. Last access Nov 7, 2017 https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/#parent-fieldname-title.

NEI, 2016. National Emissions InventoryUS Environmental Protection Agency. Last access Nov 2, 2017 https://www.epa.gov/air-emissions-inventories.

Ferreira, J., Guevara, M., Baldasano, J., Tchepel, O., Schaap, M., Miranda, A., Borrego, C., 2013. A Comparative Analysis of Two Highly Spatially Resolved European Atmospheric Emission Inventories. Atmospheric Environ. 75, 43–57.

Gallardo, Laura, Escribano, Jerónimo, Dawidowski, Laura, Rojas, Néstor, Andrade, Maria, Osses, Mauricio, 2012. Evaluation of Vehicle Emission Inventories for Carbon Monoxide and Nitrogen Oxides for Bogotá, Buenos Aires, Santiago, and São Paulo. Atmospheric Environ. 47, 12–19.

García Ferreyra, María, Curci, Gabriele, Lanfr, Mario, 2016. First Implementation of the WRF-CHIMERE-EDGAR Modeling System Over Argentina. IEEE J. Sel. Topics Appl. Earth Observ. in Remote Sens. 9 (12), 5304–5314.
Garg, A., Shukla, P., Kapshe, M., 2006. The Sectoral Trends of Multigas Emissions Inventory of India. Atmospheric Environ. 40 (24), 4608–4620.

Granier, C., Bessagnet, B., Bond, T., D’Angiola, A., van Der Gon, H.D., Frost, G., Heil, A., et al., 2011. Evolution of Anthropogenic and Biomass Burning Emissions of Air Pollutants at Global and Regional Scales during the 1980-2010 Period. Climatic Change 109, 163.

Grell, Georg A., Peckham, Steven, Schmitz, Rainer, McKeen, Stuart, Frost, Gregory, Skamarock, William, Eder, Brian, 2005. Fully Coupled ‘online’ Chemistry within the WRF Model. Atmospheric Environ. 39 (37), 6957–6975.

Gurjar, B., Butler, T., Lawrence, M., Lelieveld, J., 2008. Evaluation of emissions and air quality in megacities. Atmospheric Environ. 42, 1593–1606.

INDEC, 2016. National Population CensusArgentine National Statistical Office. Last access Nov 2, 2017 www.indec.gov.ar.

IPA, 2015. Statistical Yearbook of the Petrochemical and Chemical Industry of Argentina. Last access Nov 2, 2017 www.ipa.gov.ar.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas InventoriesIn: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), Hayama Japan: Institute for Global Environmental Strategies (IGES). Last access Nov 7, 2017 https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

Janssens-Maenhout, G., Pagliari, V., Guizzardi, D., Muntean, M., 2012. Global emission inventories in the Emission Database for Global Atmospheric Research (EDGAR) –Manual (I). Gridding: EDGAR emissions distribution on global grid mapsLuxembourg: European Union. Last access Nov 7, 2017 http://publications.jrc.ec.europa.eu/repository/bitstream/JRC78261/edgarv4_manual_i_gridding_pub-sy_final.pdf.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Dentener, F., Muntean, M., Pouliot, G., Keating, T., Zhang, Q., Kurokawa, J., Wankmüller, R., van der Gon, H. D., Klimont, Z., Frost, G., Darras, S., Koffi, B., Liu, M., Kuenen, J.J.P., 2015. HTAP_v2: a mosaic of regional and global emission gridmaps for 2008 and 2010 to study hemispheric transport of air pollution. Atmos. Chem. Phys. 15, 11411–11432.

Kurokawa, J., Ohara, T., Morikawa, T., Hanayama, S., Janssens Maenhout, G., Fukui, T., Kawashima, K., Akimoto, H., 2013. Emissions of Air Pollutants and Greenhouse Gases over Asian Regions during 2000-2008: Regional Emission Inventory in ASia (REAS) Version 2. Atmospheric Chem Phys 13 (21), 11019–11058.

Longo, K., Freitas, S., Pirre, M., Marécal, V., Rodrigues, L., Panetta, J., Alonso, M., et al., 2013. The Chemistry CATT-BRAMS Model (CCATT-BRAMS 4. 5): A
Regional Atmospheric Model System for Integrated Air Quality and Weather Forecasting and Research. Geosci. Model Dev. Discuss. 6, 1173–1222.

MEIC, 2016. Multi-Resolution Emission Inventory for China (MEIC). Last access Nov 7, 2017 http://www.meicmodel.org.

MINEM, 2016. Ministerio de Energía de Argentina y Minería (Ministerio de Energía de Argentina y Minería (Secretary of Energy, Argentina). Last access Nov 7, 2017. http://datos.minem.gob.ar/.

NOAA-NGDC, 2010. Version 4 DMSP-OLS Nighttime Lights Time Series. Last access Nov 7, 2017 http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html.

Oda, T., Maksyutov, S., 2011. A Very High-Resolution (1 km x 1 km) Global Fossil Fuel CO2 Emission Inventory Derived Using a Point Source Database and Satellite Observations of Nighttime Lights. Atmospheric Chem. Phys. 11 (2), 543–556.

ORSNA, 2016. National Airport Regulatory Office. Last access Nov 2, 2017 https://www.orsna.gov.ar/.

Pereira, Gabriel, Freitas, Saulo, Moraes, Elisabete, Ferreira, Nelson, Shimabukuro, Yosio, Rao, Vadlamudi, Longo, Karla, 2009. Estimating Trace Gas and Aerosol Emissions over South America: Relationship between Fire Radiative Energy Released and Aerosol Optical Depth Observations. Atmospheric Environ. 43 (40), 6388–6397.

Pouliot, G., Pierce, T., van der Gon, H.D., Schaap, M., Moran, M., Nopmongcol, U., 2012. Comparing Emission Inventories and Model-Ready Emission Datasets between Europe and North America for the AQMEII Project. Atmospheric Environ. 53, 4–14.

Puliafito, E., Allende, D., Pinto, S., Castesana, P., 2015. High Resolution Inventory of GHG Emissions of the Road Transport Sector in Argentina. Atmospheric Environ. 101, 303–311.

Raupach, M., Rayner, P., Paget, M., 2010. Regional Variations in Spatial Structure of Nightlights, Population Density and Fossil-Fuel CO2 Emissions. Energy Policy 38 (9), 4754–4756.

Saikawa, E., Kurokawa, J., Takigawa, M., Klevtsoin, J.B., Mauzerall, D., Horowitz, L., Ohara, T., 2011. 2011, The Impact of China’s Vehicle Emissions on Regional Air Quality in 2000 and : A Scenario Analysis. Atmospheric Chem. Phys. 11 (18), 9465–9484.

Scire, J., Strimaitis, D., Yamartino, R., 2000. A User’s Guide for the CALPUFF Dispersion Model. Massachusetts USA: Earth Tech Inc. Concord. Last access Nov 7, 2017 http://www.src.com/calpuff/download/CALPUFF_UsersGuide.pdf.
SSPYVN, 2016. National Port Authority. Subsecretaría de Puertos Y Vías Navegables. Ministerio de Transporte. Last access Nov 2, 2017 www.sspyvn.gob.ar/sspyvn.

Trossero, M., Drigo, R., Anschau, A., Carballo, S., Flores Marco, N., 2009. Análisis del balance de energía derivada de biomasa en ArgentinaIn: Roveda, Eduardo Beaumont (Ed.), Análisis espacial de la producción y consumo de biocombustibles aplicando la metodología de Mapeo de Oferta y Demanda Integrada de Dendro combustibles (Wood fuel Integrated Supply/Demand Ove). WISDOM, ARGENTINA. Last access Oct 1, 2017 http://www.fao.org/docrep/011/i09000s/i09000s00.

UK NAEI, 2016. United Kingdom National Atmospheric Emissions Inventory. . http://naei.defra.gov.uk.

UNDP, 2017. Unsatisfied Basic Need-definition. United Nations Development Programme. http://www.undp.org.lb/programme/pro-poor/poverty/povertyinlebanon/molc/methodological/C/basicsneed.htm.

Vivanco, M.G., Andrade, M.F., 2006. Validation of the emission inventory in the Sao Paulo Metropolitan Area of Brazil, based on ambient concentrations ratios of CO, NMOG and NOx and on a photochemical model. Atmospheric Environ. 40 (7), 1189–1198.