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A Case study of light pollution in France after the change in legislation

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ABSTRACT

France issued a decree to restrict and prohibit mainly outdoor lighting effective from January 1st, 2019. Effectiveness of this legislation has been evaluated in this study using GIS data which was first used in Aksaker et al. (2020) (so called astroGIS database - `astrogis.org`). A subset of Artificial Light layer of astroGIS database has been adapted for years between January 2012 and December 2019. During 2019, radiance of 1.9×10^9 W cm^{-2} sr^{-1} has been released into space. Annual light pollution in France decreased by 6% after the enactment of artificial light legislation. France continue to have potential Dark Sky Park locations for example cities like Indre, Lot, Nievre and Creuse having the lowest light pollution values. A strong correlation between population and light pollution ($R \simeq 0.83$) has been observed. A similar but a weak correlation can also be observed for GDP ($R \simeq 0.28$). However, it is still too early to justify whether the improvements observed in the dataset are due to the enactment of the legislation or not.

Subject headings: Light Pollution

1. Introduction

The world surface continuously perturbed by the humanity and this can be seen from space at night. This effect is identified as Artificial Light at Night, namely ALAN or simply *light pollution* (Cavazzani et al. 2020; Mendoza et al. 2020; Simons et al. 2020). At the moment, one-third of

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humanity are not aware of the Milky Way because they **cannot** see it. Moreover, 80% of the world population live in light polluted regions (Falchi et al. 2016). Light pollution in the night sky makes observations of astronomical objects impossible, especially for observatories which are affected by the cumulative light above the large cities (Gronkowski et al. 2018). Light pollution is also an ecological problem besides its negative effect on astronomy (Navara and Nelson 2007).

Light pollution is monitored and studied using many different measurement techniques: Sky Quality Meter (SQM) photometers (Zamorano et al. 2016; Puschnig et al. 2019), Satellite base Defense Meteorological Satellite Program - Operational Line-Scan System (DMSP/OLS), Visible Infrared Imaging Radiometer Suite (VIIRS) (Levin et al. 2019) and International Space Station (ISS) nighttime light measurements (Kuffer et al. 2018).

When the world-wide awareness considered, UNESCO has listed **the night sky** as a universal heritage [1]. Note also that many governments and non-governmental organizations have recently made several legal sanctions to prevent the increase in artificial light pollution. In Europe, for example, many countries introduced regulations to prevent light pollution for the sake of environmental protection (Schroer et al. 2020). In Asia, Korean government has enacted the *Light Pollution Prevention Act* for the proper management of light pollution (Cha et al. 2014) which will later be studied elsewhere.

The European Union has entered into force regulations, binding all member states, which governs specific energy-related products such as regulation 245/2009(EC) on fluorescent lamps[2].

France, as an EU member state, acted further and introduced a new regulation on light pollution to prevent emission of light in outdoor spaces[3]. According to the law (articles 1, 2 and 4), the following external lighting are prohibited:

- Highlighting heritage.
- Outdoor or discoverable sports equipment.
- Non-residential buildings.
- Uncovered or semi-covered parking lots.
- Outdoor events.
- Outdoor sites.
- Limitation of lighting in the perimeter of the astronomical observation sites.

The law's enforcement can be summarized as follows:

- Limits on the allowed emission of light directly into the night sky.
- Restrictions on the emission of blue light.
- Light trespass into dwellings is prohibited.
- The use of skybeams, lasers, and similar high-intensity light is generally prohibited

As can be noted from the summary, enforcement of the French government to prevent further increase in light pollution as well as energy release to space can be counted as a good step forward for people and observers when it is well controlled and managed.

In this study, we investigate possible improvements expected in energy release into space from the whole area under France, after one year of enactment of the light pollution legislation. For this purpose, astroGIS database will be used which is introduced in Aksaker et al. (2020). Details of Artificial Light (AL) layer in astroGIS database can be accessed online[4]. A general view of the adapted dataset from astroGIS database is given in Fig. 1.

2. GIS and Nighttime Dataset

Geographical Information System (GIS) is a robust, easy to use and, time and cost efficient technique. The GIS data can be produced by using remote sensing techniques from satellite imagery. Our astroGIS database (Aksaker et al. 2020) contains GIS dataset with several different layers. The demographic dataset of this study contains digitized data from recent GADM[5] (Database of

[1] `astronomicalheritage.net`

[2] Official Journal of EU: 24.3.2009/L76/17

[3] France Legislation: 28.12.2018/17

[4] `astrogis.org`

[5] `gadm.org`

Global Administrative Areas) and GDP[6] (Gross Domestic Product) for 2015. France has 96 cities and, their boundaries and total surface area were digitized from GADM dataset (see Table 1). The Table 1 also contains official municipality population data[7], dated on 1 January 2017. The summary of demographic data can be viewed in the left panel of Fig. 1.

The nighttime data are taken from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on board SUOMI-NPP satellite in the Day Night Band (DNB) which corresponds to visible spectrum. The radiometric resolution is up to 14 bits in between visible and red ($0.5 - 0.9\mu$m) which gives a minimum of approximately 2×10^{-9} W cm^{-2} sr^{-1} radiation counts (Nurbandi et al. 2016). The GIS dataset containing daily produced, nighttime images cover the world from 75 N to 65 S latitudes with 15″ grid size in a GEOTIFF format corresponding to a spatial resolution of 463 m per pixel. The nighttime data filtered out from non-artificial light sources (e.g. lightning, fishing boats, clouds etc.) by Elvidge et al. (2017) and, monthly and yearly averaged images are stored in a publicly accessible database [8]. VIIRS data is presented to end user in six layouts where France's surface area is found under "Tile 2". The dataset contains 558 images for the whole time span from April 2012 to December 2019. Each image's storage size is approximately 1.6 GB, therefore, the dataset mounts up to 1 TB. As an example, overall view of the nighttime data for December 2019 is given in the right panel of Fig. 1.

3. Analysis of the data

Monthly averaged nighttime data from astroGIS database contains 93 images from April 2012 to December 2019. Surface area of France was extracted using digitized GADM boundaries. Furthermore, each city in France have to be extracted from the same dataset. Using a pre-filtering algorithm in Python, above 3σ values with respect to average light pollution value over the whole time span were excluded for each pixel. A model in Zonal Statistics tool of ArcGIS Desktop 10.4.1 has to be created to process 96 cities in total in calculating pixel averages within each city boundary. The filtered-out light pollution data is produced by using monthly nighttime data for each city. Yearly averages were also calculated from the monthly data (Table 2). In the table, a linear regression fit applied to yearly averages (column 'L.R.') along with goodness of fits (R^2).

In order to evaluate whether enactment of the legislation improved country's energy release into space or not, 2018 (before the legislation) and 2019 (after the legislation) data were taken into account to calculate a possible variation in annual dataset (column $\Delta(\%)$ of Table 2). To further confirm the effectiveness of the legislation, radiance values of 4 highest and 4 lowest light polluting cities were taken into account (Fig. 2).

Overall view of variations were needed to visualize this effectiveness of the legislation. Therefore, annual variations for 2018 and 2019 were produced from monthly average images (see Fig. 3).

4. Results and Discussions

We investigated the light pollution dataset (running from January 2012 to December 2019) for France created from our earlier astroGIS database (Aksaker et al. 2020). The analysis of the France dataset can be concluded with the following outcomes:

- During 2019, radiance of 1.9×10^9 W cm^{-2} sr^{-1} has been released into space from the total surface area of France. This value for 2019 shows a clear decrease trend which is very close to 2012 level.
- During the time span of the data set, only 27 cities show a decrease in light pollution over 96 cities. However, an increase is observed for the remaining 69 cities (Table 2).

  For the last two years (2018–2019), cities Loiret and Haute-Loire, show the maximum decrease (20%) and maximum increase (6%) in the light pollution, respectively.

  The total energy released to space from the whole country decreased by 6% during 2019, after the enactment of artificial light legislation.
- Through the time span of the dataset, strongly light polluted cities tend to show

[6] stats.oecd.org

[7] data.gouv.fr

[8] eogdata.mines.edu

slight improvements, however, the cities which have less light pollution shows almost constant and sometimes increasing trend (see Fig. 2).

- The most populated four cities (Paris, Seine-Saint-Denis, Hauts-de-Seine, Val-d'Oise and Val-de-Marne) produced 55.9% of the total light pollution of the country during 2019 which is 1.4% less than the previous year.
- When meteorological and astronomical parameters (e.g. elevation and cloud coverage) excluded, France has dozens of potential **Dark Sky Park** locations where Indre, Lot, Nievre and Creuse can be counted as the darkest among the others.
- Light pollution variation (Fig. 3) over the whole country might give the impression of 'no improvement'. In the reality of data, accumulation of light pollution over the large cities (an increase – red colored pixels) might hide the improvements (a decrease – blue colored pixels). For example, decrease in light pollution along the Rhine riverside of Paris were actually the places that the legislation has banned use of outdoor lighting; therefore in Fig. 3 Paris looks still in red-color however, the data trend is in blue-color.
- When the light pollution distribution over the whole country considered for 2019, geographical "points" (i.e. pixels in our dataset) Indre-et-Loire and Sarthe have the minimum (0.1) and maximum (4,666.2) values in VIIRS's radiance units, respectively.
- Correlating human activity (e.g. electric consumption) to the energy escaped to space is given as an example in Shi et al. (2014) for China. We also found a strong correlation between population and light pollution with 0.84 confidence in Table 1 (see also Fig. 4). A similar but not so good correlation can also be observed for GDP with 0.28 confidence.
- In conclusion, it is too early to justify whether the improvements observed in the dataset are due to the enactment of the legislation or not.

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Compliance with ethical standards The authors declare that they have no potential conflict and will abide by the ethical standards of this journal.

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Table 1: Limited number of demographic values for all cities in France. Area is in square km, GDP is in USD and population is for 2017. See section 2 for the discussion.

City	Area	Population	GDP	City	Area	Population	GDP
Ain	5.775	65918	30141	Indre-et-Loire	6.149	61882	35788
Aisne	7.426	546527	26775	Isre	7.865	1283384	37765
Allier	7.366	347035	30153	Jura	5.041	269344	31391
Alpes-de-Haute-Provence	7.026	168381	30231	Landes	9.352	419709	36935
Alpes-Maritimes	4.321	1097496	40957	Loir-et-Cher	6.410	340499	31256
Ardche	5.560	334688	26005	Loire	4.798	777328	32663
Ardennes	5.249	280032	27522	Loire-Atlantique	6.893	1423152	41116
Arige	4.930	15721	26489	Loiret	6.803	69254	37692
Aube	6.021	317118	29865	Lot	5.223	179556	29657
Aude	6.268	379094	25375	Lot-et-Garonne	5.382	34127	29077
Aveyron	8.771	289488	29169	Lozre	5.172	8024	32513
Bas-Rhin	4.795	1141511	40176	Maine-et-Loire	7.221	833154	31481
Bouches-du-Rhne	5.254	2048504	42048	Manche	6.059	512923	29451
Calvados	5.605	708344	35291	Marne	8.191	580671	37372
Cantal	5.769	150185	28719	Mayenne	5.207	31675	32137
Charente	5.964	361539	32709	Meurthe-et-Moselle	5.281	7453	33019
Charente-Maritime	6.934	659968	30258	Meuse	6.236	192588	29730
Cher	7.296	311456	30231	Morbihan	6.874	771911	31016
Corrze	5.891	249135	34535	Moselle	6.252	1062217	30746
Corse-du-Sud	4.049	159768	35806	Nivre	6.862	212742	30197
Cte-d'Or	8.789	545798	39593	Nord	5.765	2635255	35384
Ctes-d'Armor	7.029	617107	29915	Oise	5.894	841948	31420
Creuse	5.589	122133	28154	Orne	6.143	291557	28676
Deux-Svres	6.029	384479	32851	Paris	105	2204773	118440
Dordogne	9.212	424095	27540	Pas-de-Calais	6.730	1489983	26895
Doubs	5.244	552643	34512	Puy-de-Dme	7.999	668301	39671
Drme	6.554	524574	37193	Pyrnes-Atlantiques	7.699	695965	36639
Essonne	1.818	1310599	45887	Pyrnes-Orientales	4.131	482368	27116
Eure	6.037	614926	28373	Rhne	3.253	1869599	53324
Eure-et-Loir	5.928	443538	29592	Sane-et-Loire	8.599	569531	30596
Finistre	6.848	933992	33759	Sarthe	6.237	57965	34043
Gard	5.877	757764	27339	Savoie	6.297	443787	40594
Gers	6.303	197953	24825	Seine-et-Marne	5.925	1420469	36071
Gironde	10.084	1607545	39689	Seine-Maritime	6.335	1275559	37910
Haut-Rhin	3.528	777917	33041	Seine-Saint-Denis	237	1630133	47742
Haute-Corse	4.727	180465	30145	Somme	6.227	582464	31601
Haute-Garonne	6.369	1385122	48366	Tarn	5.782	398412	27344
Haute-Loire	4.998	23419	28271	Tarn-et-Garonne	3.729	26413	25188
Haute-Marne	6.250	180753	31488	Territoire de Belfort	611	14564	32790
Haute-Sane	5.383	243264	25669	Val-d'Oise	1.254	1239262	35468
Haute-Savoie	4.872	828417	35609	Val-de-Marne	246	1397035	50988
Haute-Vienne	5.550	381379	32959	Var	6.049	1075653	28679
Hautes-Alpes	5.718	145883	30018	Vaucluse	3.578	570762	34955
Hautes-Pyrnes	4.534	234591	30350	Vende	6.775	693455	32672
Hauts-de-Seine	175	1625917	119778	Vienne	7.024	44715	33439
Hrault	6.231	1162867	33778	Vosges	5.892	378986	31971
Ille-et-Vilaine	6.854	1084554	39655	Yonne	7.448	346902	29089
Indre	6.885	227999	28324	Yvelines	2.304	1463091	47937

Table 2: Annual Artificial Light at Night (ALN) for all cities of France Light pollution values are in units of $Wcm^{-2}sr^{-1}$. Three different values are given for ALN: Ave-7, Ave-18, Ave-19 representing average of annual ALN values in between 2012-2018, for 2018, for 2019, respectively. L.R. and R^2 columns are the slope of linear regression and its correlation coefficient of the regression, respectively for annual ALN values in between whole range of 2012–2019. Lastly, $\Delta(\%)$ column is the percentage of the change between 2018 and 2019. See section 2 for the discussion on the trend of the change.

City	Ave-7	Ave-18	Ave-19	L.R.	R^2	$\Delta(\%)$	City	Ave-7	Ave-18	Ave-19	L.R.	R^2	$\Delta(\%)$
Ain	1.79	1.88	1.81	0.02	0.45	-0.03	Indre-et-Loire	1.50	1.81	1.57	0.08	0.38	-0.13
Aisne	0.94	1.06	1.00	0.01	0.41	-0.05	Isre	2.02	1.99	1.95	0.00	0.01	-0.02
Allier	0.51	0.56	0.59	0.01	0.47	0.04	Jura	0.75	0.80	0.81	0.01	0.27	0.02
Alpes-de-Haute-Provence	0.51	0.58	0.59	0.02	0.51	0.00	Landes	0.67	0.70	0.68	0.00	0.11	-0.02
Alpes-Maritimes	3.00	3.02	3.03	0.03	0.38	0.00	Loire	1.98	1.87	1.86	-0.02	0.37	0.00
Ardche	0.86	0.83	0.93	0.00	0.11	0.11	Loire-Atlantique	1.90	1.79	1.92	0.01	0.03	0.07
Ardennes	0.81	0.81	0.85	0.01	0.26	0.04	Loiret	1.35	1.50	1.21	0.01	0.02	-0.19
Arige	0.67	0.73	0.75	0.02	0.63	0.01	Loir-et-Cher	0.53	0.57	0.54	0.00	0.00	-0.05
Aube	0.86	0.87	0.93	0.01	0.47	0.06	Lot	0.43	0.44	0.48	0.00	0.14	0.09
Aude	1.21	1.19	1.23	0.01	0.12	0.03	Lot-et-Garonne	0.86	0.90	0.95	0.02	0.60	0.05
Aveyron	0.59	0.60	0.60	0.00	0.09	0.00	Lozre	0.45	0.50	0.50	0.01	0.31	0.00
Bas-Rhin	2.65	2.83	2.51	0.03	0.11	-0.11	Maine-et-Loire	0.71	0.74	0.76	0.01	0.37	0.02
Bouches-du-Rhne	5.88	5.80	5.86	0.00	0.04	0.01	Manche	0.78	0.76	0.82	0.00	0.18	0.08
Calvados	1.32	1.24	1.15	-0.02	0.42	-0.06	Marne	1.14	1.28	1.22	0.03	0.78	-0.04
Cantal	0.52	0.48	0.53	0.00	0.02	0.10	Mayenne	0.54	0.54	0.58	0.00	0.05	0.06
Charente	0.63	0.71	0.68	0.01	0.38	-0.04	Meurthe-et-Moselle	1.90	1.98	1.76	0.00	0.00	-0.11
Charente-Maritime	0.98	0.83	0.80	-0.03	0.82	-0.03	Meuse	0.51	0.58	0.61	0.02	0.69	0.04
Cher	0.70	0.82	0.84	0.03	0.60	0.01	Morbihan	0.83	0.75	0.73	-0.02	0.69	-0.03
Corrze	0.50	0.57	0.56	0.01	0.27	-0.01	Moselle	2.69	2.88	2.55	0.03	0.09	-0.11
Corse-du-Sud	0.62	0.72	0.73	0.02	0.65	0.01	Nivre	0.39	0.43	0.47	0.01	0.35	0.07
Cte-d'Or	0.88	0.91	0.93	0.00	0.09	0.02	Nord	5.67	6.01	5.49	-0.02	0.01	-0.08
Ctes-d'Armor	0.49	0.50	0.55	0.00	0.12	0.08	Oise	2.09	2.18	2.06	0.01	0.10	-0.05
Creuse	0.29	0.39	0.37	0.01	0.45	-0.03	Orne	0.51	0.51	0.55	0.00	0.23	0.07
Deux-Svres	0.50	0.57	0.59	0.02	0.73	0.02	Paris	63.95	61.16	56.57	-1.08	0.63	-0.07
Dordogne	0.56	0.61	0.61	0.01	0.36	0.00	Pas-de-Calais	2.96	3.18	2.94	0.02	0.06	-0.07
Doubs	1.31	1.34	1.32	0.01	0.08	-0.01	Puy-de-Dme	0.97	1.00	0.97	0.00	0.00	-0.02
Drme	1.24	1.19	1.34	0.01	0.08	0.12	Pyrnes-Atlantiques	1.17	1.18	1.13	0.01	0.17	-0.04
Essonne	7.55	6.82	7.05	-0.08	0.43	0.03	Pyrnes-Orientales	2.50	2.47	2.49	0.00	0.02	0.00
Eure	1.24	1.29	1.21	0.00	0.00	-0.06	Rhne	6.14	6.14	5.85	-0.02	0.08	-0.04
Eure-et-Loir	1.09	1.12	1.11	0.01	0.35	-0.01	Sane-et-Loire	0.81	0.82	0.82	0.00	0.04	0.00
Finistre	0.87	0.90	0.95	0.01	0.13	0.05	Sarthe	0.78	0.82	0.73	0.00	0.00	-0.11
Gard	2.09	2.06	2.07	0.00	0.10	0.00	Savoie	1.36	1.41	1.36	0.00	0.04	-0.02
Gers	0.53	0.55	0.53	0.00	0.18	-0.03	Seine-et-Marne	3.08	3.00	3.14	0.05	0.19	0.04
Gironde	2.06	1.65	1.82	-0.02	0.16	0.10	Seine-Maritime	2.72	2.88	2.54	0.00	0.00	-0.11
Haute-Corse	0.77	0.83	0.82	0.02	0.45	-0.01	Seine-Saint-Denis	48.32	49.61	46.06	0.19	0.04	-0.07
Haute-Garonne	3.06	2.76	2.72	-0.03	0.10	-0.01	Somme	1.24	1.36	1.31	0.01	0.18	-0.04
Haute-Loire	0.61	0.51	0.59	-0.01	0.15	0.16	Tarn	0.88	0.89	0.87	0.01	0.14	-0.02
Haute-Marne	0.59	0.56	0.53	0.01	0.47	-0.05	Tarn-et-Garonne	0.97	0.97	0.98	0.01	0.23	0.00
Hautes-Alpes	0.59	0.63	0.67	0.01	0.30	0.06	Territoire de Belfort	2.59	2.41	2.13	-0.05	0.38	-0.11
Haute-Sane	0.62	0.65	0.59	0.00	0.00	-0.08	Val-de-Marne	39.83	40.22	36.82	-0.16	0.06	-0.08
Haute-Savoie	2.34	2.14	2.19	-0.02	0.17	0.02	Val-d'Oise	9.53	9.67	9.02	0.00	0.00	-0.06
Hautes-Pyrnes	0.84	0.91	0.89	0.01	0.48	-0.02	Var	2.62	2.722	2.78	0.02	0.41	0.02
Haute-Vienne	1.03	1.07	0.95	0.00	0.03	-0.10	Vaucluse	2.53	2.38	2.49	-0.01	0.09	0.04
Haut-Rhin	2.76	2.89	2.38	-0.03	0.16	-0.17	Vende	0.85	0.81	0.87	0.00	0.06	0.06
Hauts-de-Seine	45.65	48.88	43.06	-0.01	0.00	-0.08	Vienne	0.56	0.62	0.62	0.01	0.62	0.00
Hrault	3.05	2.92	2.93	0.00	0.01	0.00	Vosges	0.88	0.89	0.85	0.00	0.01	-0.05
Ille-et-Vilaine	1.55	1.47	1.36	0.01	0.05	-0.07	Yonne	0.62	0.73	0.66	0.01	0.28	-0.09
Indre	0.42	0.48	0.50	0.01	0.38	0.05	Yvelines	6.52	5.89	6.05	-0.07	0.23	0.02

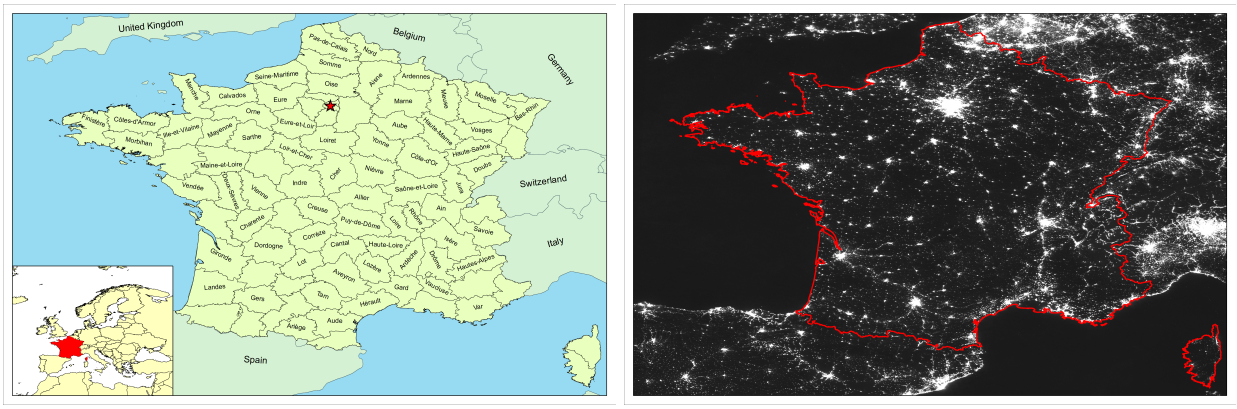


Fig. 1.— Left Panel: Demographic map of France showing the name and boundaries of each city. Names not fitting to their boundaries are left as unnamed. The red star marks the capital, Paris. Boundary of neighbouring countries are also drawn with no other details. Right Panel: Artificial Light (AL) distribution of France for December 2019. AL seen from space is colored as white. As expected, Paris and other heavily populated major cities dominate the AL distribution. Note also that geographically less populated regions, for example, rural areas, mountains, lakes etc. are colored with black.

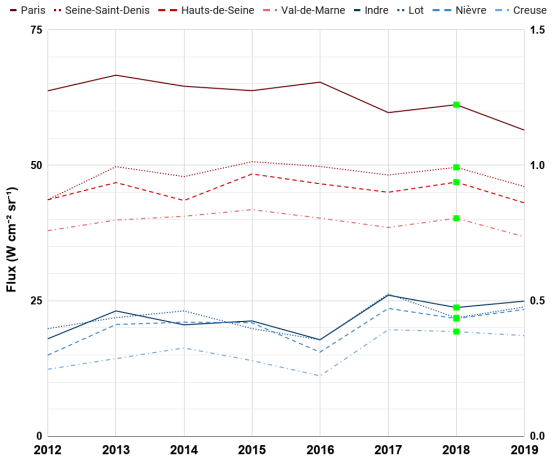


Fig. 2.— Radiance of Artificial Light (AL) averaged annually for selected cities (four brightest, red in color with values on left y–axis and four darkest, blue in color with values on right y–axis) in between 2012–2019. Green squares represent the start of enactment of artificial light legislation.

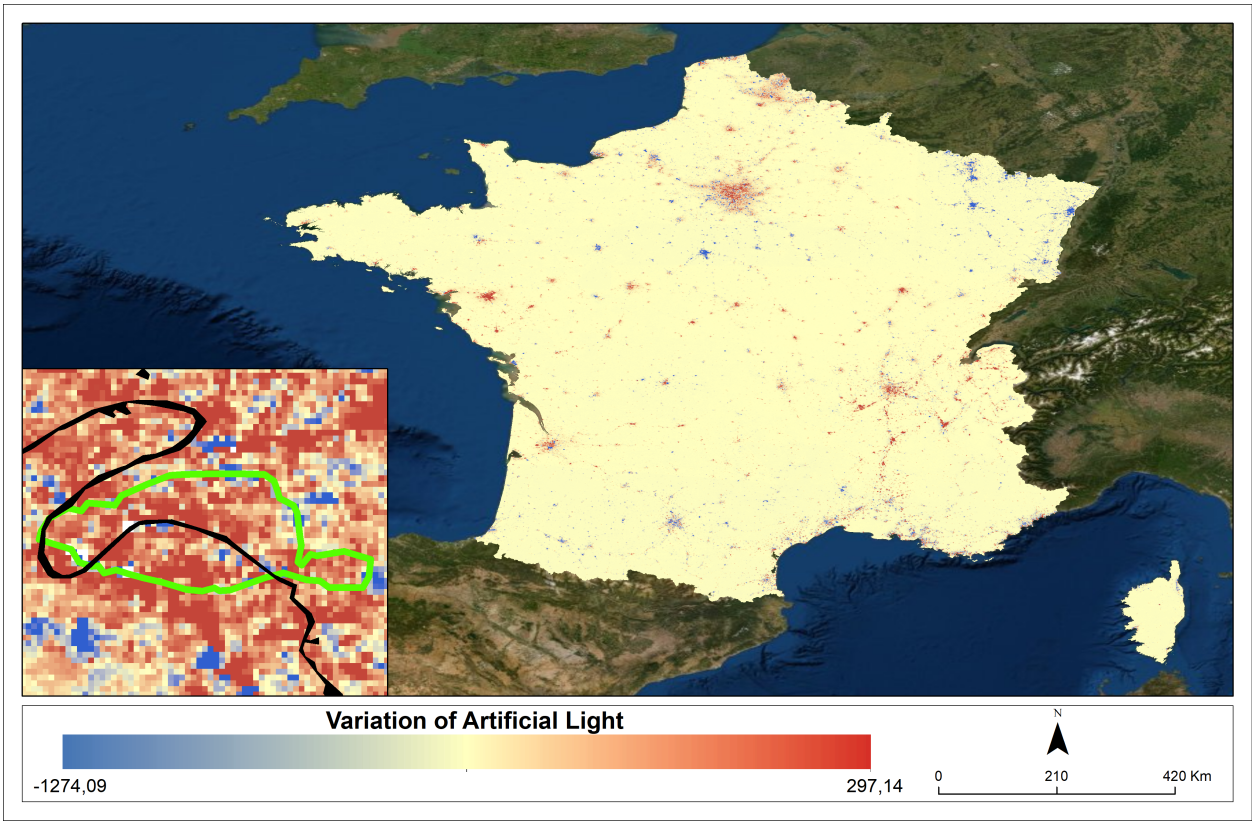


Fig. 3.— Annual Artificial Light (AL) variation in between 2018 and 2019. AL's color gradient runs from blue (darker, less light pollution) to red (brighter, higher light pollution). The values are in W cm^{-2} sr^{-1}. An inset representing the capital, Paris zone, is placed on the lower left corner with some extra color codes: Green is the official city boundary; Black is the river Renne.

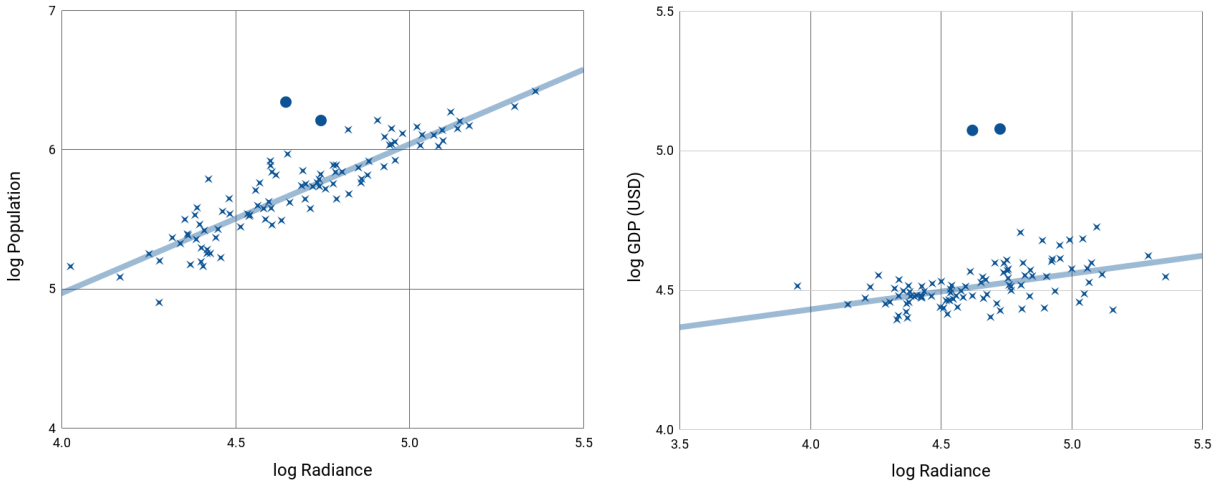


Fig. 4.— Left Panel: Total radiance versus population for the year of 2017 in logarithmic scale. Thick solid line represents the linear regression ($y = 0.82x - 3.26, R^2 \sim 0.64$). Right Panel: Total radiance versus GNP in logarithm scale. Thick solid line represents the linear regression ($y = 0.12x + 3.18, R^2 \sim 0.32$). Note that, four most polluting cities (Paris, Seine-Saint-Denis, Hauts-de-Seine, Val-d'Oise and Val-de-Marne) stand out as outliers with their exaggerated radiance in both graphs effecting the general expected trend/fit: higher the population or GDP, higher the radiance. When their values included (thin solid lines) the goodness of fit gets worse by 7% for population and improves by 25% for GDP, indicating once again the strong correlation between radiance and population.