DANGEROUS NO_2 AIR POLLUTION IN MIDDLE EASTERN AND NORTH AFRICAN CITIES HAS INCREASED BACK TO PRE-COVID LEVELS

December 2021

GREENPEACE
غرينبيس

Authors:
Andreas Anhäuser (Greenpeace East Asia)
Aidan Farrow (Greenpeace International)

Contributors:
Kenzie Azmi and Ahmed El Droubi (Greenpeace MENA)

Published by:
Greenpeace MENA

Suggested citation:
Anhäuser, A., Farrow, A. Dangerous NO_2 air pollution in Middle Eastern and North African cities has increased back to pre-Covid levels, December 2021.

TABLE OF CONTENTS

KEY MESSAGES

Background

- In 2019, air pollution was ranked as the fourth leading risk factor for premature death globally, accounting for an estimated 6.67 million deaths (Health Effects Institute, 2020). High blood pressure, tobacco use and poor diet were the only more significant risk factors identified. A newer study estimated that the number of premature deaths from fossil-fuel combustion alone is as high as 8.7 million per year (Vohra et al., 2021).

- Nitrogen dioxide (NO_2) is a toxic air pollutant that causes severe health impacts and premature death.

- The health impact of air pollution also inflicts substantial economical costs to society. Air pollution from burning fossil fuels alone, for example, has been estimated to cause an annual loss of USD 6.9 billion (ffiEGP 108 billion) in Egypt (Farrow et al., 2020).

- The WHO strengthened its Air Quality Guidelines in 2021, citing increased evidence that there is no known safe level of exposure to NO_2 pollution. Where national guidelines for air pollution in Middle Eastern and North African countries are specified at all, each of them is less stringent than the WHO Air Quality Guidelines.

- NO_2 is emitted by human activities; including from industry, land and marine traffic, thermal power plants (fired by fuels like coal, oil or gas) and household heating. To protect our health, pollutant emissions from these industries must be reduced.

Findings

- Satellite observations reveal NO_2 pollution hotspots over cities and industrial facilities in the Middle East and North Africa. These hotspots are the result of human activity.

- In all but one of the cities studied, NO_2 air pollution decreased substantially during the lockdowns in 2020.

- In most of the cities studied, NO_2 rebounded towards pre-Covid levels when looking at the same period in 2021.

- 13 out of 16 locations saw a reduction in NO_2 during 2020 and a rebound during 2021.

- The satellite observations of air pollution observed here show no evidence that NO_2 levels are improving in cities in the Middle East and North Africa.

Recommendations

- There is an urgent need to reduce NO_2 pollution in the places we live to protect human health. This requires adjusting and setting emission standards for all pollutants, as well as ensuring compliance by polluting industries.

- It is vitally important that reliable long-term data from ground air pollution monitors is made available in the Middle East and North Africa in order to manage and improve air pollution in the region.

- Clean technology available today means that we no longer need to rely on burning dirty fuels like coal, oil and gas. This technology is increasingly affordable. The cost of utility scale renewable energy generation has fallen dramatically over the past decade (-50% for wind, -68% for concentrating solar power and -85% for photovoltaic), to the point that the construction of new wind and solar capacity is increasingly cheaper even than the continued operation of many already existing coal-fired power stations. Developing renewable energy sources, such as wind and solar, is frequently less expensive than constructing new power plants that use fossil fuels (IRENA, 2021). These cost benefits of renewables are greater still when the externalities damaged by fossil-fuel combustion, like shorter lifetime and impaired health (Lelieveld et al., 2019; Marais et al., 2019; Farrow et al., 2020) are taken into account. Such costs are often overlooked because they are not paid by the power plant operators, but by society as a whole.

INTRODUCTION

Early responses to the Covid-19 pandemic led to dramatic reductions in air pollutant concentrations in many locations worldwide (e.g. Shi et al., 2021, Hu et al., 2021, Beloconi et al., 2021). This report investigates nitrogen dioxide (NO_2) pollution data from satellite observations across territories in the Middle East and North Africa during the Covid-19 pandemic.

The health impact of air pollution is severe. A previous study published by Greenpeace Southeast Asia estimated that air pollution from burning fossil fuels – primarily coal, oil, and gas – was responsible for an estimated 4.5 million deaths each year worldwide and over 50,000 annual deaths in the Middle East and North Africa (Farrow et al., 2020).

Energy production, transport and industrial processes often lead to the production of air pollutants, especially when these activities involve the combustion of fossil fuels. In common with most regions of the world, economies in the Middle East and North Africa rely heavily on combustion of fossil fuels, meaning that when restrictions were imposed to prevent the spread of Covid-19, less fuel was burnt and some pollutant emissions were reduced.

After the severe restriction of public life in spring and summer 2020, economic activity has continued or quickly returned in many places. This often occurred with governmental support, for example, the Egyptian government's Energy Pricing Committee reduced the price of fossil gas for industries as well as the price of electricity for heavy industries (such as steel) during the pandemic to alleviate economic losses (Ahram Online, 2020). In such cases where economies remain tied to fossil fuels, the return of economic activity has driven increases in the emission of dangerous air pollutants, such as NO_2, compared to emissions during lockdown.

Research has suggested that significant health benefits could be realised if the air pollution reductions which occurred in many places during 2020 could be achieved in the long-term, after government restrictions are relaxed (e.g. Myllyvirta and Thieriot, 2020). A transition to clean energy sources such as wind and solar, and to clean and sustainable mobility must be central to the ongoing recovery efforts. The recovery from the pandemic must not come at the expense of the quality of the air we breathe. Governments now have the chance to take a clean and healthy path to the future by choosing to create job opportunities and enhance economic activity in sustainable energy sectors, such as wind and solar, by improving mobility and public transportation infrastructure to make these modes of transport safe and attractive to everybody, and by stimulating electrification of individual transport.

METHODS

Satellite observations of the air pollutant NO_2 are analysed in 16 locations across seven countries in the Middle East and North Africa. These are the cities of Fez, Rabat and Casablanca in Morocco, Sousse, Sfax and Gabes in Tunisia, Cairo, Alexandria and Damietta in Egypt, Beirut in Lebanon, Amman in Jordan, Jeddah in Saudi Arabia, Dubai in the UAE. In addition the industrial sites of Gabès Cement Works in Tunisia, Chekka cement works in Lebanon and Damietta Port in Egypt are included. We do not present results for the Tunisian capital city, Tunis, because of defects in the 2019 satellite data.

Satellite Data

The satellite observations of NO_2 included in this study have been retrieved by the Tropomi sensor on board the Sentinel-5P satellite (Copernicus, 2018). Tropomi has been operating since February 2018. In contrast to ground-based sensors, Tropomi does not measure near-surface concentration, but instead atmospheric column amount, i.e. the amount of NO_2 over the entire thickness of the lower atmosphere (surface to ca. 10km above ground). Although satellite observations alone do not allow us to determine the actual pollution concentrations close to the ground, they are a reasonable proxy for near-surface air pollution (Lamsal et al, 2008, Seltenrich, 2014). Relative changes in atmospheric column amount (the quantity measured by the satellite) are highly likely to correspond with similar changes in near-surface concentrations; especially when averaging over longer time periods. Column amounts presented here represent that observed above a circle of 10 km radius around each study location. Air pollution is highly sensitive to weather conditions. Therefore, data are averaged to periods of at least 11-weeks and compared to the equivalent period in different calendar years (Table 1). These averaging periods are designed to reflect the period of most severe restrictions during the outbreak of Covid-19 in each territory and are used to analyse whether a measurable change in NO_2 column amount coincided with the onset of Covid-19 restrictions as described below.

Covid-19 Restrictions

As in most countries worldwide, the Middle East and North Africa region has been affected by the ongoing Covid-19 pandemic. The timing and stringency of restrictions imposed by governments differ from one place to another. We used an objective measure to determine the onset and duration of the initial period of severe restrictions to public life ("lockdown") in each country in spring and summer 2020; this is described in the Technical Appendix (section Lockdown periods and mobility). Table 1 gives an overview of these periods in each country. Some countries experienced ensuing lockdowns later in 2020 or 2021, but the reduction in people's mobility was by far the most pronounced in the periods listed in Table 1. All periods are rounded (downward) to multiples of 7 days in order to eliminate weekend effects in year-on-year comparisons.

Table 1. Study periods for the countries in this report. Periods are selected such that they are those with the most stringent government restrictions related to the Covid-19 pandemic in spring and summer 2020. See Technical appendix for details.

Country	Period of study[1]		
	Start	End	Duration
Morocco	20 March	4 June	11 weeks
Tunisia	20 March	4 June	11 weeks
Egypt	25 March	30 June	14 weeks
Lebanon	18 March	14 July	17 weeks
Jordan	18 March	2 June	11 weeks
Saudi Arabia	16 March	9 August	21 weeks
United Arab Emirates	25 March	30 June	14 weeks

Inter-annual comparisons

Period average data for the intervals described in Table 1 is presented and differences in pollution between these periods in 2020 and 2021 are reported. Changes in each year are reported relative to the same period in the previous year.

[1]Start and end dates are included.

RESULT SUMMARY

Figure 1 gives an overview of the observed NO_2 column amounts in seven cities in the Middle East and North Africa during the study period. All cities except Cairo see a strong reduction during the initial lockdowns in 2020 and a rebound in 2021 to NO_2 levels comparable to pre-Covid pollution.

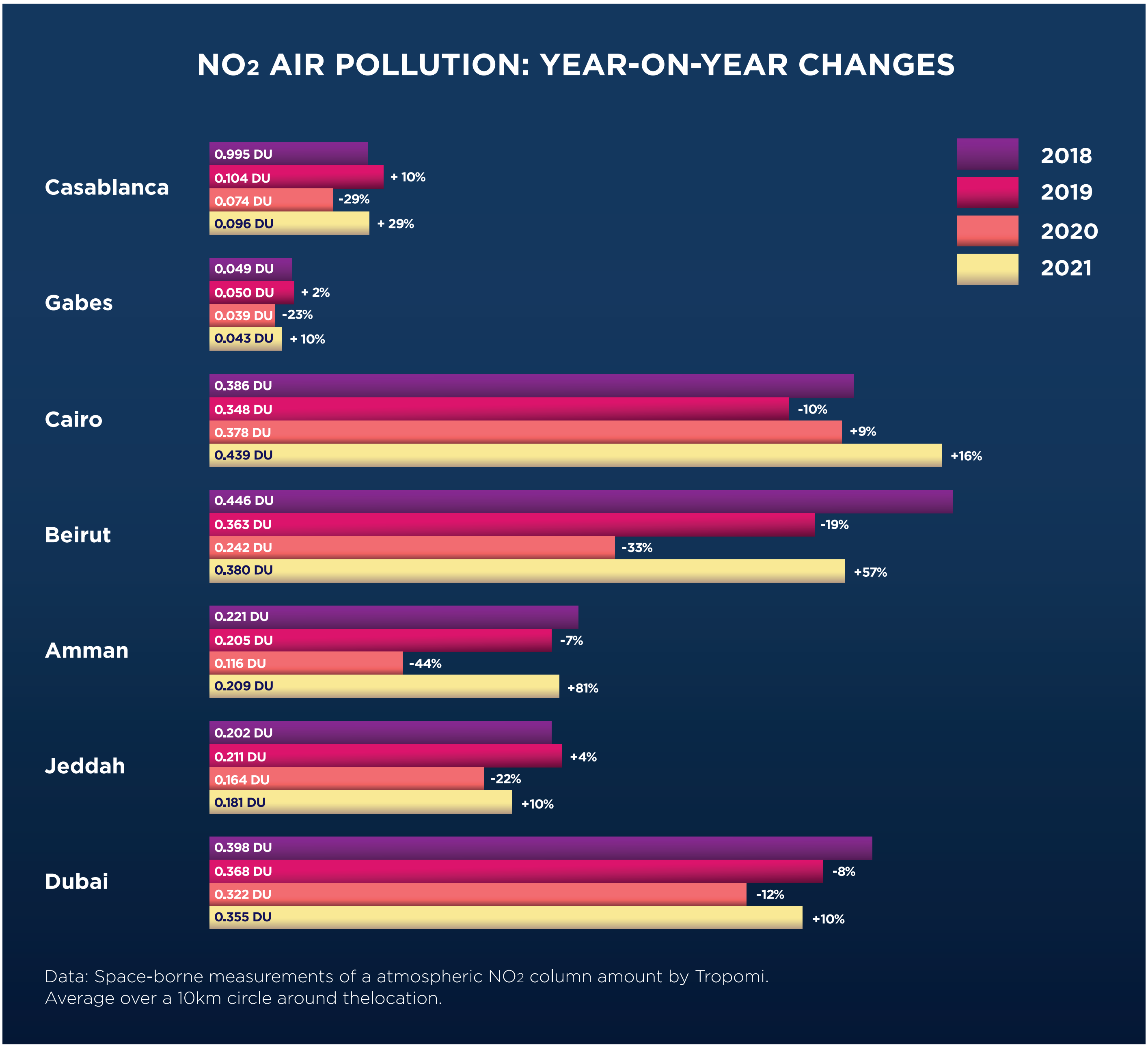

Figure 1. NO_2 atmospheric column amount during the study periods in a circle with 10km radius around seven cities across the Middle East and North Africa. One city is selected for each country considered in the study. Percentage changes are given to the year prior. Thus, a decrease by X-%, followed by an increase of the same percentage X-% (relative to that decreased value) does not lead to the initial value. For the same reason, Beirut and Amman have very different percentage numbers for 2020 and 2021, although the 2021 value is similar to the 2019 value.

BOX 1: ATMOSPHERIC COLUMN AMOUNT AND DOBSON UNIT (DU)

Atmospheric column amount is what satellite instruments estimate when they monitor air pollution. It denotes the amount of an air pollutant summed up between the Earth's surface and space over a certain area. Atmospheric column amount can be used as a proxy for pollutant concentration near the surface but it is not the same thing. For example, if there is little vertical mixing within the atmosphere, then all the pollution emitted near ground level will stay within a thin layer close to the ground. In cases like this, it may happen that the concentration within this thin layer is very high, but the satellite measures a low atmospheric column amount (because most of the atmosphere above that layer is clean).

Atmospheric column amount is measured in Dobson units (DU) or alternatively in milligramme per square metre.

MOROCCO

Of the cities studied here, Casablanca was the most polluted city in Morocco in terms of NO_2 measured from space during the study periods (Figure 2). During the initial 11-week lockdown from 20 March to 4 June, observed NO_2 pollution over the Casablanca study area dropped by 29% relative to the year before. In the same period in 2021, air pollution was higher by 29%[2]. Fez and Rabat see similar changes in NO_2 pollution with a decrease in 2020 and a rebound in 2021, although the 2020 anomaly is less pronounced than in Casablanca. This indicates that a smaller proportion of the NO_2 that was observed over those cities was emitted by sectors that were heavily restricted during the pandemic.

Figure 3 shows the NO_2 column amount in northern Morocco on the map. Cities stand out as pollution hotspots. To the south west of Casablanca, pollution from the Jorf Lasfar power station is clearly discernible as a hotspot comparable to cities like Rabat and Fez. In and around the Strait of Gibraltar emissions from ship traffic contribute to a west-east band of NO_2 pollution.

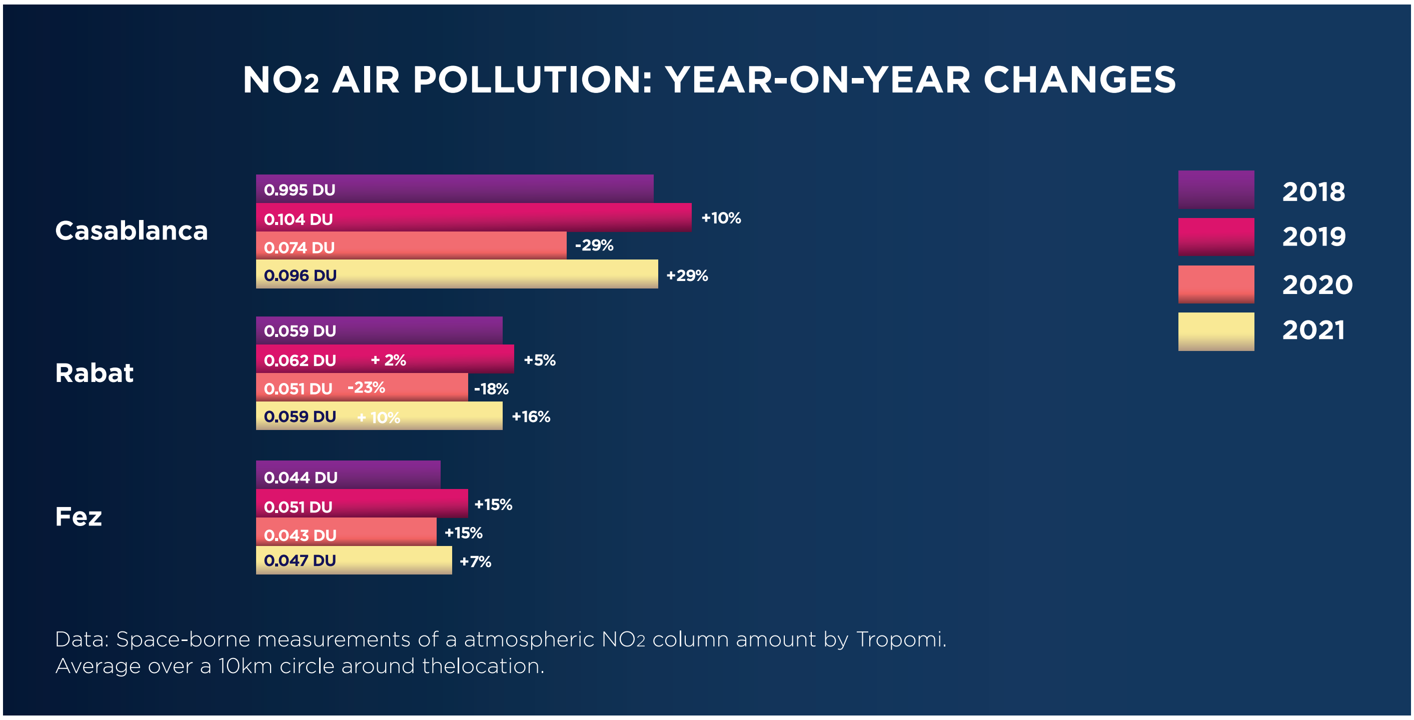

Figure 2. NO_2 atmospheric column amount during the study period in a circle with 10km radius around three Moroccan cities.

[2]Note that percentage changes are given to the year prior. Thus, a decrease by 29%, followed by an increase of 29% (relative to that decreased value) does not lead to the initial value.

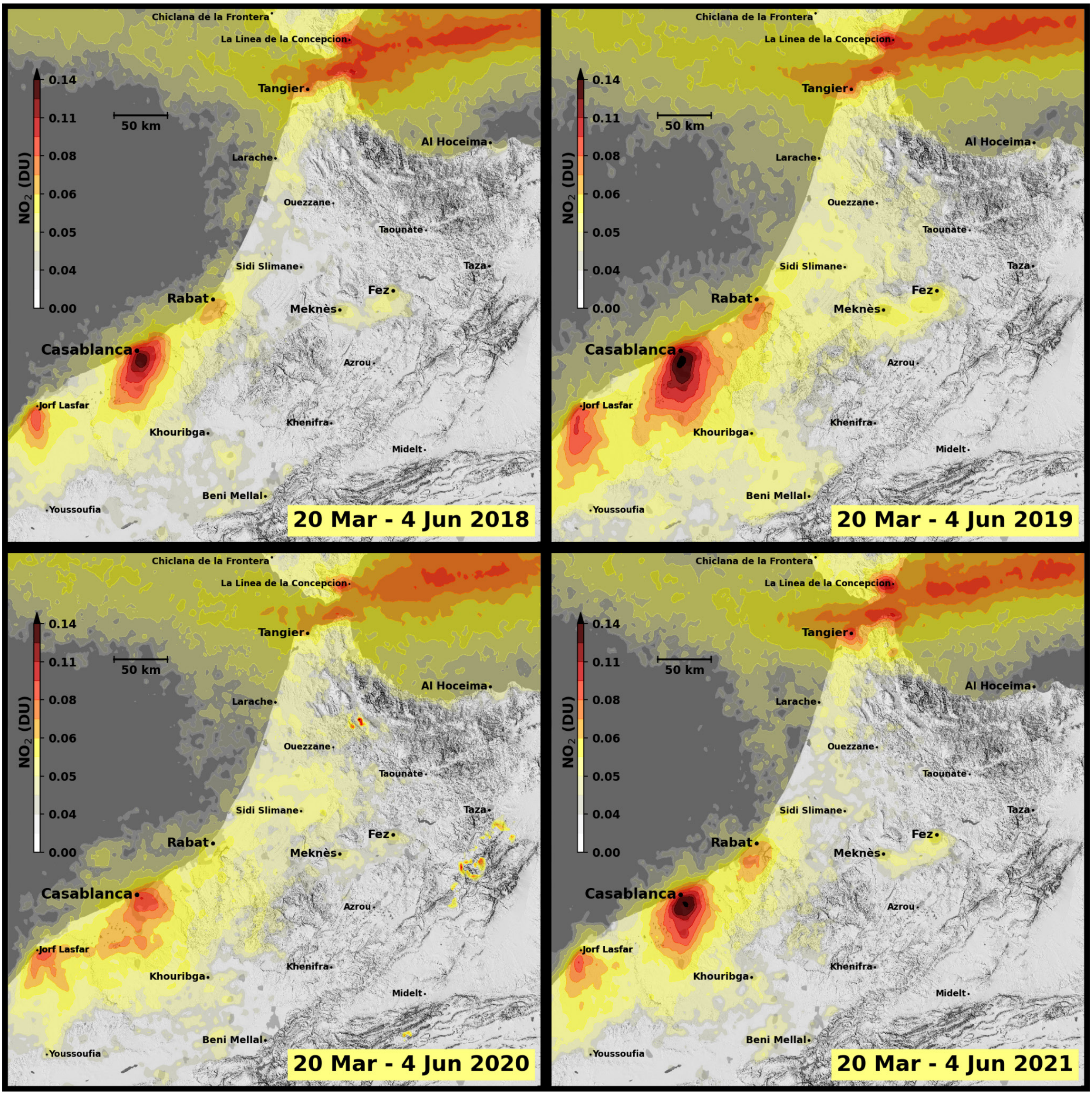

Figure 3. NO2 atmospheric column amount in Morocco during the study period in 2018-2021.

TUNISIA

Cities

In the Tunisian city Sousse, NO_2 pollution during the study period dropped in 2020 by 11% (Figure 4). Even larger decreases are observed in Sfax (-14%) and Gabès (-23%). NO_2 rebounded in 2021 by 9% in Sousse and 10% in Gabès. By contrast, Sfax experienced a further reduction of NO_2 pollution by another 6% in 2021. We do not present results for the capital city Tunis because of defects in the 2019 satellite data.

Cement works west of Gabès

In a 5km circle around the cement factory Cimenterie de Gabès, NO_2 changes followed the pattern of the nearby city of Gabès, but both the 2020 reduction (-28%) and the 2021 increase (+19%) are somewhat larger. Without further investigation it remains unclear whether this is indeed due to emission changes by the cement factory or influences by the nearby city. Figure 5 shows NO_2 pollution around Gabès during the study period in the years 2018-2021. A clear reduction can be seen over both the city and the cement works in 2020. However, the spatial resolution of the satellite data is not sufficient to determine if there are distinct differences in NO_2 conditions between the cement works and the residential areas of the city.

Offshore hotspot near Gabès

High NO_2 pollution levels can be seen above the Gulf of Gabès, an area which contains offshore oil fields (Beavington-Penney et al., 2008; North Africa Post, 2012; Leon, 2014) with estimated flaring in the order of tens of millions of cubic metres per year (Skytruth, 2021). The NO_2 hotspot can be seen in all four years from 2018 to 2021.

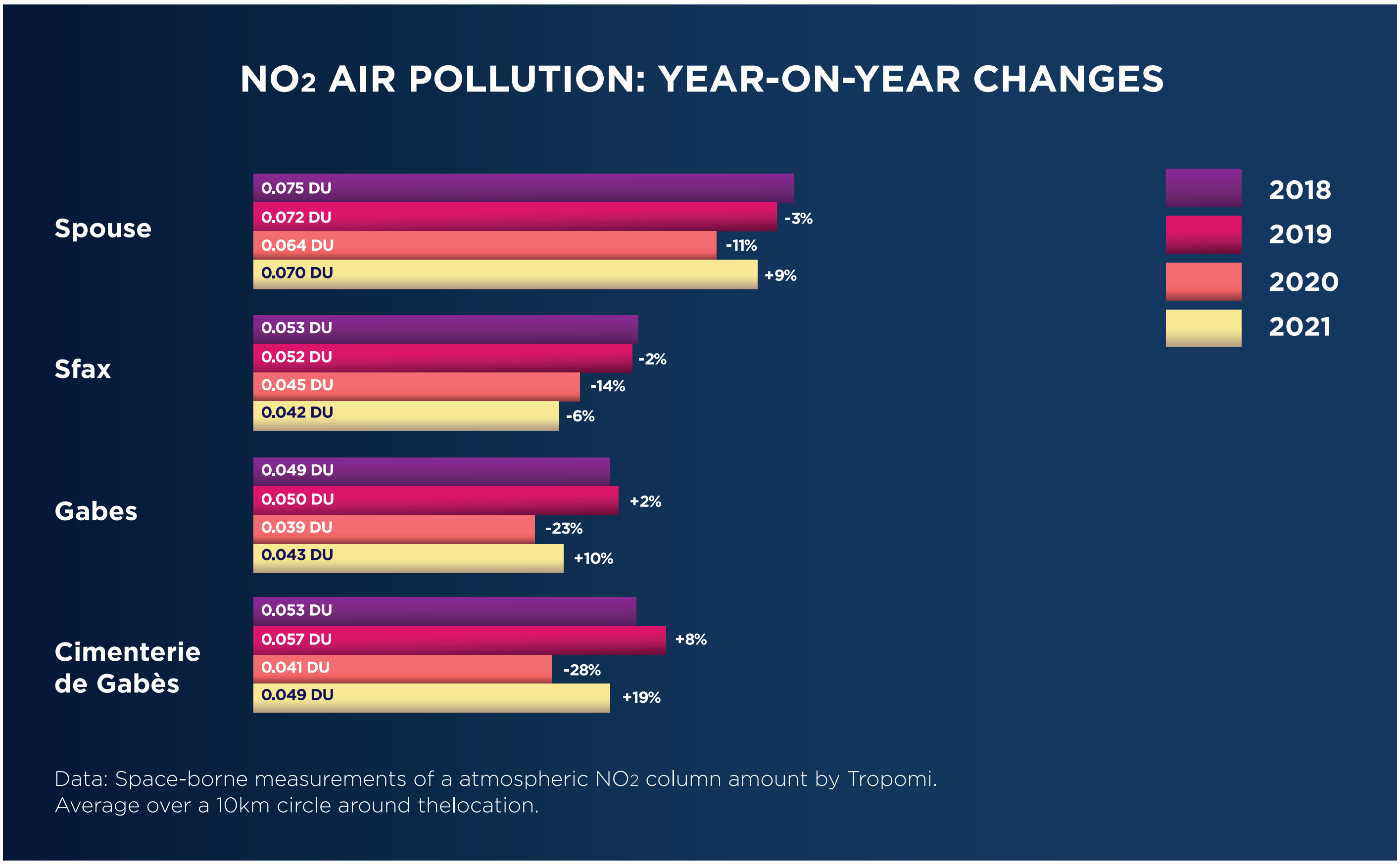

Figure 4. NO_2 atmospheric column amount during the study period in a circle with 10km radius around three Tunisian cities. For comparison between residential and industrial areas, the cement factory 10km West of the centre of Gabès is shown, too. In an attempt to separate the localized air quality changes around the cement factory, NO_2 column amounts are averaged over a 5km-radius circle for the cement factory.

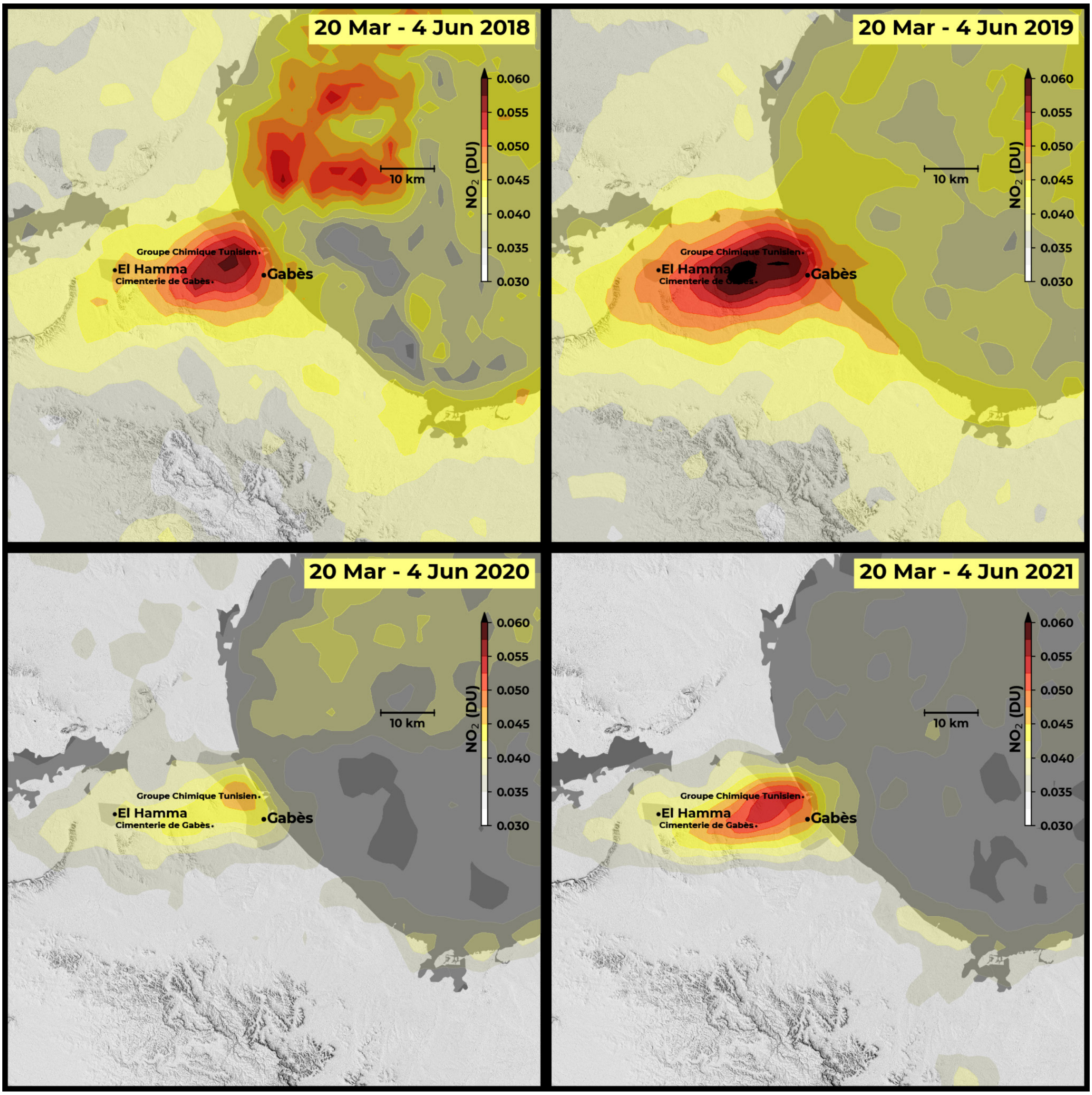

Figure 5. NO_2 atmospheric column amount around Gabès (Tunisia) during the study period in 2018-2021.

EGYPT

In the Egyptian cities Cairo and Damietta, NO_2 pollution does not seem to have reduced during the 2020 lockdown (Figure 6). In fact, it increased by 9% in Cairo and by 6% in Damietta during the study period in 2020, compared to 2019. In 2021, NO_2 pollution increased once again to its highest value on record, while in Damietta, NO_2 remained almost unchanged from 2020 to 2021. Alexandria experienced a 9% decrease in 2020, followed by a 13% increase in 2021.

Figure 7 shows the NO_2 pollution around Cairo and the Nile Delta during the study period in the years 2018-2021 on a map. The NO_2 hotspot centred on Cairo dominates the entire region. It is therefore likely that pollution from Cairo influences the local air quality in Alexandria and Damietta to some extent.

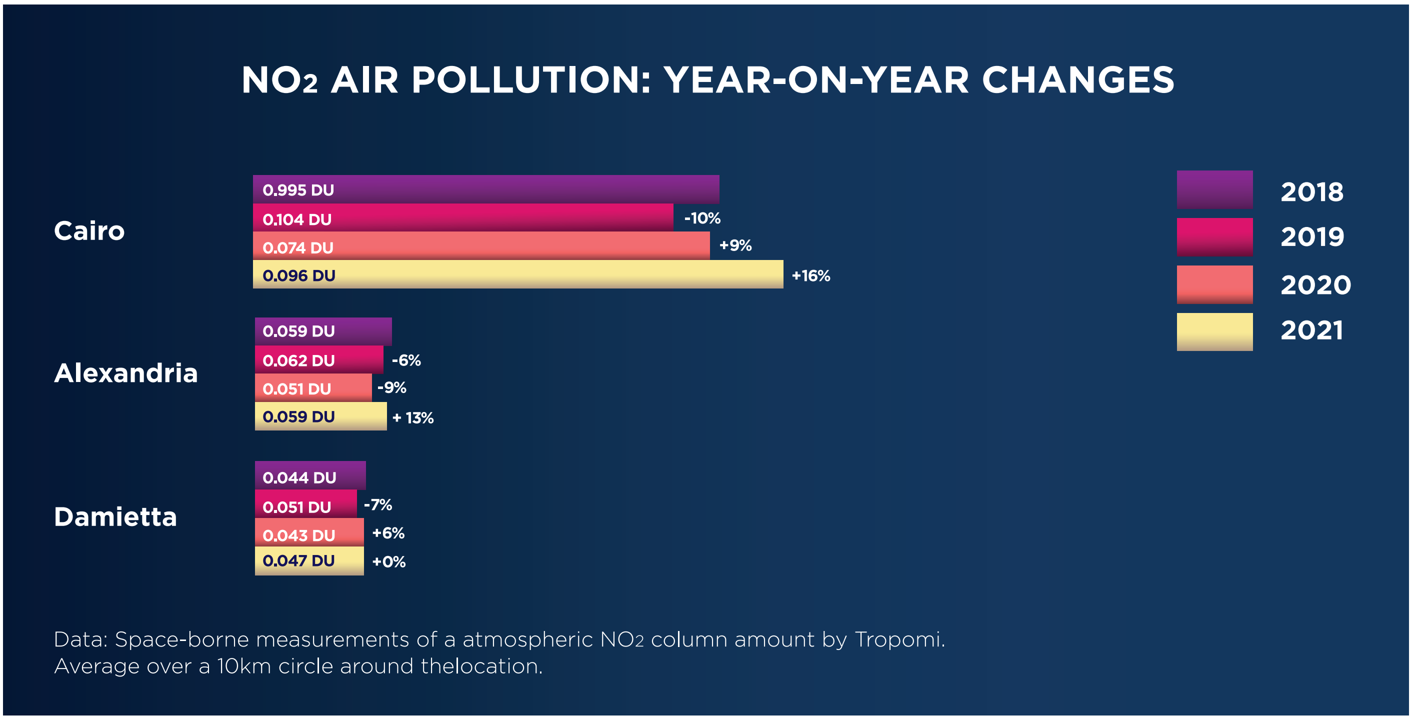

Figure 6. NO_2 atmospheric column amount during the study period in a circle with 10km radius around three Egyptian cities. The locations are shown in Figure 7. Damietta is in the North Eastern part of the map on the coast.

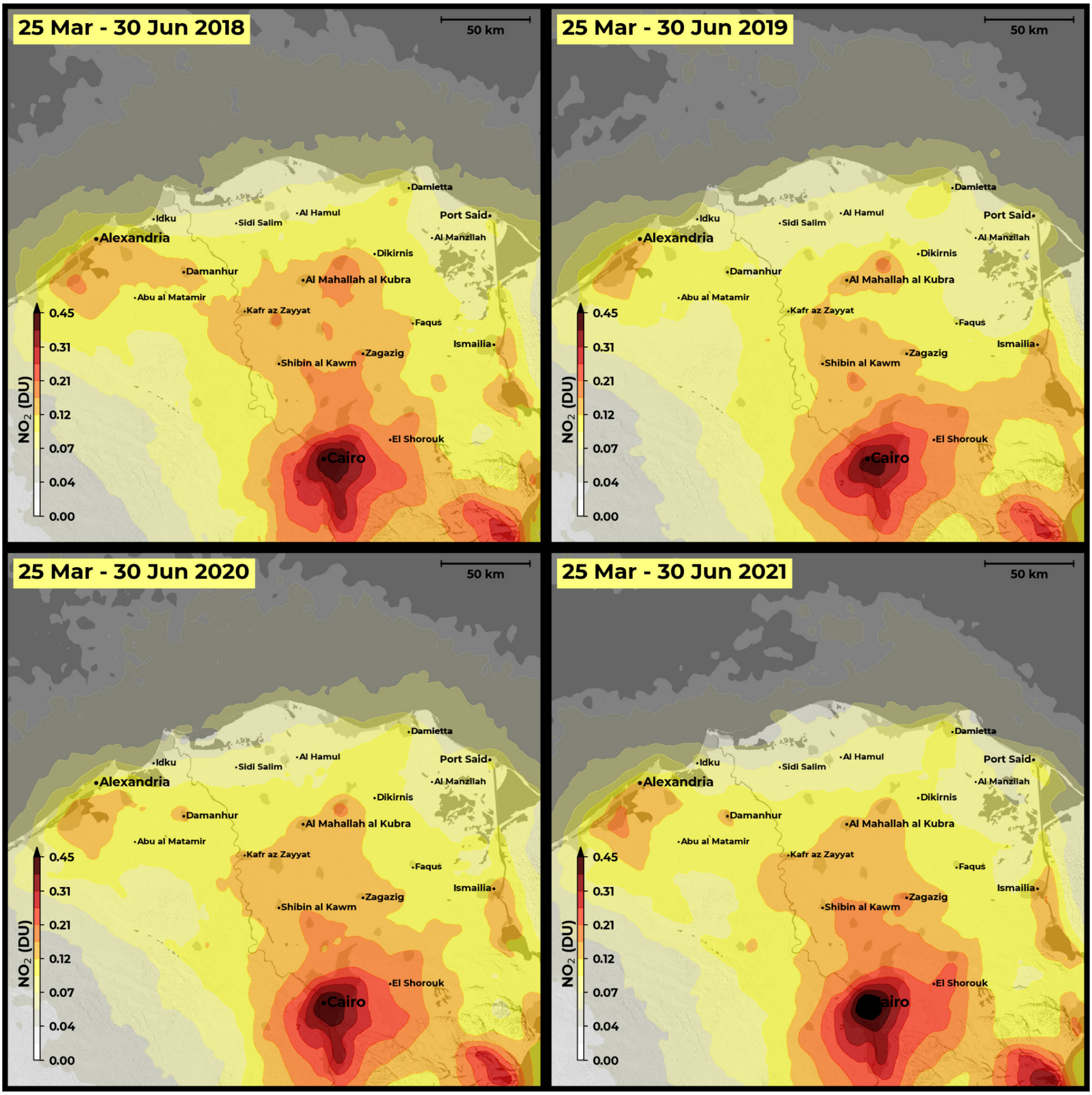

Figure 7. NO2 atmospheric column amount around Cairo and the Nile Delta during the study period in 2018-2021.

MIDDLE EAST

In the Middle Eastern study locations, NO_2 air pollution dropped during the study period in 2020 in all of the five cities studied (Figure 8). Extremely large decreases were observed in the Lebanese capital Beirut (-33%) and the coastal town of Chekka (-42%), as well as in the Jordan capital Amman (-44%). In Jeddah (Saudi Arabia) the 2020 decrease was 22% and in Dubai 12%. In all of these five cities, air pollution in 2021 returned to levels at or close to 2019 levels.

Figure 9 shows a map of the Arabian Peninsula with NO_2 pollution during the study period in 2018 as an example. Places of high population and intense industrial activity are clearly visible as hotspots of NO_2 pollution.

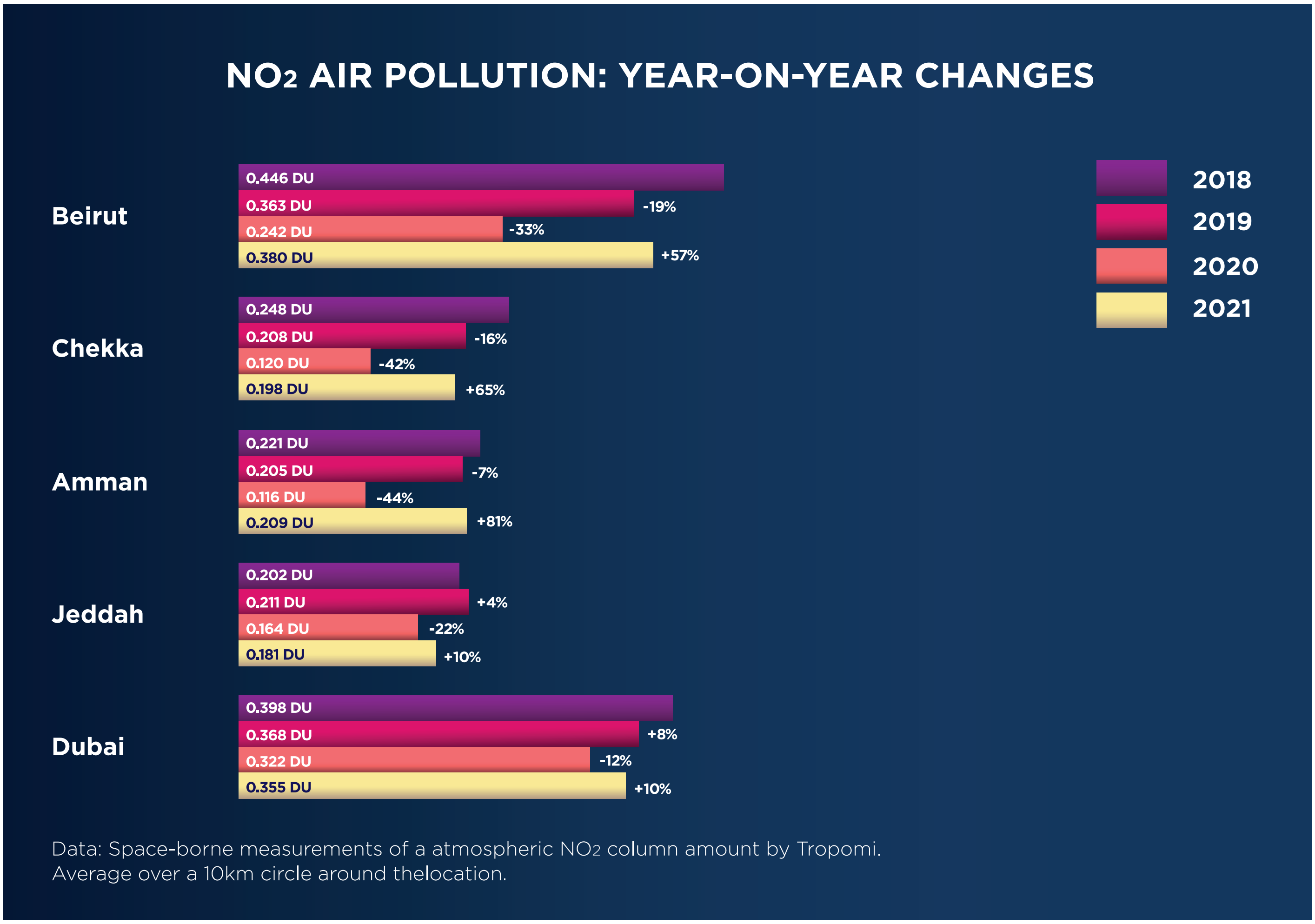

Figure 8. NO_2atmospheric column amount during the study period in a circle with 10km radius around five Middle Eastern cities.

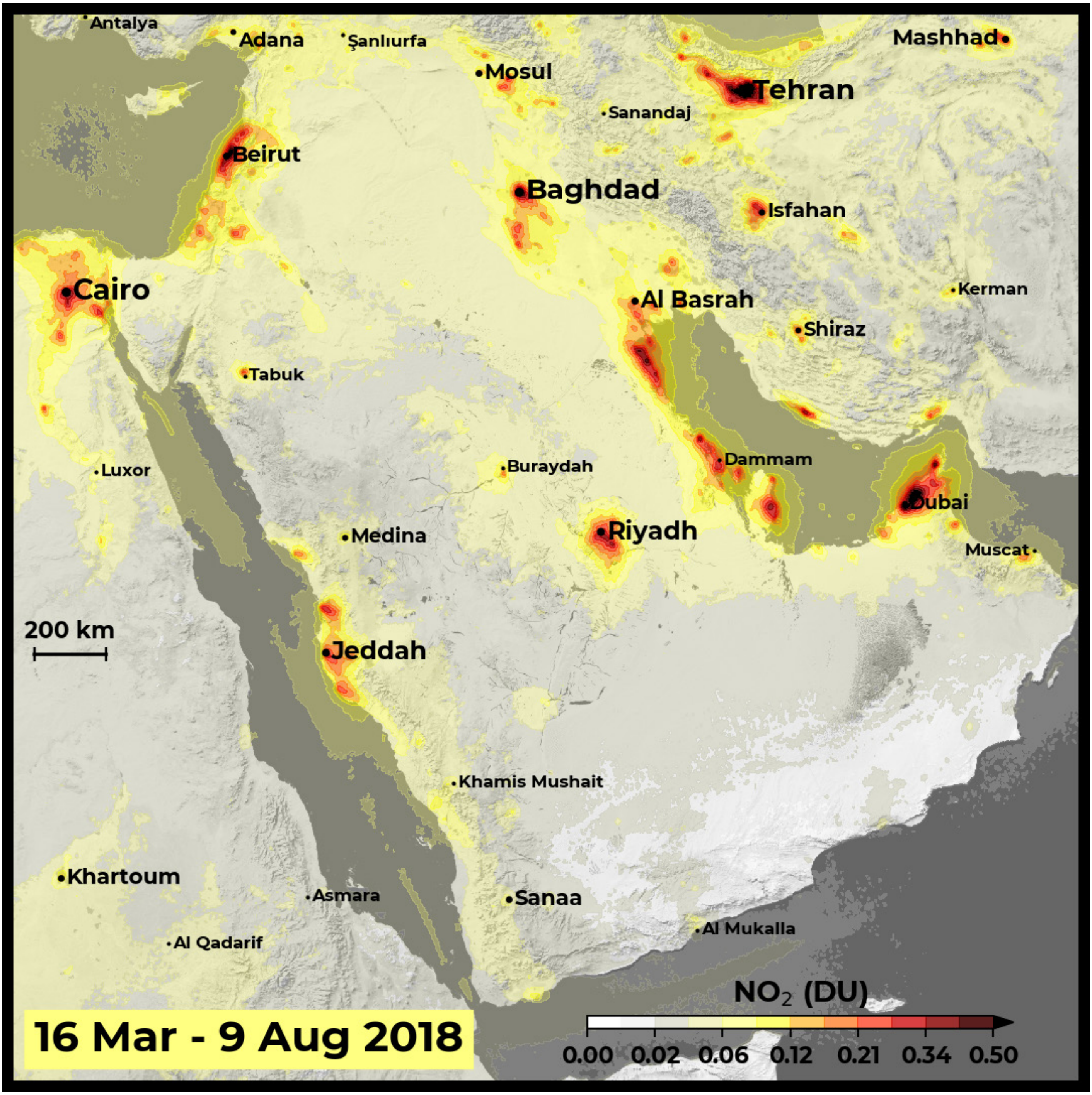

Figure 9. NO2 atmospheric column amount in the Middle East during the study period in 2018.

Lebanon

Figure 10 shows air pollution in the region around Beirut during the study period in the years 2018-2021. A clear reduction is visible in 2020.

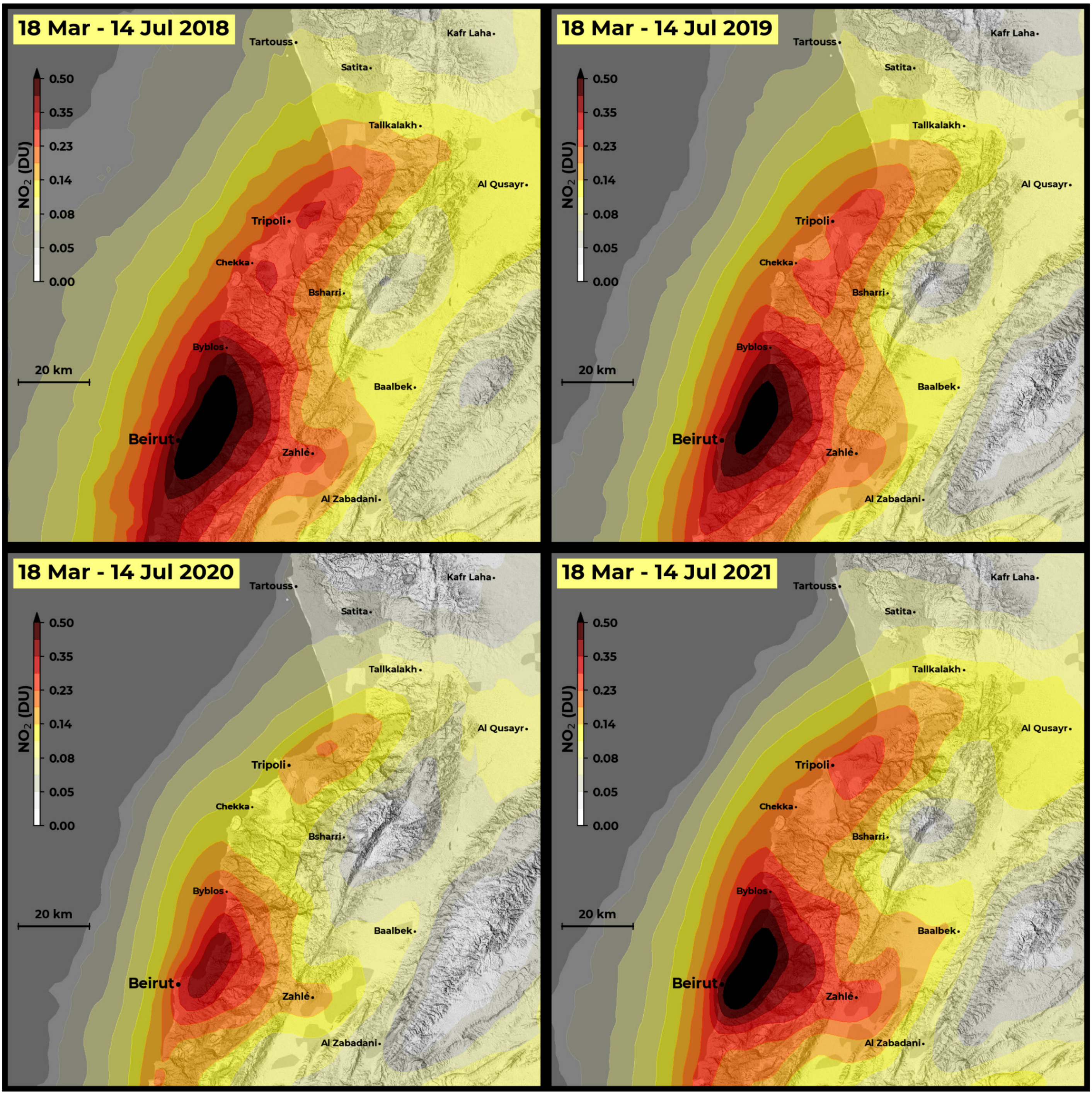

Figure 10. NO2 atmospheric column amount around Beirut during the study period in 2018-2021.

Amman

Figure 11 shows air pollution in the region around Amman during the study period in the years 2018-2021. A marked reduction is visible in 2020.

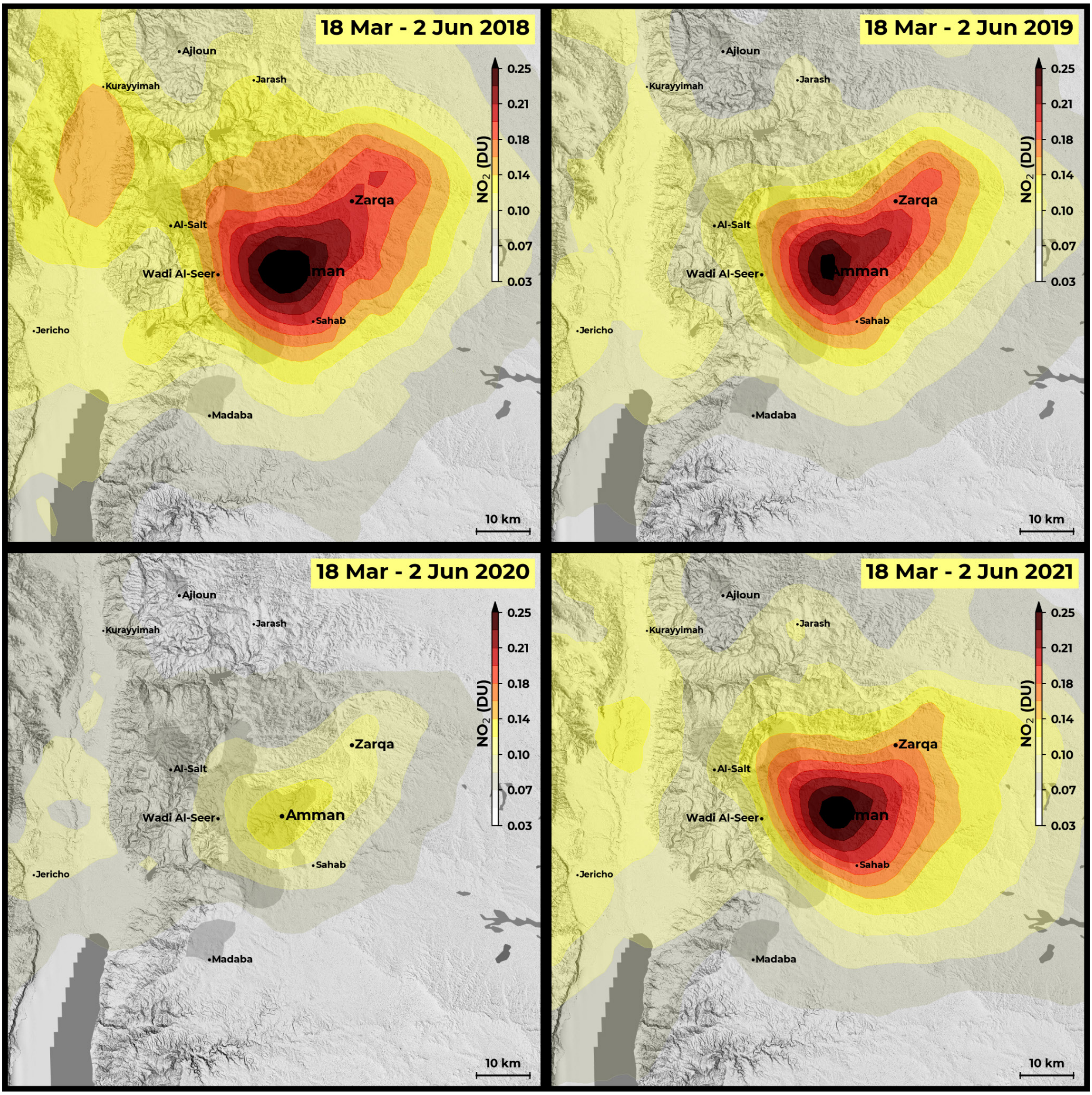

Figure 11. NO2 atmospheric column amount around Amman during the study period in 2018-2021.

Jeddah

Figure 12 shows air pollution in the region around Jeddah during the study period in the years 2018-2021. In 2020, pollution in a 10km circle around the city is 22% lower than in 2019.

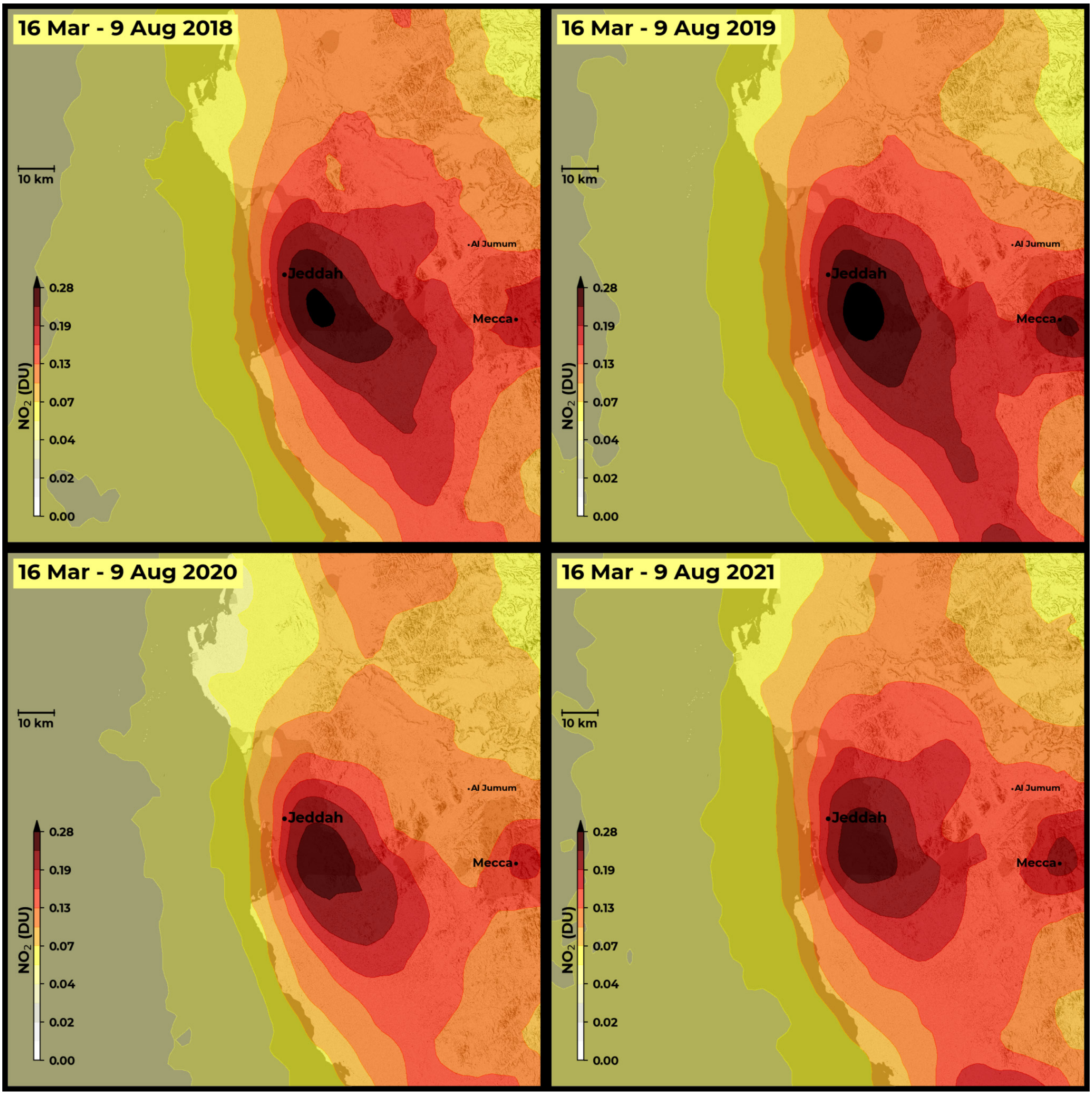

Figure 12. NO_2 atmospheric column amount around Jeddah during the study period in 2018-2021.

Dubai

Figure 13 shows air pollution in the region around Dubai during the study period in the years 2018-2021. In 2020, pollution in a 10km circle around the city is 12% lower than in 2019.

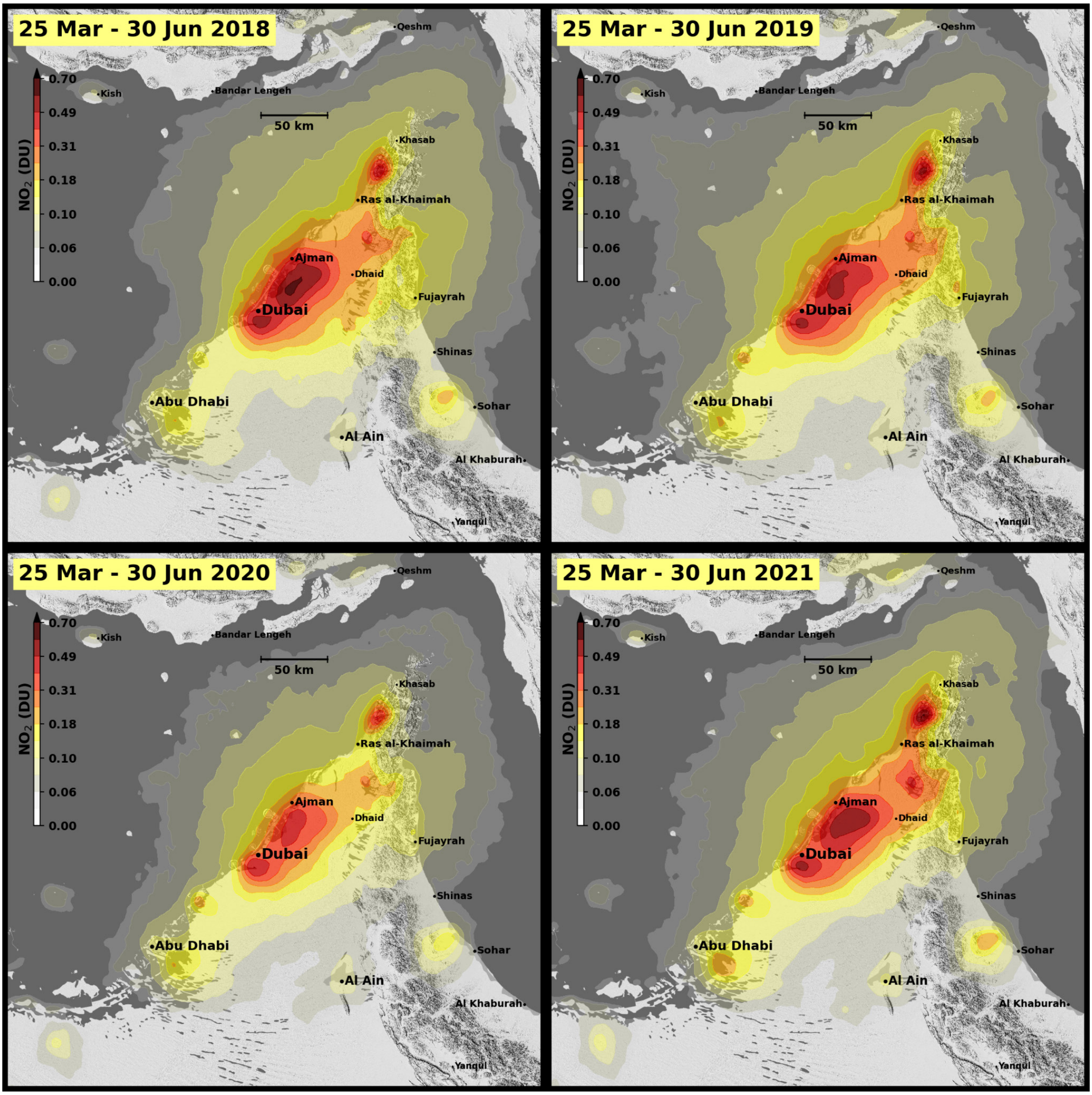

Figure 13. NO2 atmospheric column amount around Dubai during the study period in 2018-2021.

CONCLUSIONS

In all of the studied cities except those in Egypt, satellite-measured NO_2 air pollution was clearly reduced during the 2020 lockdowns compared to previous years. In 13 out of 16 cities, it returned to near or above pre-Covid levels in 2021.

These pollution changes have been calculated by averaging observations over periods of between 11 and 21 weeks, depending on the timing and duration of lockdowns in different locations. This temporal averaging is expected to minimise the influence of weather on the results and increase the likelihood that the observed changes are due to corresponding changes in emissions.

There is a strong observed link between lockdown stringency and NO_2 pollution. NO_2 levels were substantially lower during the first lockdown in 2020 than in other periods. It is therefore likely that the changes in society's behaviour, like reduced motor vehicle traffic and less economic activity during lockdown periods are responsible for changes in air pollution.

NO_2 atmospheric column amounts from satellite observations cannot be directly converted to ground NO_2 concentration. However, there is little or no reliable long-term ground air pollution monitoring in the Middle East and North Africa (Figure 14). The absence of consistent and comprehensive air pollution monitoring in the region is a major barrier to the effective management and improvement of air quality. As long as this lack of ground monitoring continues to exist, using NO_2 atmospheric column amount data from satellite measurements as a proxy for near-surface NO_2 concentration, as we did in this report, remains the best available source of information.

The UNEP "Environmental Rule of Law" report has identified clean air as a fundamental human right in 2019. Many MENA countries have adopted this constitutional right, however in most cases it is not implemented. Air pollution (just like most environmental impacts) often affects poor and marginalized communities the most. To protect these communities, governments must undertake systemic changes that recognise 'the vital linkages between environment, economic growth, public health, social cohesion, and security.' (UNEP, 2019). Including these communities in decision-making by enabling access to data is an important first step.

Air pollution monitoring that can inform decision makers and the public is essential for the management and timely improvement of air quality. Such data can help target actions to reduce pollutant emissions. Monitoring data can inform the implementation and enforcement of emission standards for all air pollutants to protect people's health, and is especially important where such standards are lacking.

Actions to improve air quality can also bring benefits for efforts to reduce human driven climate change. Air pollutants (such as NO_2) share the same principle source as greenhouse gases (such as CO_2): the burning of fossil fuels like coal, gas and oil. This is especially true for countries with high greenhouse gas emissions, especially in the Gulf region.

Commenting on recent NASA research into the effects of the pandemic on air pollutants and greenhouse gases, Dr. Joshua Laughner stated that, "We're past the point where we can think of these as two separate problems" (NASA 2021).

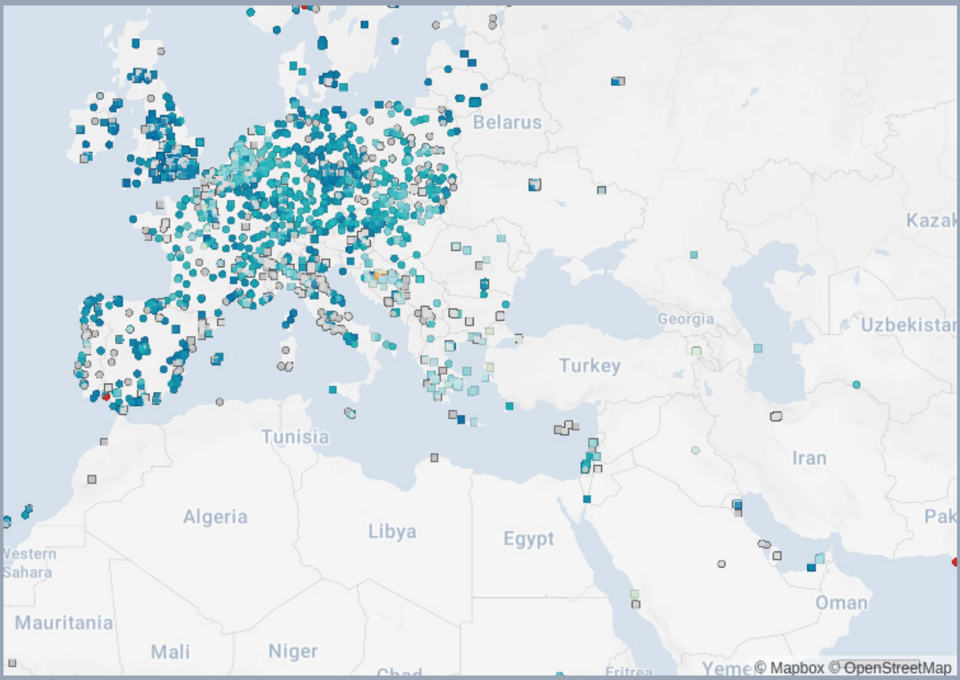

Figure 14. Locations of ground air pollution monitors available through OpenAQ. Most of Europe is densely monitored while there is only very sparse coverage in the Middle East and North Africa. Screenshot from https://openaq.org on 2021-11-09. Basemap: OpenStreetMap contributors.


Al Safa St
Financial Center St
2.0 km
شارع الصفا
شارع المركز المالي
Umm Amara St
4.0 km
شارع أم عمارة
Al Hadiqa St
Al Meydan St
5.5 km
شارع الحديقة
شارع الميدان
80
80
80
80

REFERENCES

Ahram Online, "Egypt: Cheaper Energy for Industry", 27 Mar 2020, retrieved from https://english.ahram.org.eg/NewsContent/50/1201/365943/AlAhram-Weekly/Egypt/Egypt-Cheaper-energy-for-industry.aspx on 2021-11-29.

Beavington-Penney, Simon & Nadin, Phil & Wright, V. & Clarke, Edward & McQuilken, Jonathan & Bailey, Haydon. (2008). Reservoir quality variation on an Eocene carbonate ramp, El Garia Formation, offshore Tunisia: Structural control of burial corrosion and dolomitisation. Sedimentary Geology. 209. 42-57. doi:10.1016/j.sedgeo.2008.06.006

Beloconi, Anton, Nicole M. Probst-Hensch, and Penelope Vounatsou. "Spatio-temporal modelling of changes in air pollution exposure associated to the Covid-19 lockdown measures across Europe." Science of The Total Environment (2021): 147607. https://doi.org/10.1016/j.scitotenv.2021.147607

Copernicus Sentinel-5P (processed by ESA), TROPOMI Level 2 Nitrogen Dioxide total column products. Version 01. European Space Agency. (2018) https://doi.org/10.5270/S5P-s4ljg54

Farrow, Aidan., Kathryn. A. Miller, and Lauri Myllyvirta. "Toxic air: the price of fossil fuels." Greenpeace Southeast Asia 44 (2020).

Google Mobility Reports (2021), retrieved from https://www.google.com/covid19/mobility/ on 2021-11-06.

Hale, Thomas, et al. "A global panel database of pandemic policies (Oxford Covid-19 Government Response Tracker)." Nature Human Behaviour 5.4 (2021): 529-538.

Health Effects Institute. 2020. State of Global Air 2020. Special Report. Boston, MA:Health Effects Institute.

Hu, Jiabao, et al. "Changes in air pollutants during the Covid-19 lockdown in Beijing: Insights from a machine-learning technique and implications for future control policy." Atmospheric and Oceanic Science Letters (2021): 100060. https://doi.org/10.1016/j.aosl.2021.100060

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

IRENA (2021), "Renewable Power Generation Costs in 2020", International Renewable Energy Agency, Abu Dhabi. Retrieved from https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020 on 2021-11-25.

Lamsal, L.N. L, R.V. Martin, A. van Donkelaar, M. Steinbacher, E.A. Celarier, E. Bucsela, E.J. Dunlea, J. Pinto

Ground-level nitrogen dioxide concentrations inferred from the satellite-borne ozone monitoring instrument. J. Geophys. Res., 113 (2008), p. D16308, 10.1029/2007JD009235

Lee, Han and Greenstone, Michael. Air Quality of Life Index. "2021 Annual Update." Figure 11. Retrieved from https://aqli.epic.uchicago.edu/reports/ on 2021-09-02.

Lelieveld, J., K. Klingmüller, A. Pozzer, R. T. Burnett, A. Haines, V. Ramanathan, Effects of fossil fuel and total anthropogenic emission removal on public health and climate, Proceedings of the National Academy of Sciences Apr 2019, 116 (15) 7192-7197; https://doi.org/10.1073/pnas.1819989116

Leon, Audrey, Setting sights on Tunisia, in Offshore Engineer, 1 Sep 2014, Retrieved from https://www.oedigital.com/news/454986-setting-sights-on-tunisia on 2021-11-22.

Marais, Eloise A., Rachel F. Silvern, Alina Vodonos, Eleonore Dupin, Alfred S. Bockarie, Loretta J. Mickley, and Joel Schwartz, Air Quality and Health Impact of Future Fossil Fuel Use for Electricity Generation and Transport in Africa, Environ. Sci. Technol. 2019, 53, 22, 13524–13534, Publication Date:October 24, 2019 https://doi.org/10.1021/acs.est.9b04958

Myllyvirta, Lauri, and Hubert Thieriot. Centre for Research on Energy and Clean Air: 38,000 air pollution-related deaths avoided in Europe in 2020, as fossil fuel burning dropped. Centre for Energy and Clean Air. (2020) Retrieved from

https://energyandcleanair.org/air-pollution-related-deaths-avoided-in-europe-in-2020 on 21-11-08.

NASA Global Climate Change (2021). Emission Reductions From Pandemic Had Unexpected Effects on Atmosphere. 2021-11-09. Retrieved from https://climate.nasa.gov/news/3129/emission-reductions-from-pandemic-had-unexpected-effects-on-atmosphere/ on 2021-11-15.

North Africa Post, The, Tunisia / Libya: Sonde to carry 2nd exploration phase, 7 Dec 2012, Retrieved from https://northafricapost.com/1706-tunisia-libya-sonde-to-carry-2nd-exploration-phase.html on 2021-11-22.

Seltenrich N. 2014. Remote-sensing applications for environmental health research.Environ Health Perspect 122:A268-A275; doi:10.1289/ehp.122-A26825272250.

Shi, Zongbo, et al. "Abrupt but smaller than expected changes in surface air quality attributable to Covid-19 lockdowns." Science Advances 7.3 (2021). https://doi.org/10.1126/sciadv.abd6696.

Skytruth (2021). Annual Flaring Volume Estimates from Earth Observation Group (2012-2020), https://viirs.skytruth.org/apps/heatmap/flarevolume.html accessed on 2021-11-25. Two sources (0.022 BCM + 0.013 BCM (billion cubic metres per year)) are visible in the Gulf of Gabès.

Methods in: Elvidge CD, Zhizhin M, Baugh K, Hsu F-C, Ghosh T. Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data. Energies. 2016; 9(1):14. https://doi.org/10.3390/en9010014

UNEP (United Nations Environmental Programme), "Environmental Rule of Law: First Global Report", 24 Jan 2019, retrieved from https://www.unep.org/resources/assessment/environmental-rule-law-first-global-report on 2021-11-29.

Vohra, K., Alina Vodonos, Joel Schwartz, Eloise A. Marais, Melissa P. Sulprizio, Loretta J. Mickley,

Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem, Environmental Research, Volume 195, 2021, 110754, ISSN 0013-9351, https://doi.org/10.1016/j.envres.2021.110754.

WHO (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329. License: CC BY-NC-SA 3.0 IGO

TECHNICAL APPENDIX

Lockdown periods and mobility

Restriction stringency and lockdown threshold

In order to objectively identify the timing and duration of the first “lockdown” in different countries, we analysed the restriction stringency index of the Oxford Covid-19 Government Response Tracker (Hale et al 2021). The index takes on values between 0 and 100 and measures the stringency of government restrictions. We defined the study period as the first contiguous interval where this index was beyond a certain threshold. The threshold is set to 67 (two thirds of 100) for all places except Morocco. For Morocco, this threshold would not identify an interval that is clearly distinct from the values in the following months (which remain close to 67). We therefore set the threshold to 80 (four fifths of 100) for Morocco. As an example, the restriction stringency index for Morocco is shown in the top panel of Figure A1. Graphs for the other countries are shown in Section Supplementary graphs.

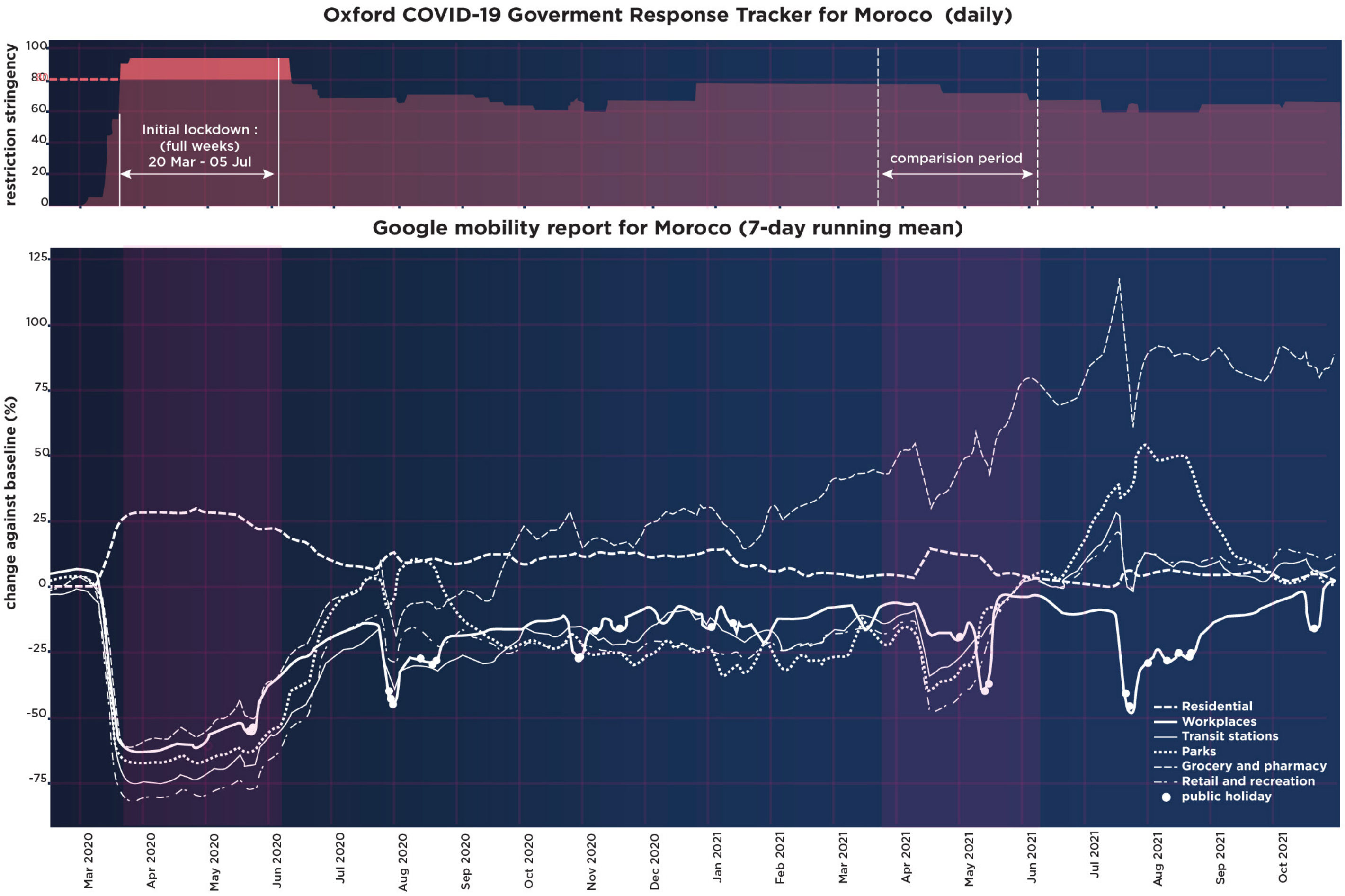

Figure A1. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for Morocco.

Weekend effects

In order to avoid artificial effects due to inclusion of different weekdays when comparing different years, we rounded all lockdown intervals (downward) to multiples of 7 days. The intervals analysed therefore always contain the same number of days for each day of the week in every year analysed.

Effects on people’s mobility

The effect of the government restrictions on people’s mobility has been measured by the Google Mobility Report (Google, 2021). As an example, the mobility report for Morocco is shown in the bottom panel of Figure A1. In all locations studied, people’s presence in workplaces and transit stations are sharply reduced during the lockdown intervals. A Google Mobility Report is not available for Tunisia.

Supplementary Graphs

Graphs for lockdown stringency, people's mobility and changes in NO_2 air pollution during the study periods for each location are listed below.

Morocco

Lockdown restrictions and Google Mobility Report for Morocco is shown in Figure A1.

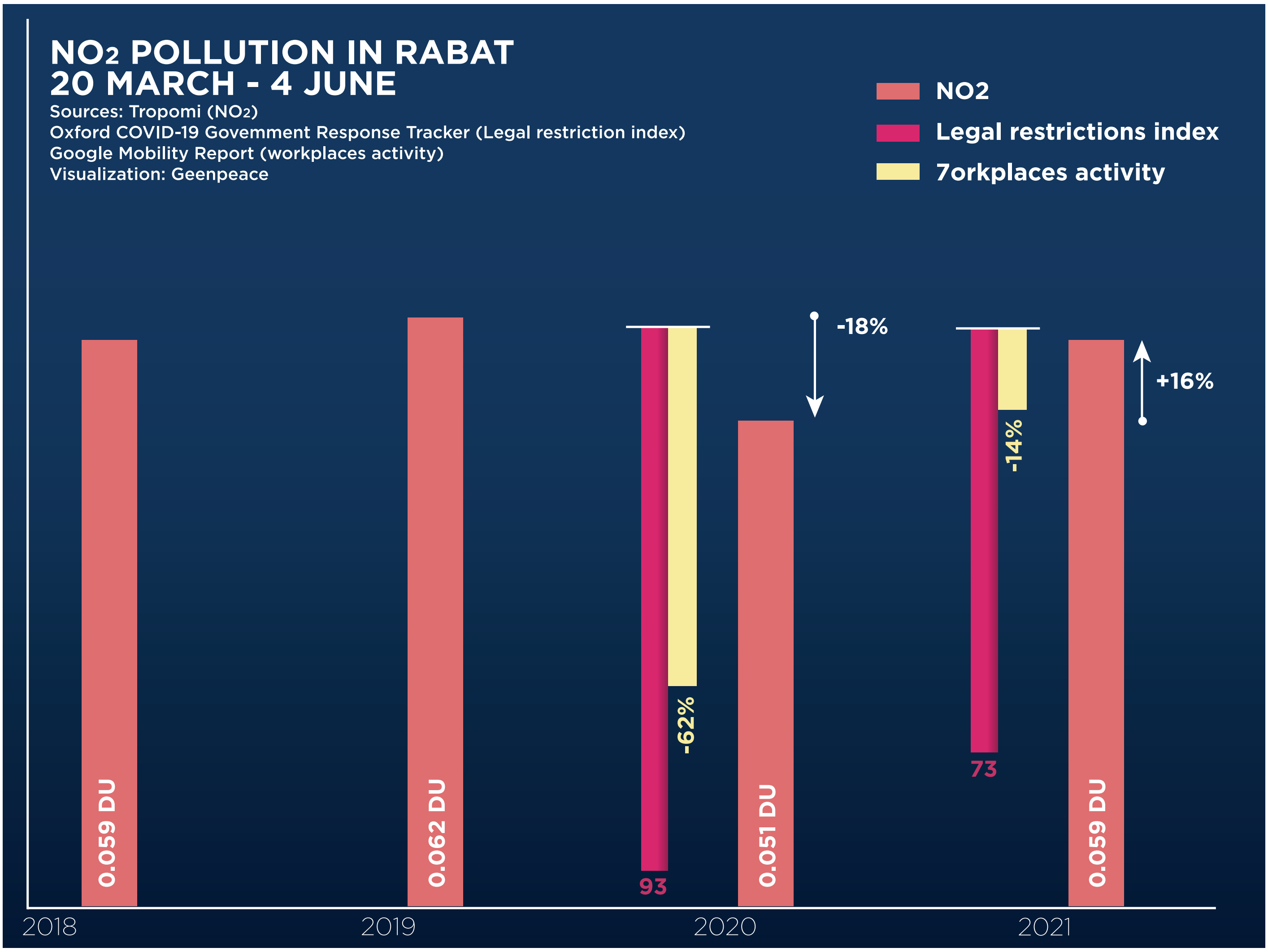

Figure A2. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Rabat, Morocco.

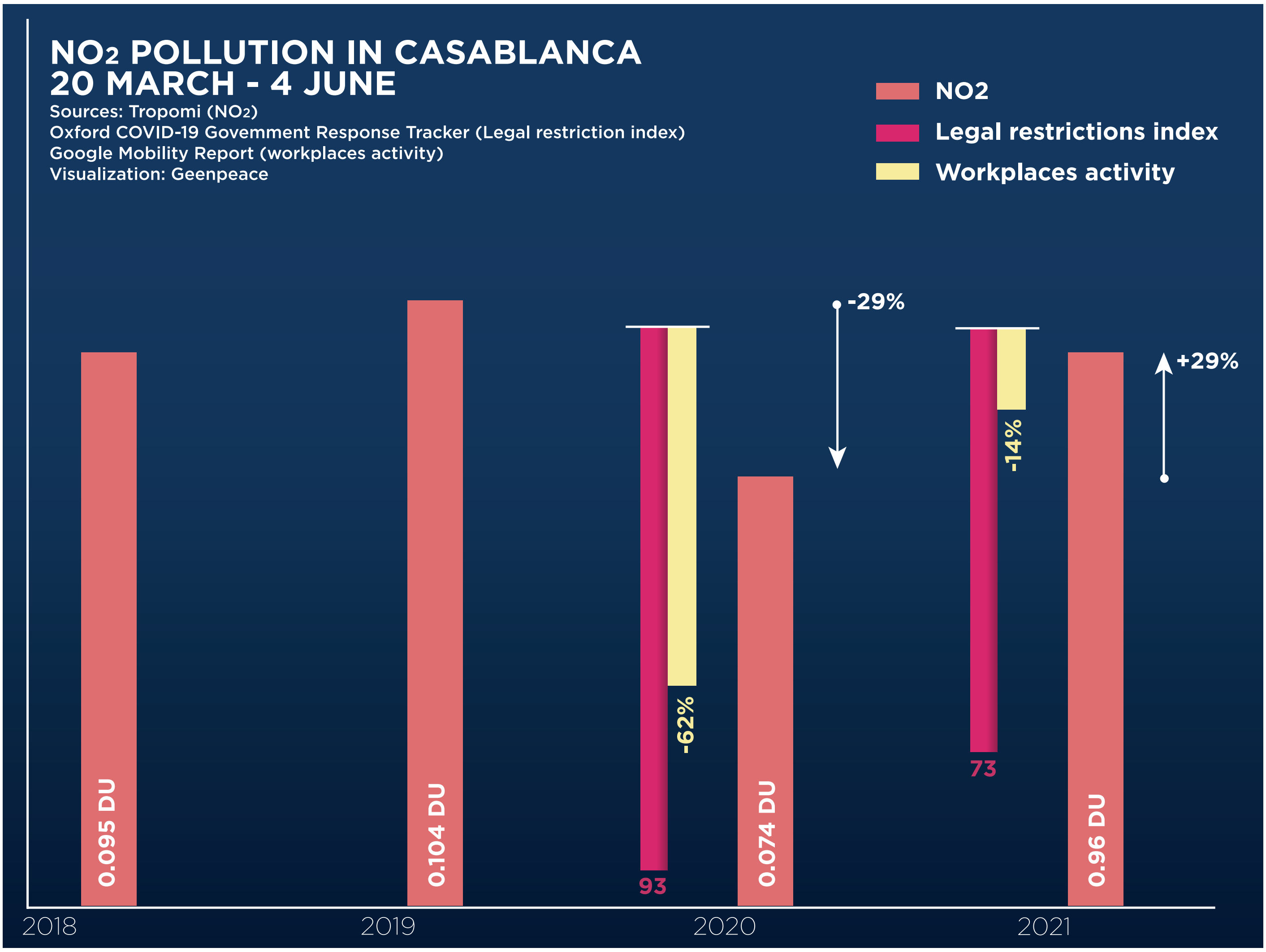

Figure A3. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Casablanca, Morocco.

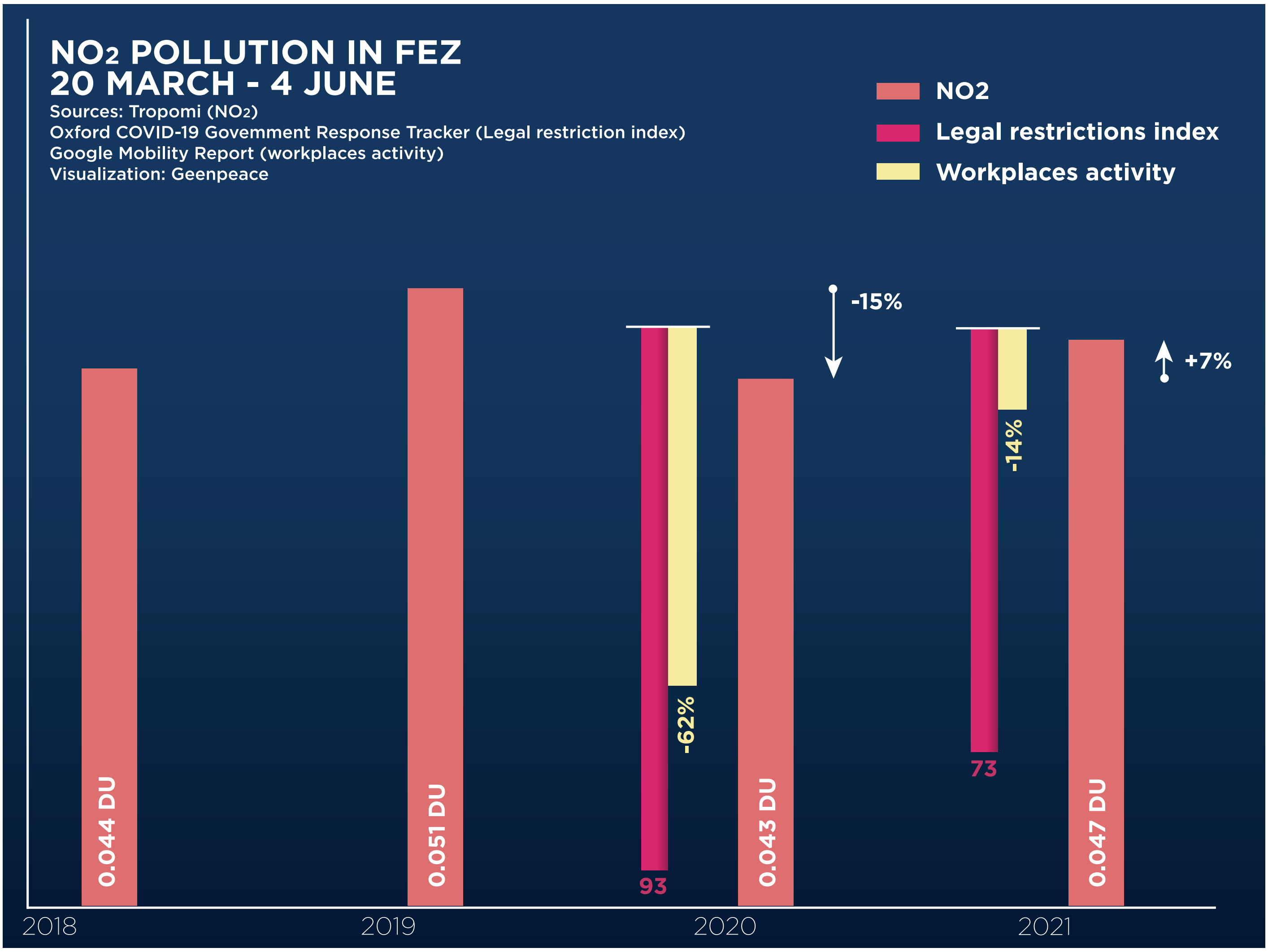

Figure A4. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Fez, Morocco.

Tunisia

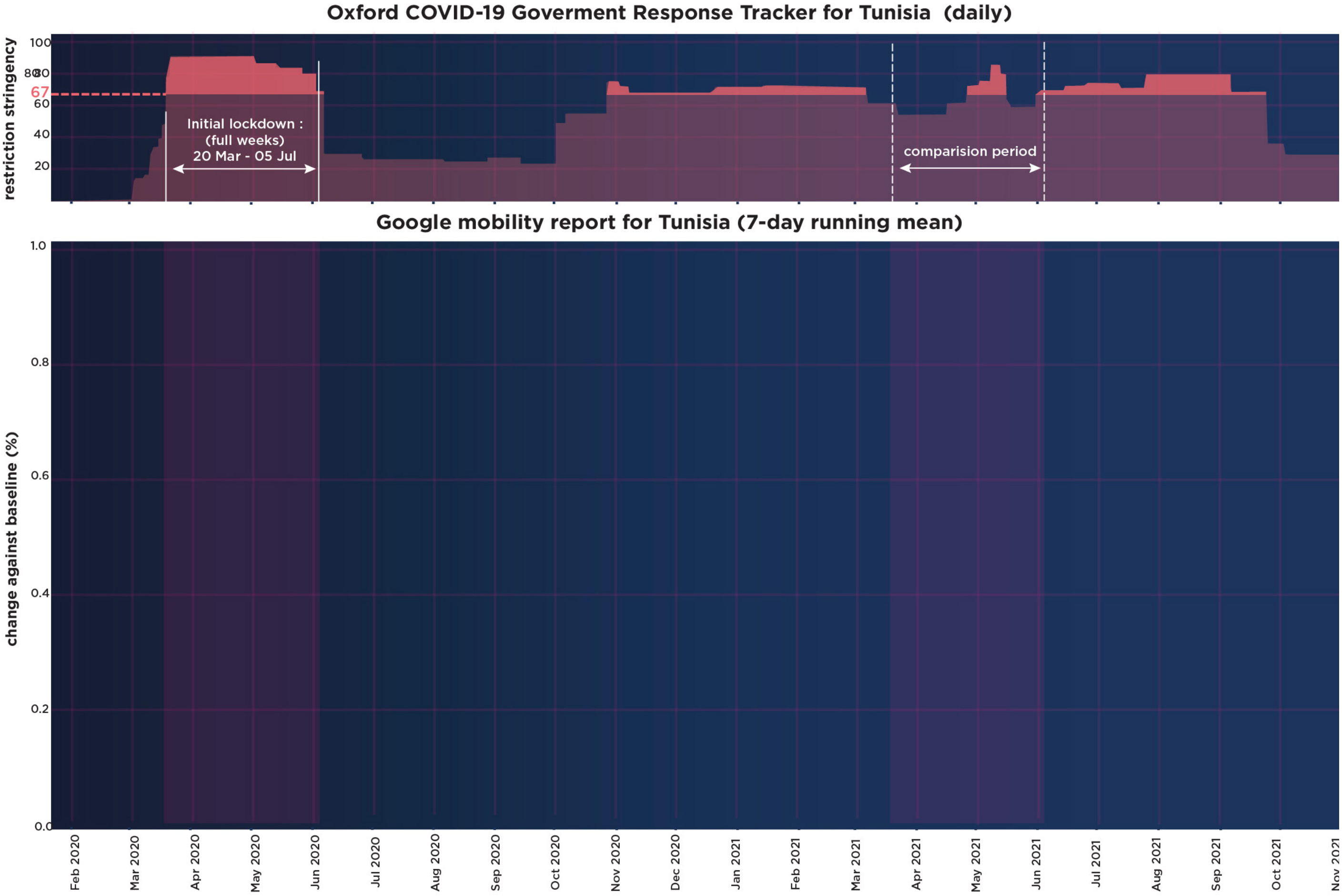

Figure A5. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for Tunisia. Google activity data is not available for Tunisia.

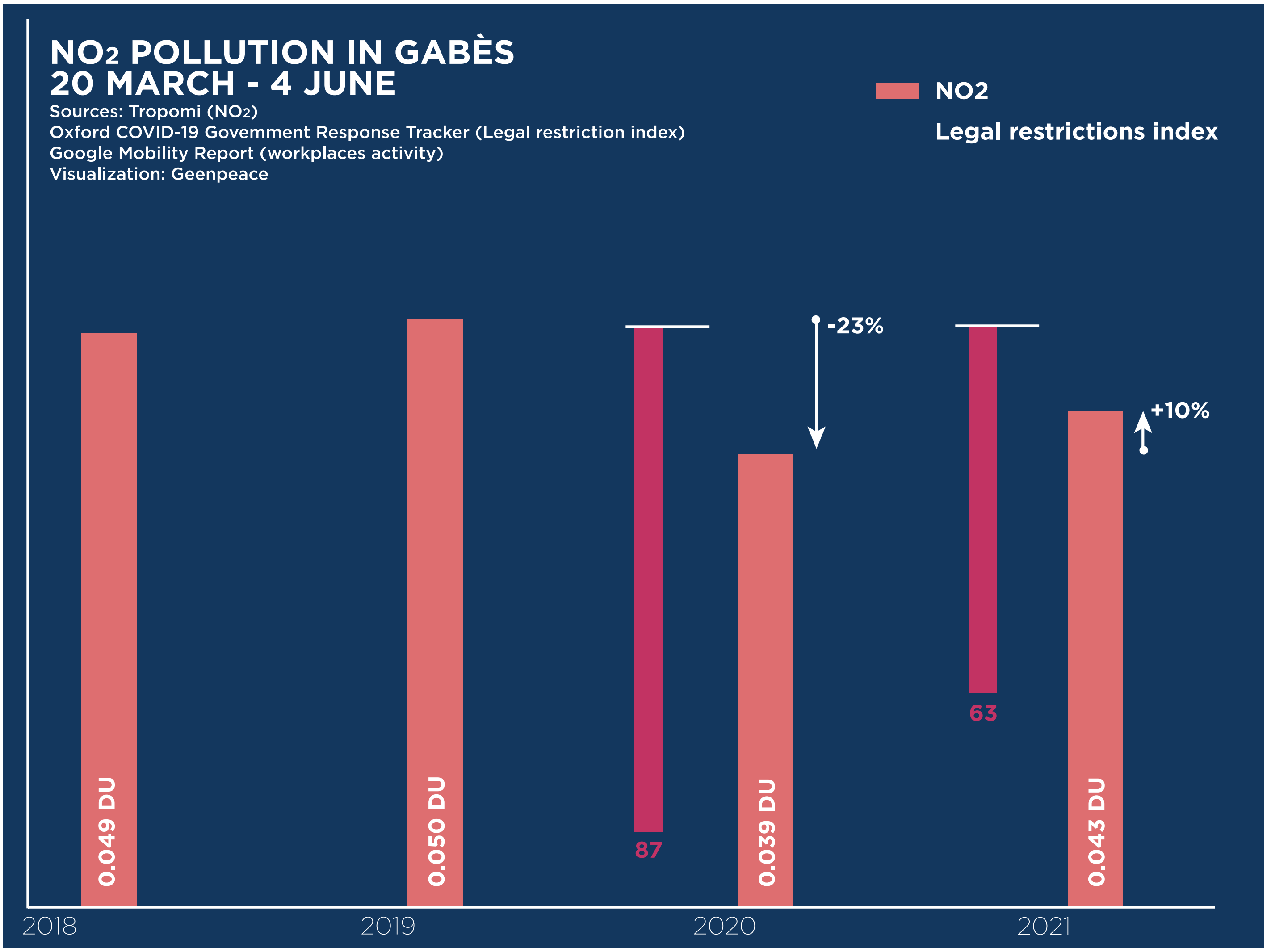

Figure A6. NO_2 atmospheric column amount and government restriction stringency for Gabès, Tunisia.

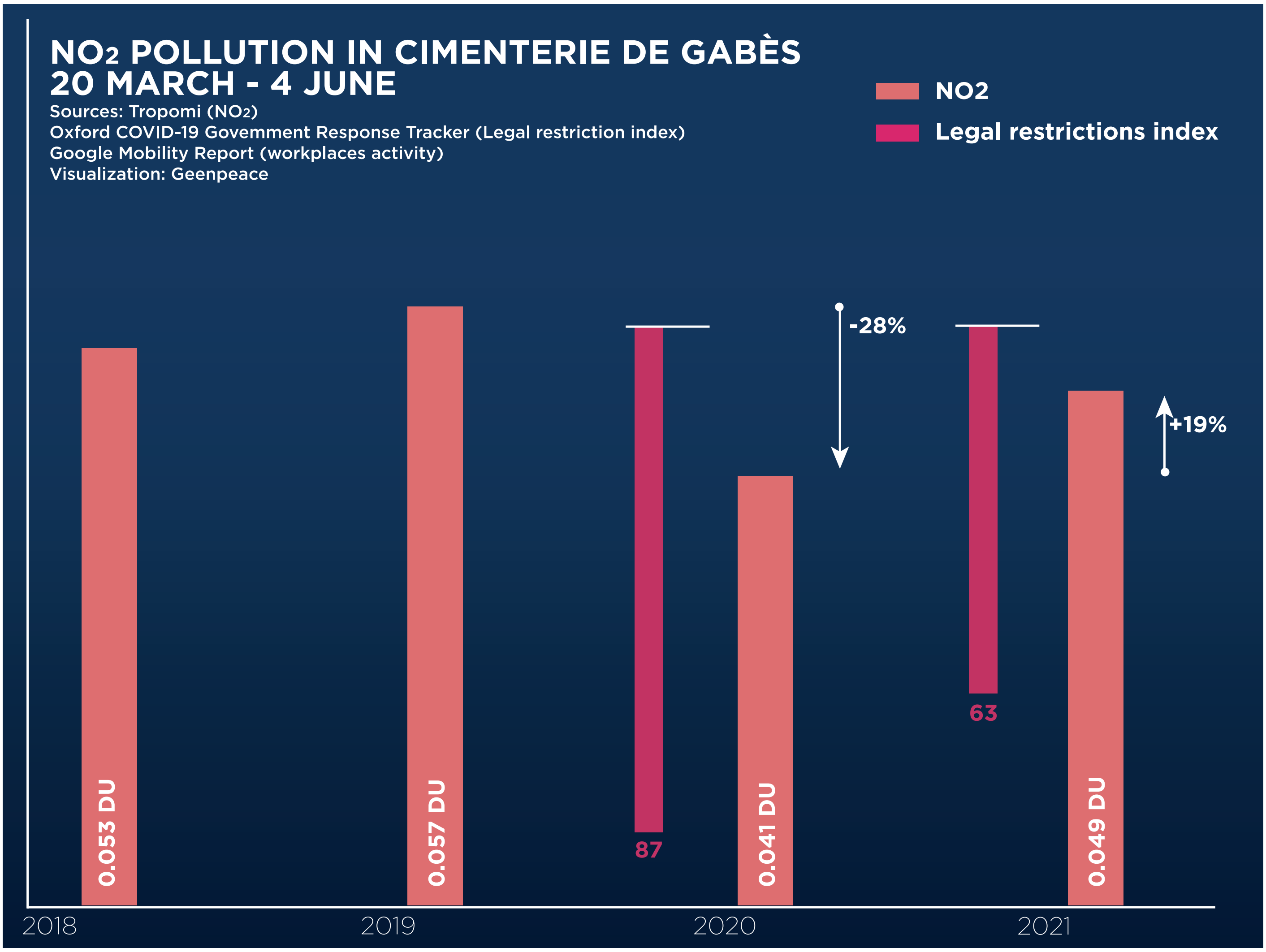

Figure A7. NO_2 atmospheric column amount and government restriction stringency for Cimenterie de Gabès, Tunisia.

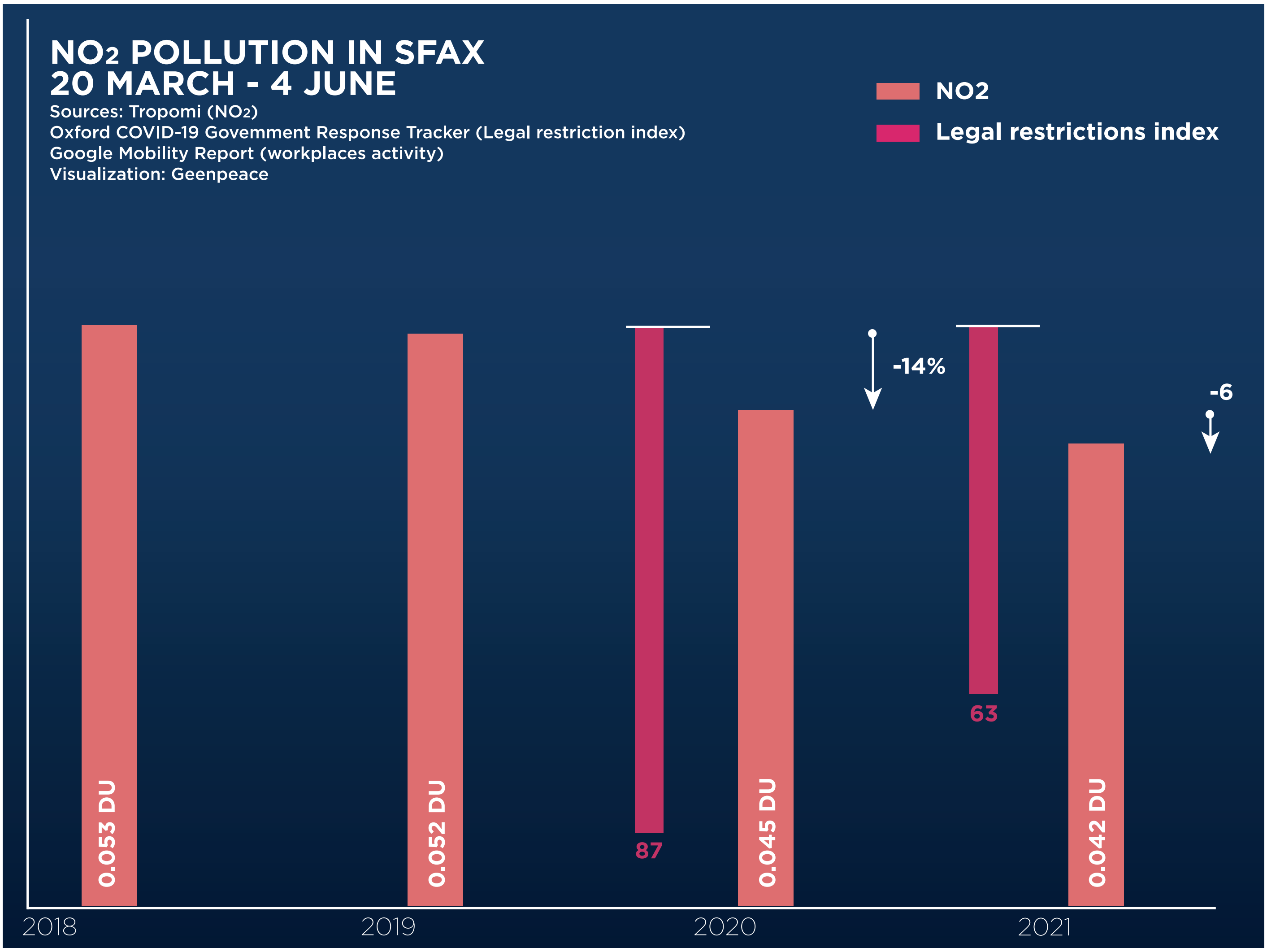

Figure A8. NO_2 atmospheric column amount and government restriction stringency for Sfax, Tunisia.

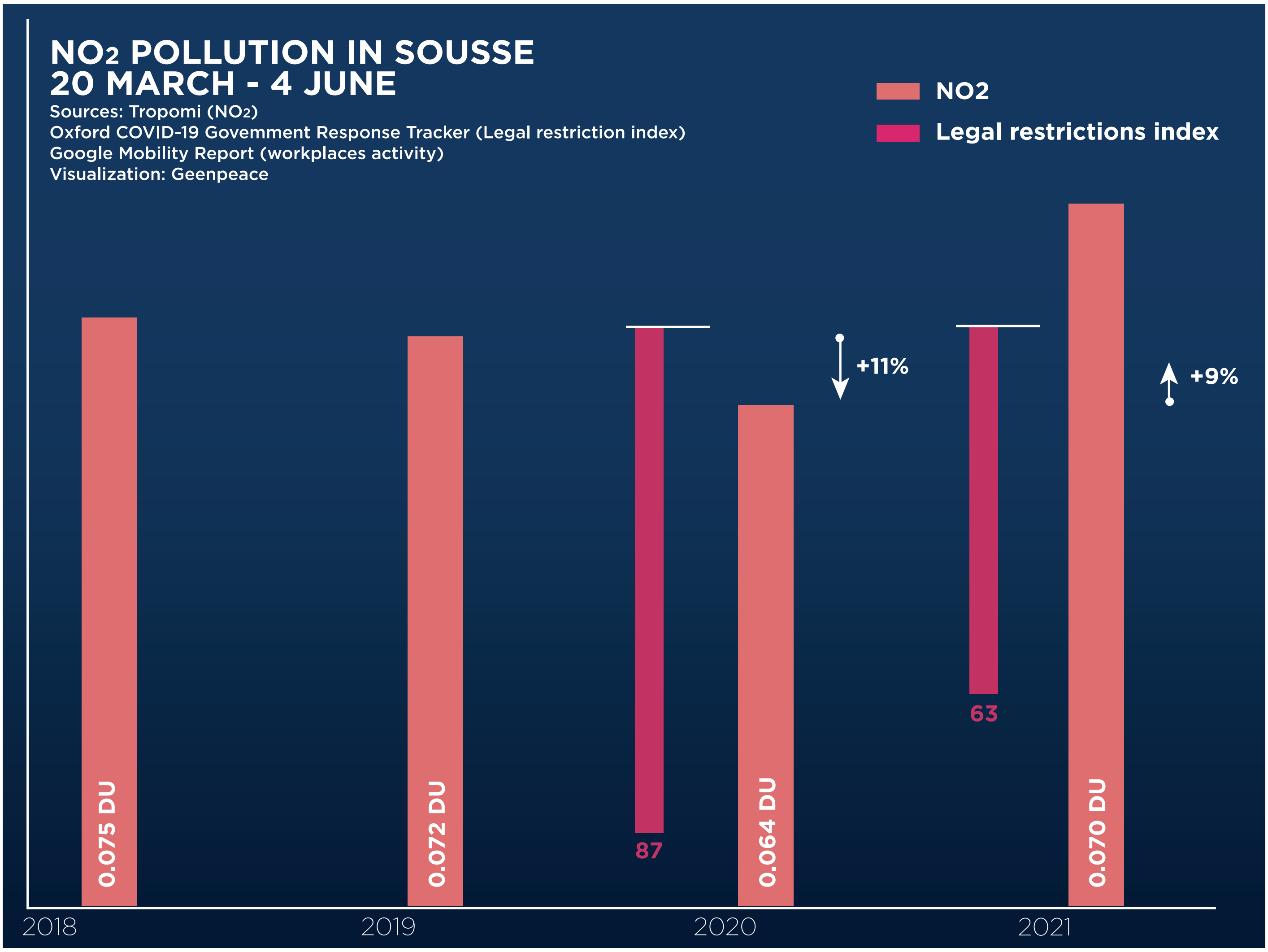

Figure A9. NO_2 atmospheric column amount and government restriction stringency for Sousse, Tunisia.

Egypt

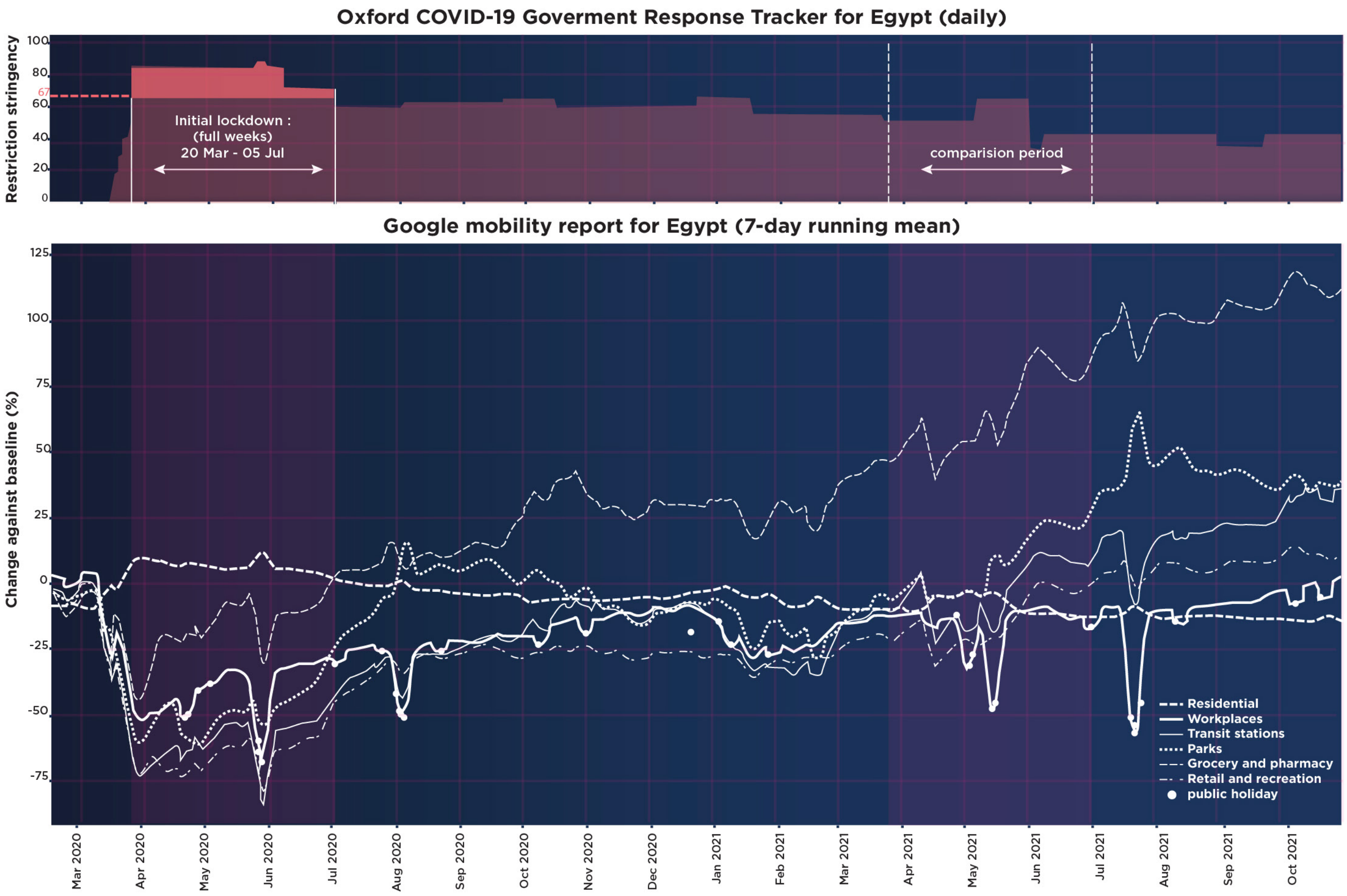

Figure A10. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for Egypt.

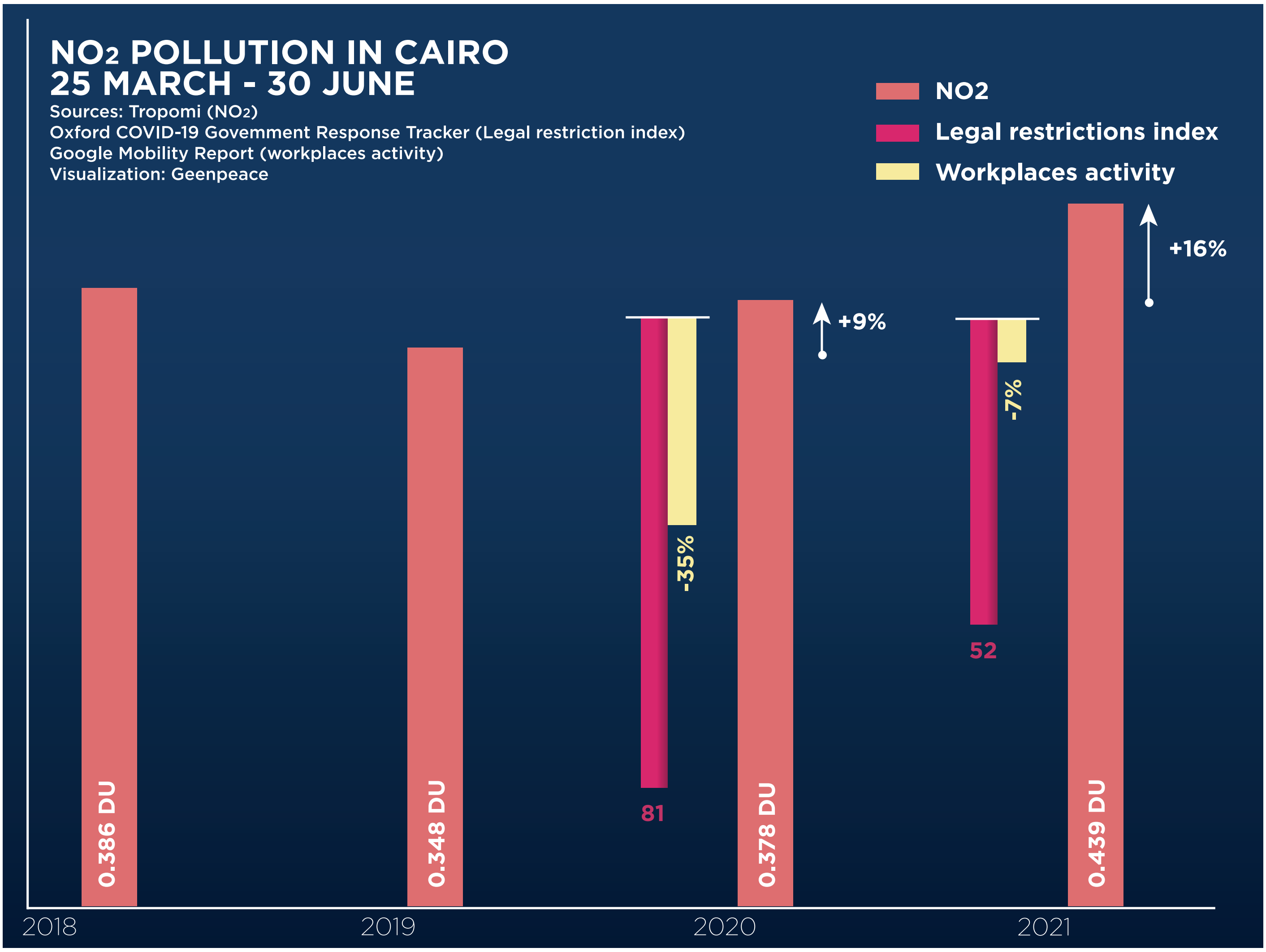

Figure A11. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Cairo, Egypt.

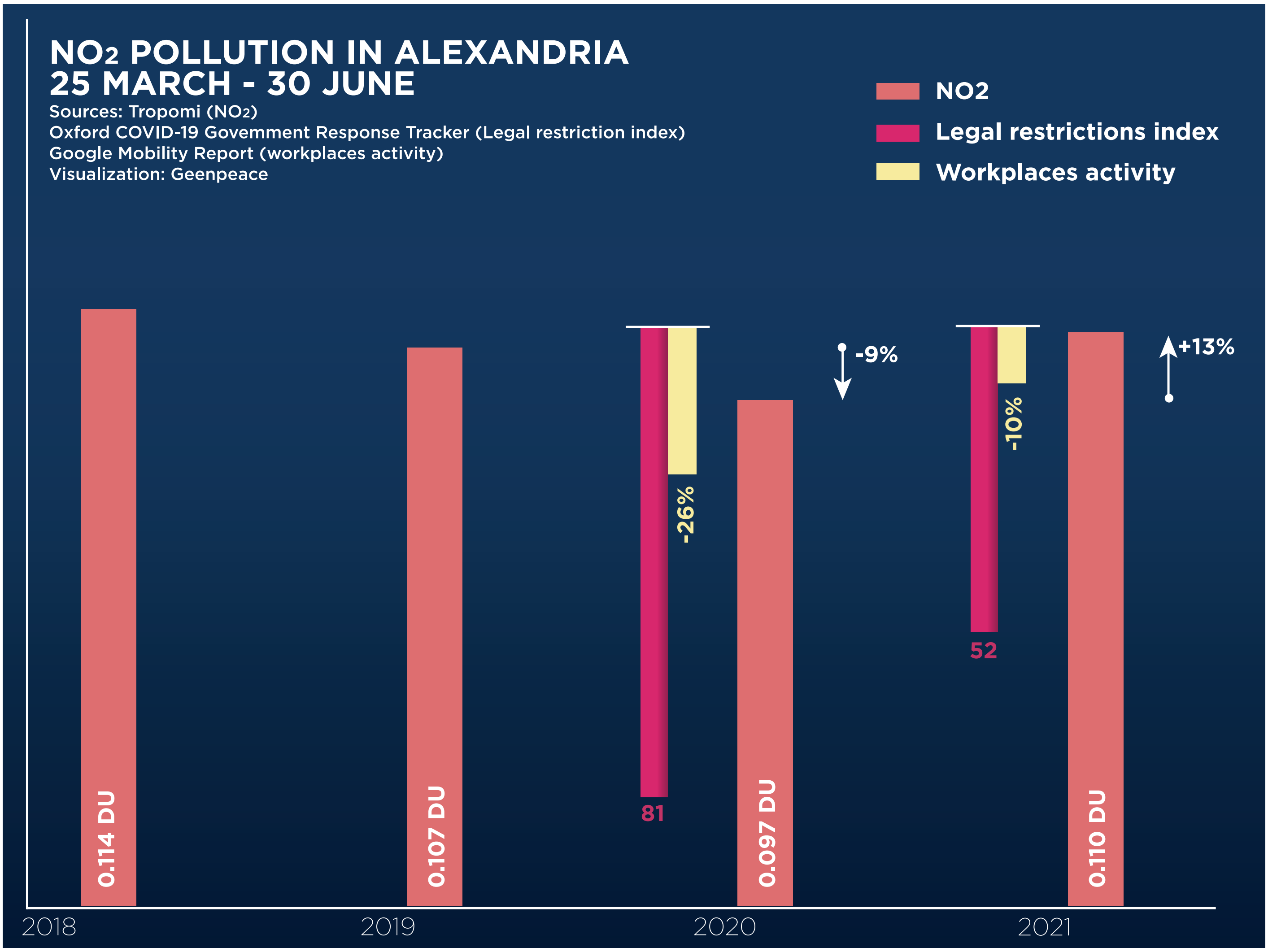

Figure A12. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Alexandria, Egypt.

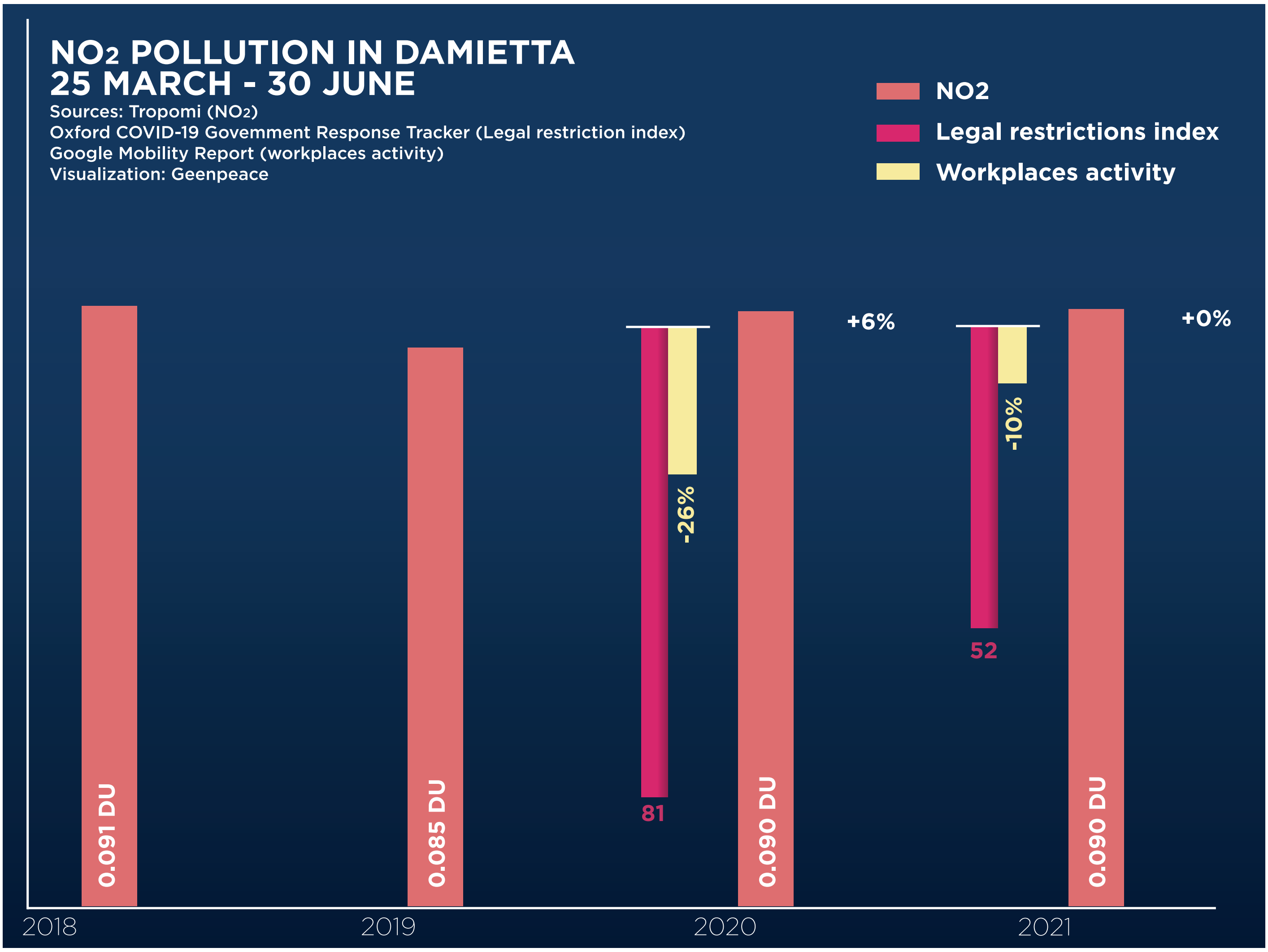

Figure A13. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Damietta, Egypt.

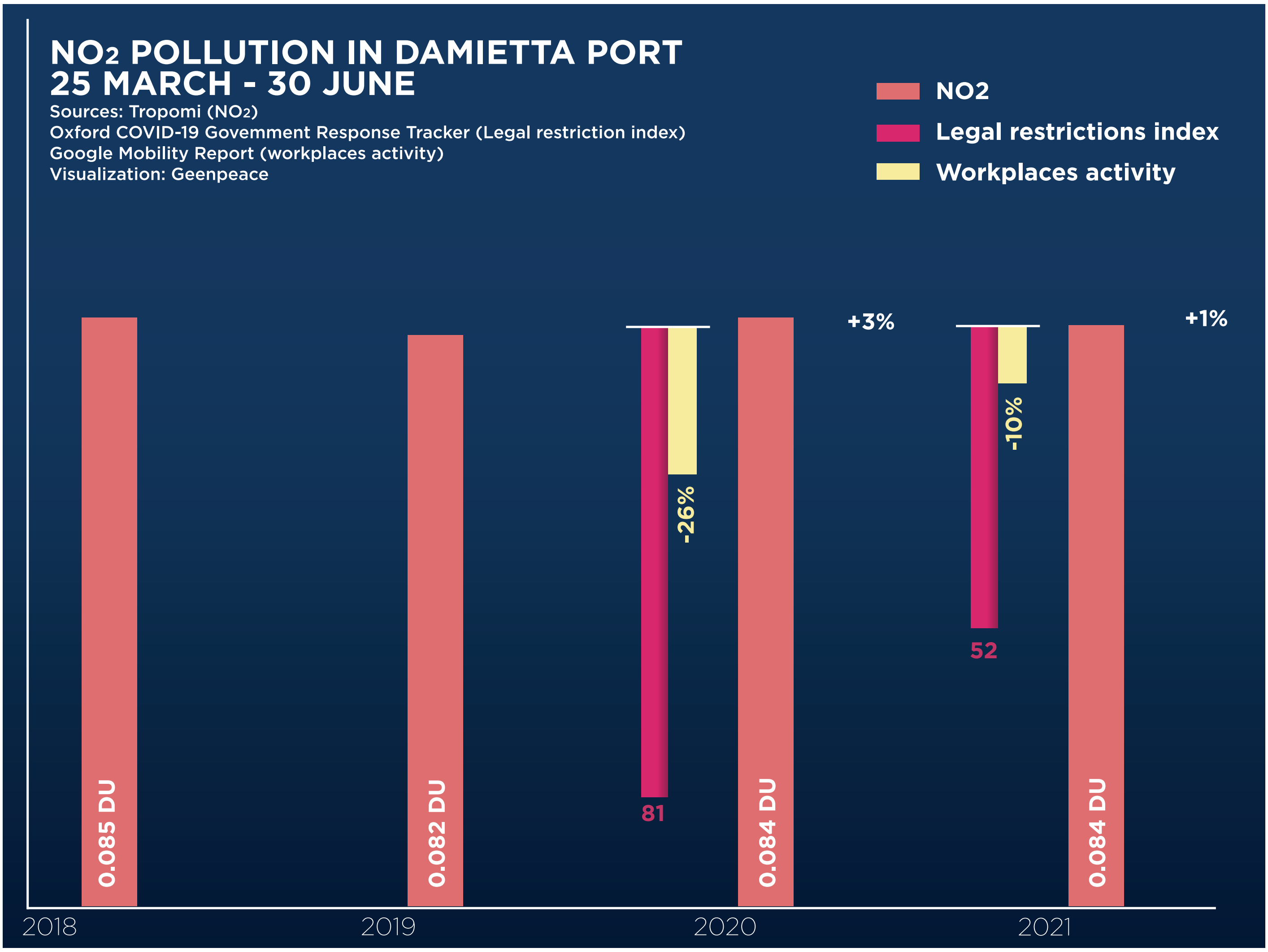

Figure A14. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Damietta Port, Egypt.

Lebanon

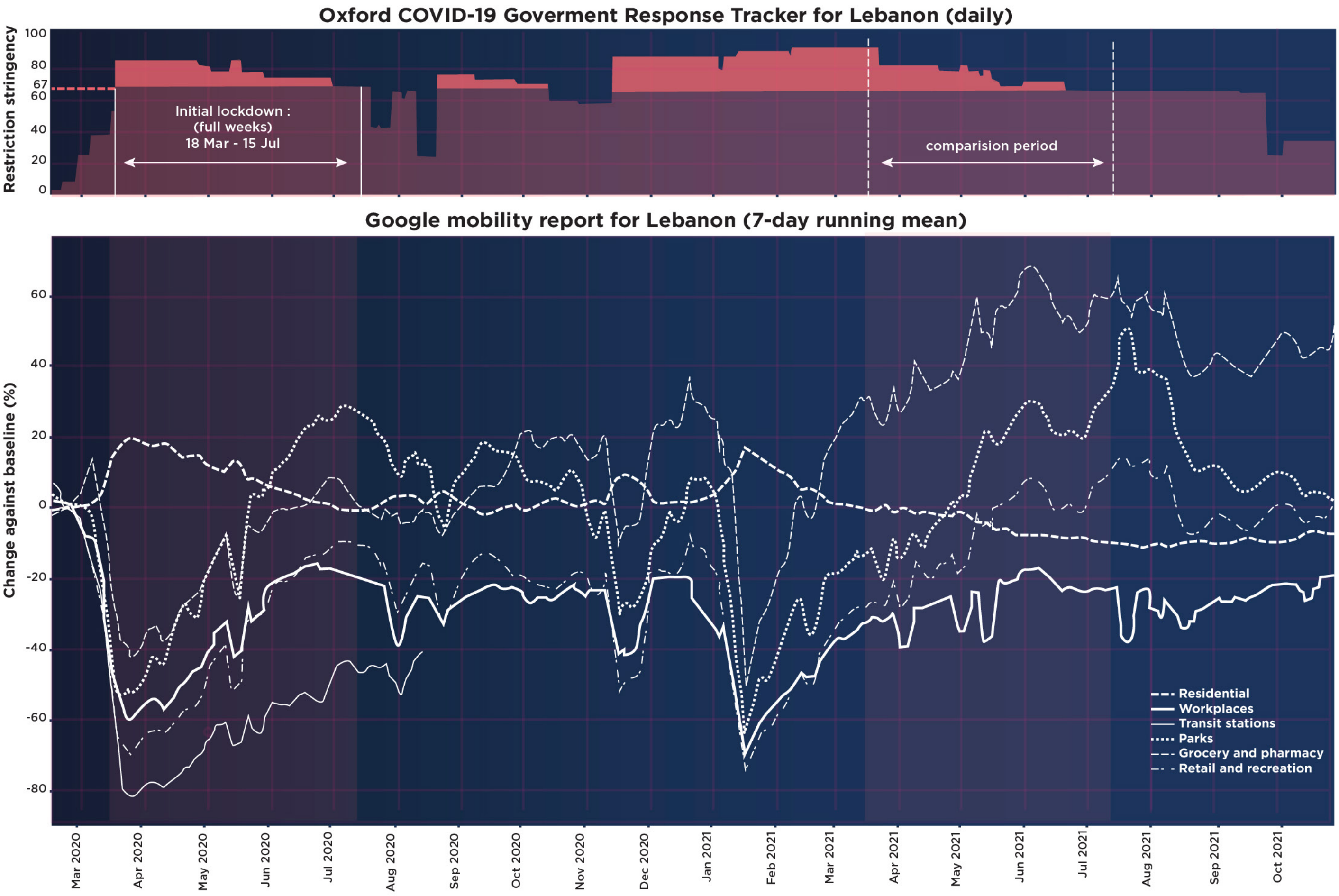

Figure A15. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for Lebanon.

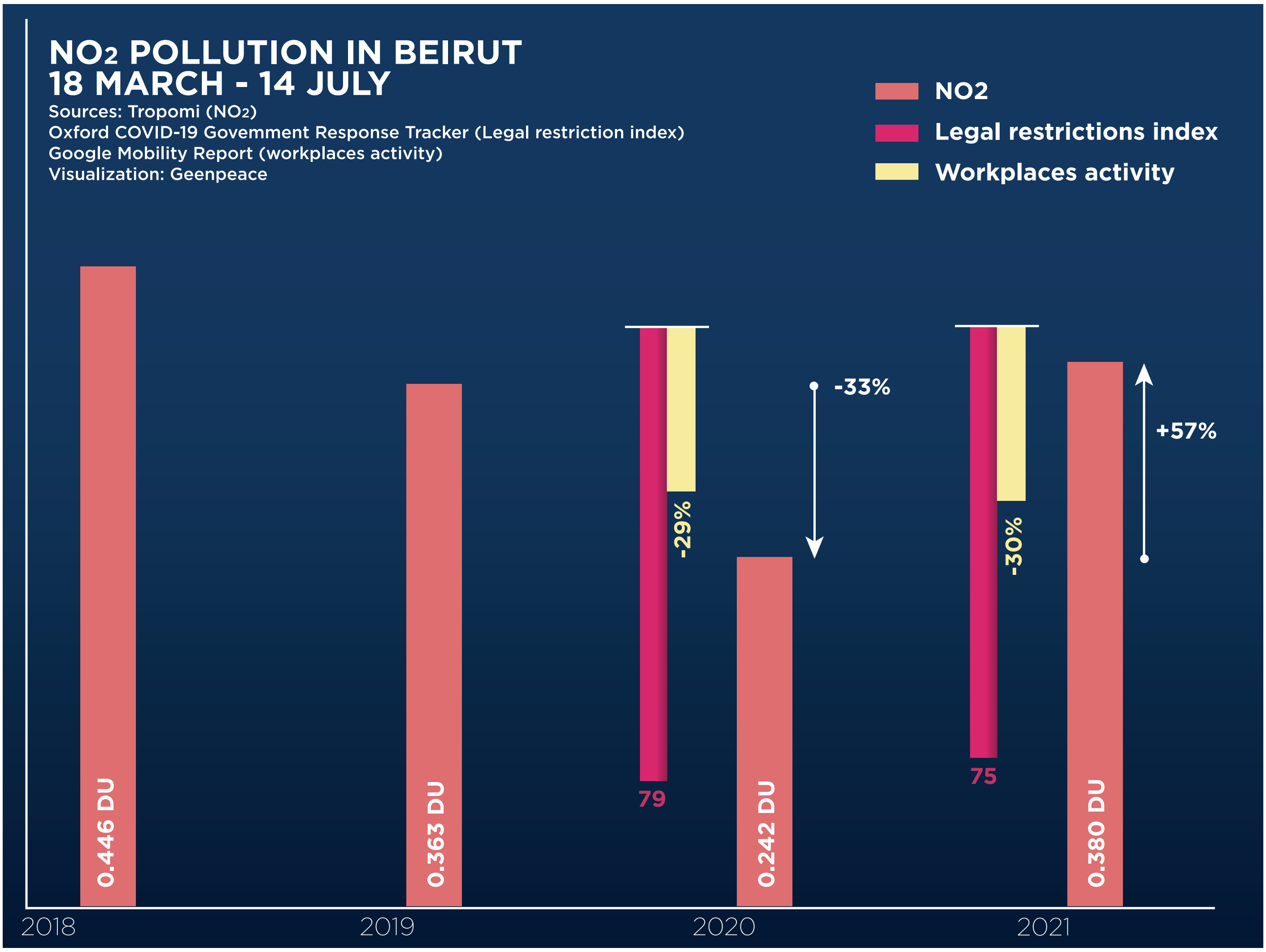

Figure A16. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Beirut, Lebanon.

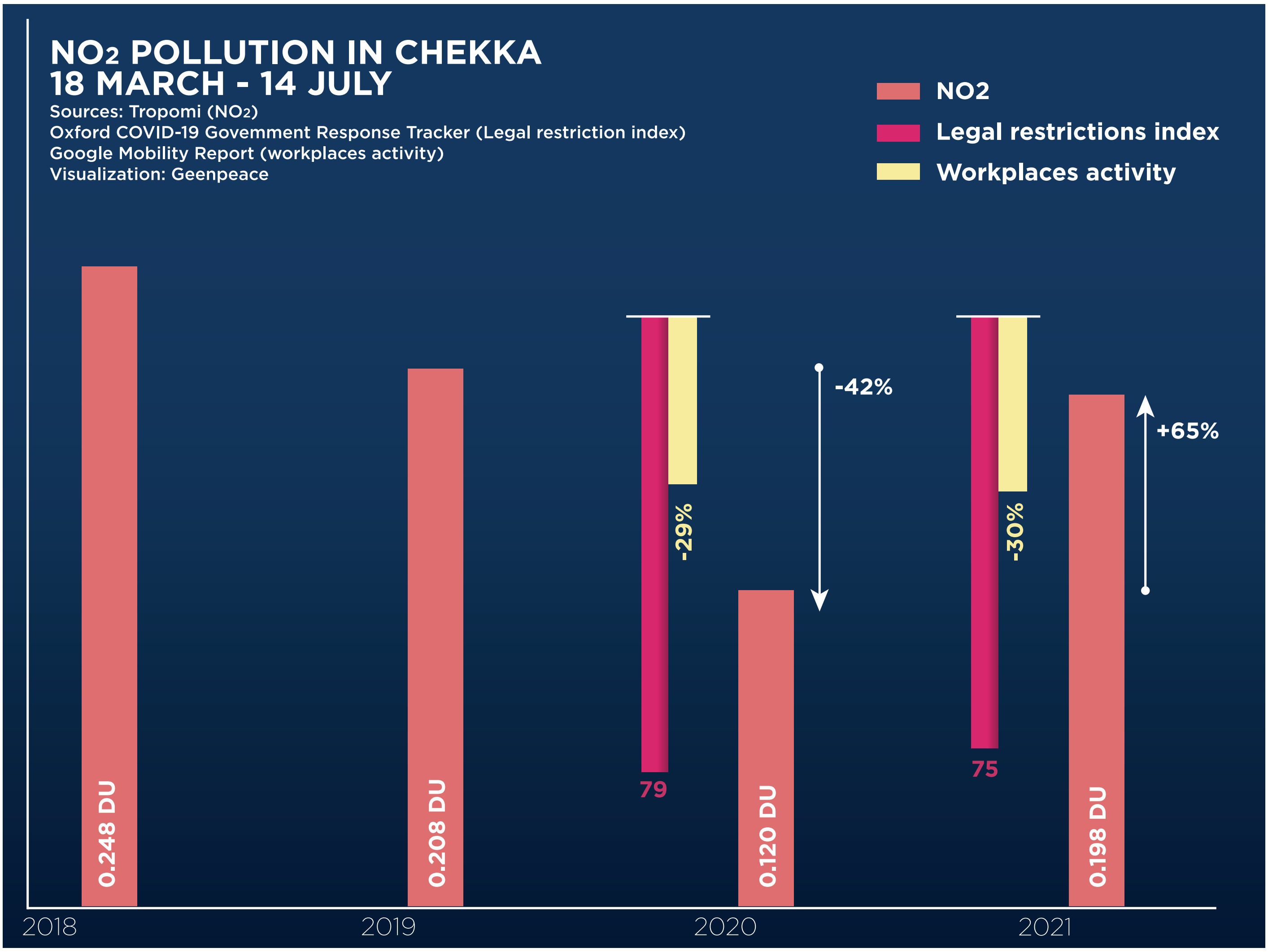

Figure A17. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Chekka, Lebanon.

Jordan

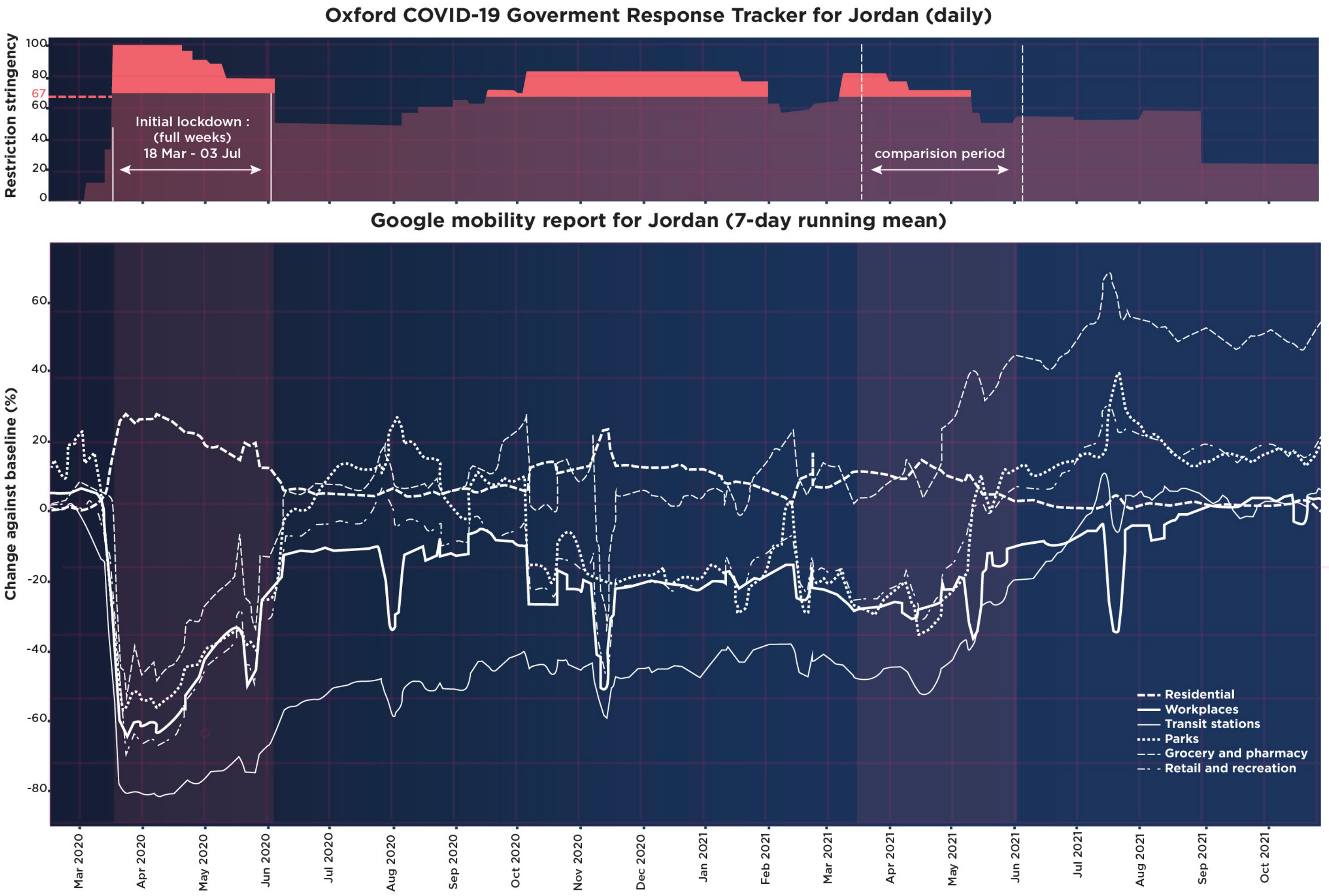

Figure A18. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for Jordan.

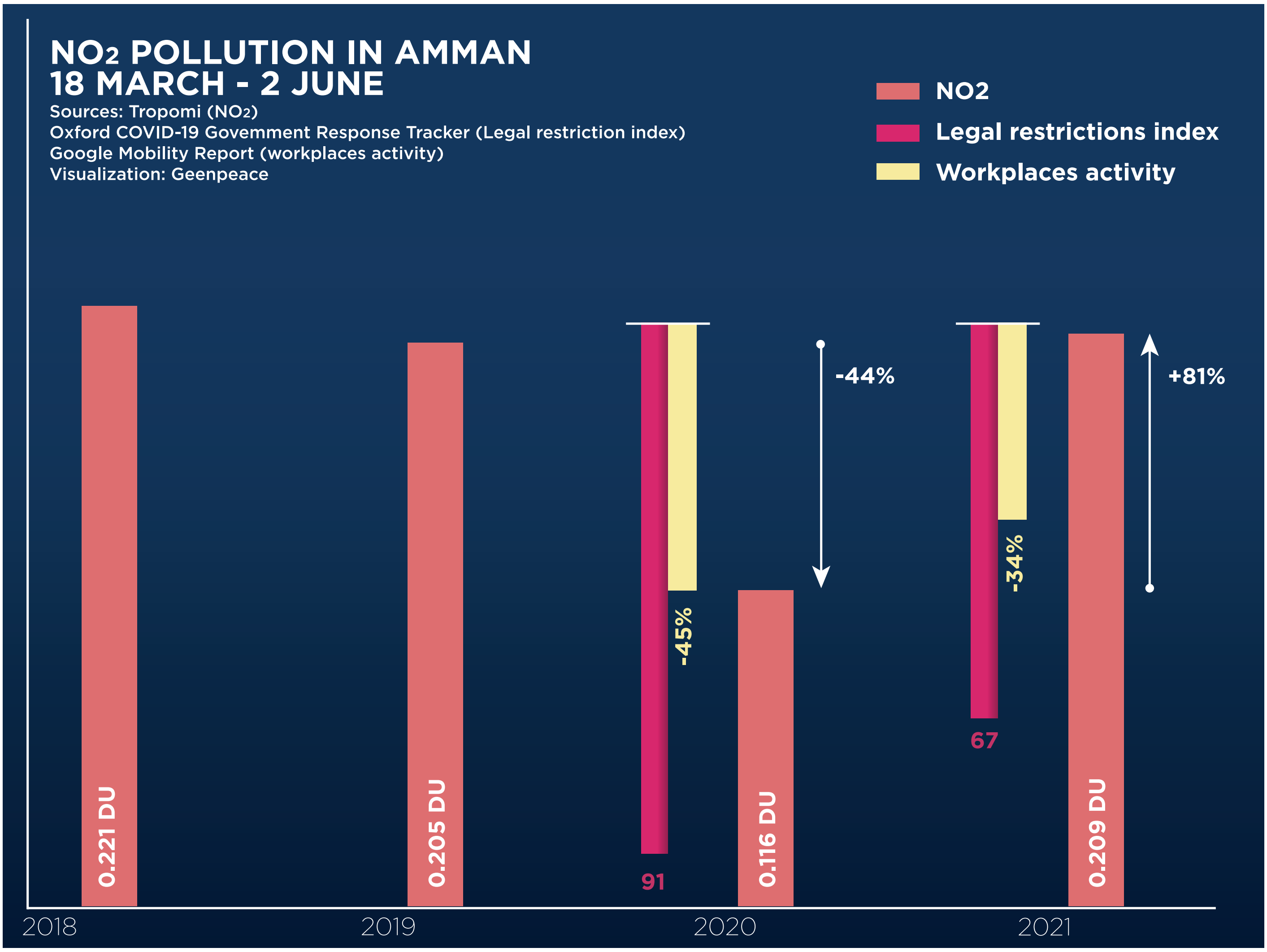

Figure A19. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Amman, Jordan.

Saudi Arabia

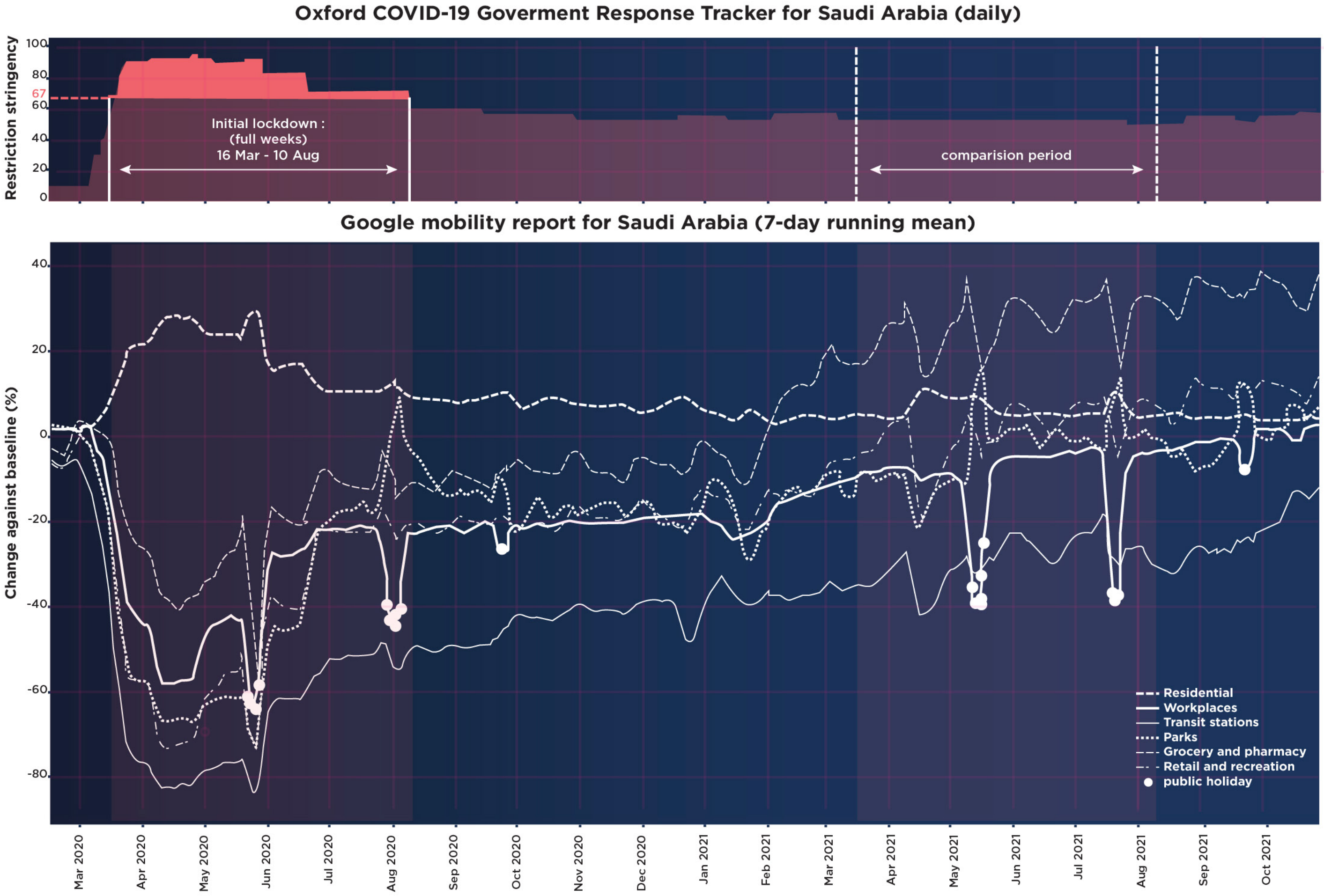

Figure A20. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for Sauudi Arabia.

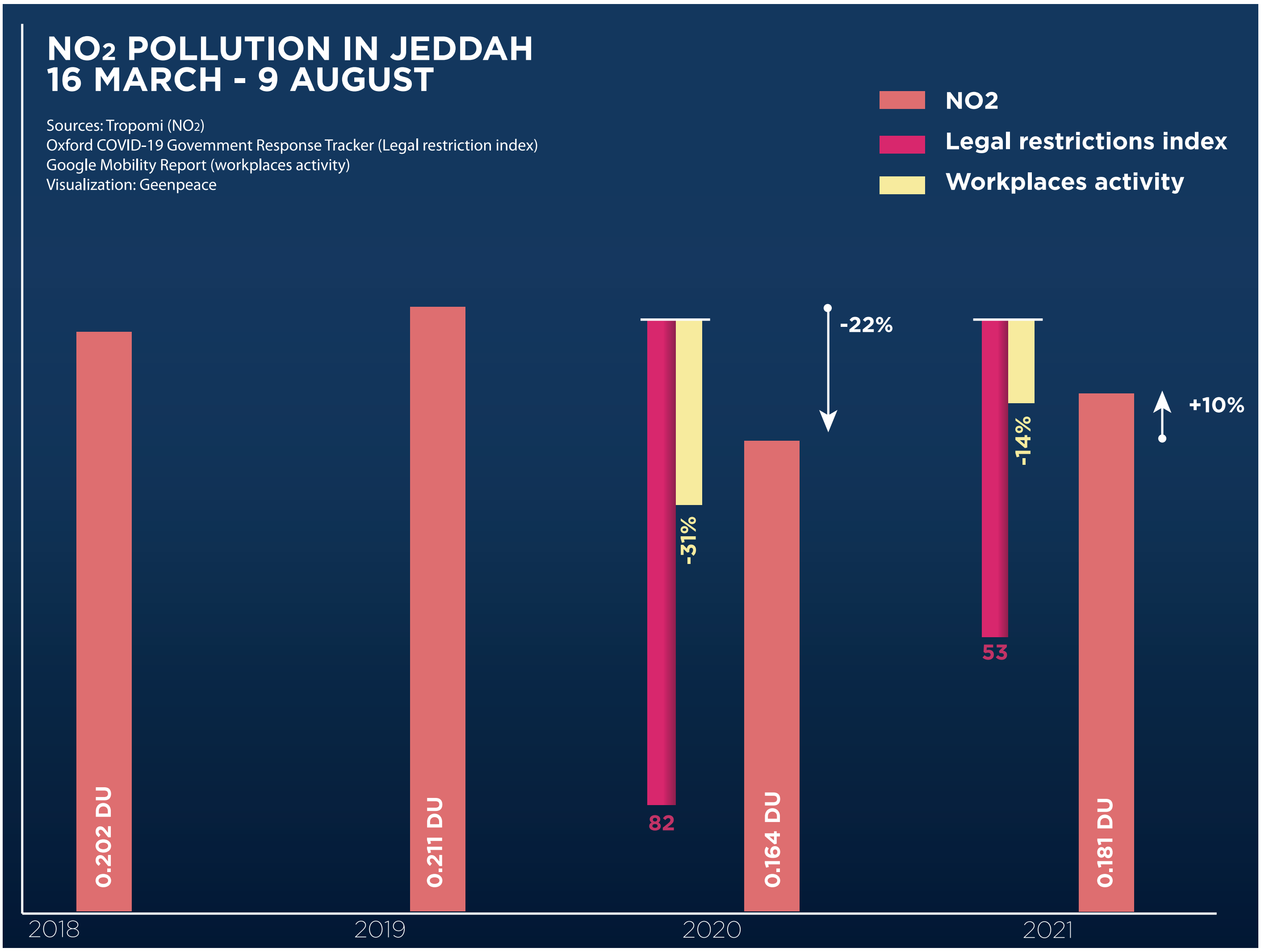

Figure A21. NO_2 atmospheric column amount, government restriction stringency and Google Mobility Report for Jeddah, Saudi Arabia.

United Arab Emirates

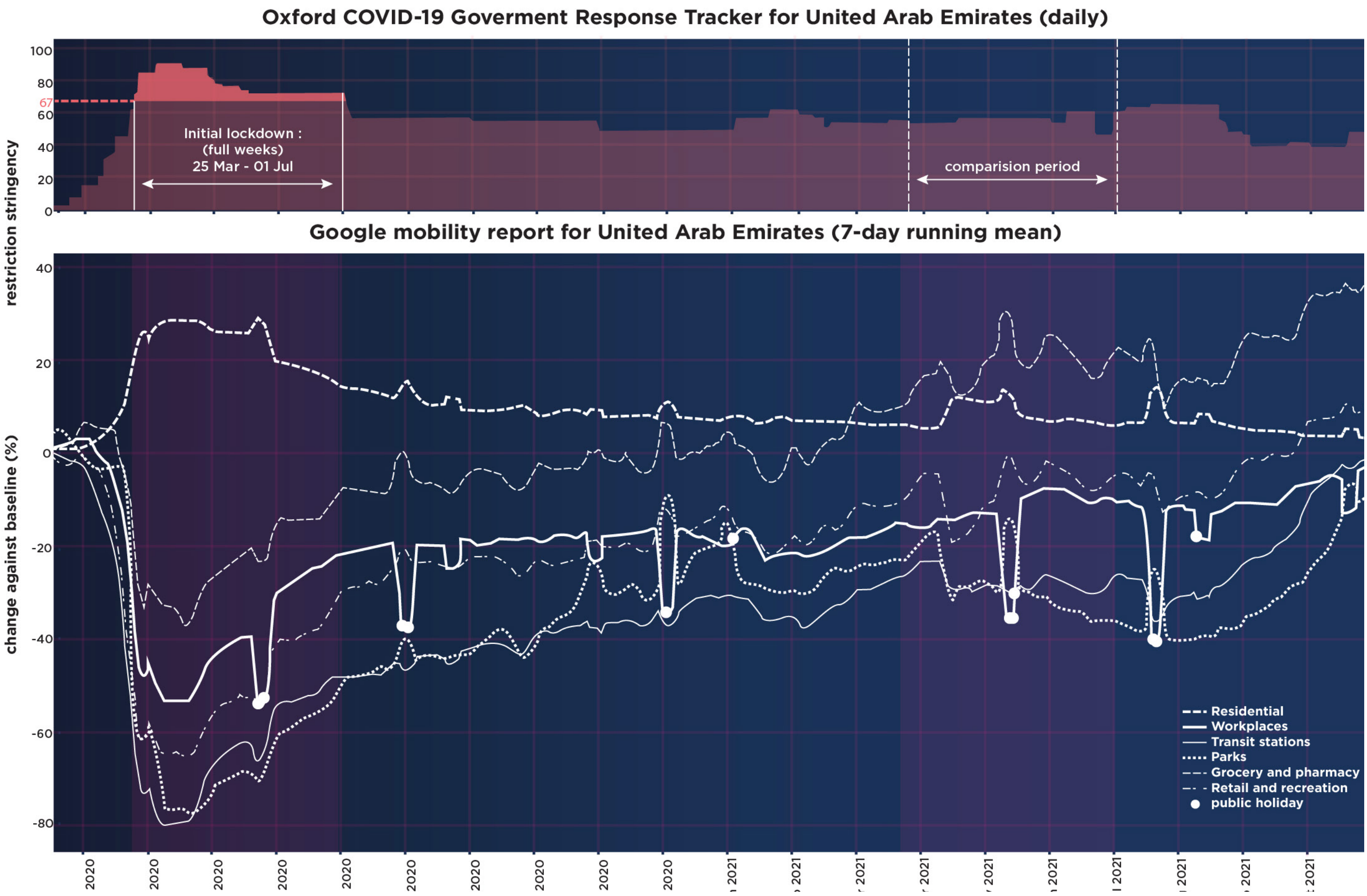

Figure A22. Government restriction stringency (top panel) and Google Mobility Report (bottom panel) for the United Arab Emirates.

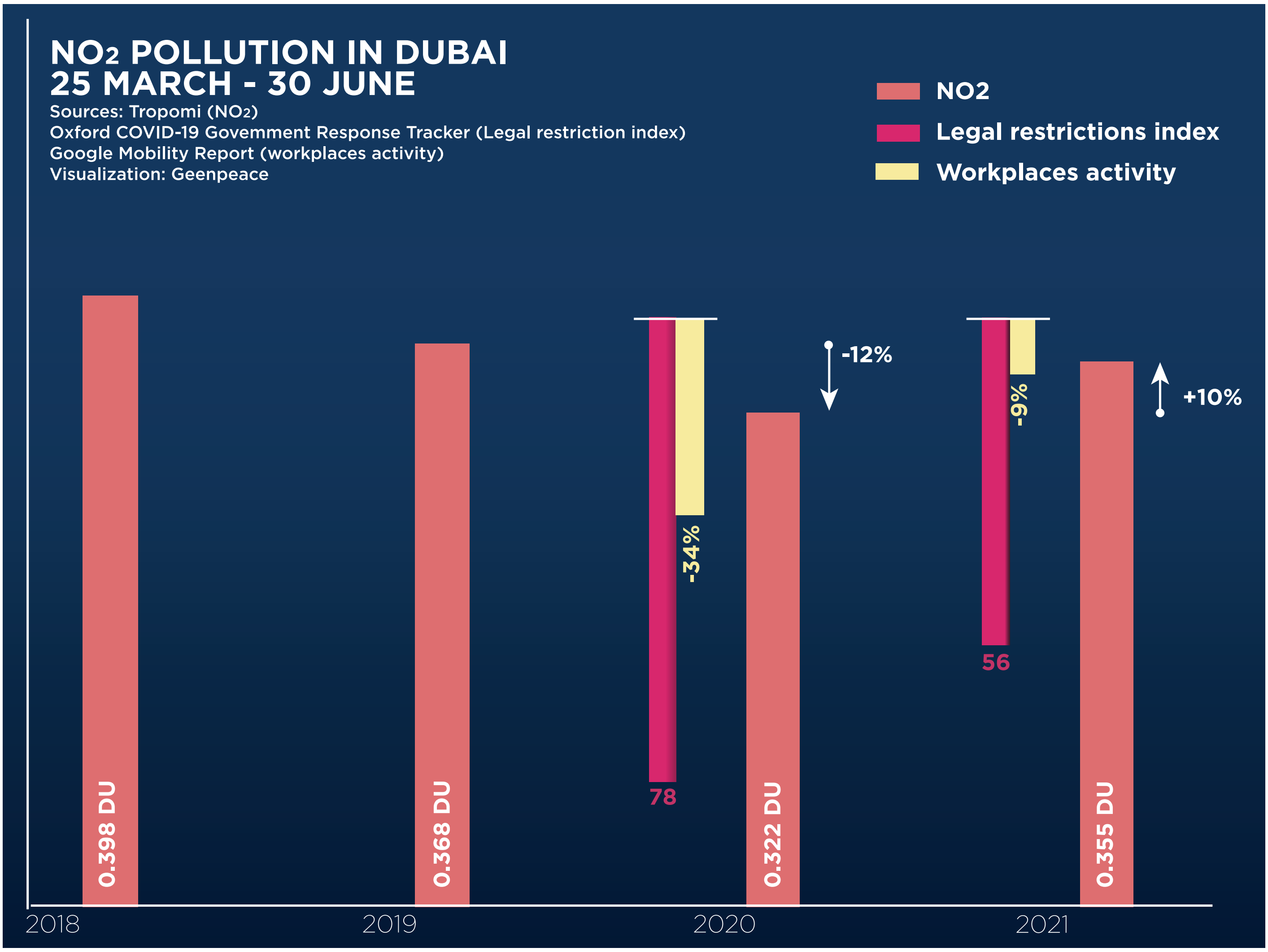

Figure A23. NO_2 atmospheric column amount government restriction stringency and Google Mobility Report for Dubai, United Arab Emirates.


GREENPEACE
غرينبيس