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To cite this article: Dene Bowdalo *et al* 2022 *Environ. Res. Lett.* **17** 021002

ENVIRONMENTAL RESEARCH
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OPEN ACCESS

RECEIVED
19 November 2021

REVISED
16 December 2021

ACCEPTED FOR PUBLICATION
20 December 2021

PUBLISHED
21 January 2022

PERSPECTIVE

Compliance with 2021 WHO air quality guidelines across Europe will require radical measures

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Keywords: air pollution, air quality, air quality legislation, environmental sustainability, environmental health

Supplementary material for this article is available online

1. Introduction

The research into the human health impacts from air pollution has advanced substantially over the last decade; in Europe ∼500 000 premature deaths are attributed annually to air pollution exposure [1], with adverse health effects beginning at much lower concentrations than previously understood [2]. The latest epidemiological evidence is now reflected in the new 2021 World Health Organization (WHO) Air Quality Guidelines (AQGs^{v2021}) [3], which represent a major revision over the previous ones set in 2005 (AQGs^{v2005}) [4]. Ten new AQGs have been set for the major health-damaging air pollutants, across different averaging times (annual$^{(AN)}$, peak season$^{(PS)}$, 24 h$^{(24H)}$, daily maximum 8 h average$^{(8H)}$), namely: particulate matter ($PM_{2.5}^{AN,\,24H}$ and $PM_{10}^{AN,\,24H}$), ozone ($O_3^{PS,\,8H}$), nitrogen dioxide ($NO_2^{AN,\,24H}$), sulphur dioxide (SO_2^{24H}) and carbon monoxide (CO^{24H}). The AQGs^{v2021} are significantly more stringent, except for a relaxation in SO_2^{24H}, and O_3^{8H} staying the same (supplementary table 1 (available online at stacks.iop.org/ERL/17/021002/mmedia)).

This article quantifies the increase in non-compliance across all European measurement stations with AQGs^{v2021} compared with AQGs^{v2005}, during business-as-usual (BAU) conditions (section 2); evaluates the impact that emission reductions during COVID-19 lockdowns had on non-compliance (section 3); and finally discusses the implications of our findings for any new European Union (EU) standards (section 4).

2. Quantification of non-compliance across Europe

Figure 1 compares the extent of non-compliance with AQGs^{v2021} and AQGs^{v2005} across all hourly reporting stations in the European Environmental Agency AQ e-Reporting network [1] between 2017 and 2019 (see methods in supplement; supplementary figure 1 shows station coverage); the period encompasses the most recent BAU conditions before the onset of the COVID-19 pandemic. Non-compliance is defined simply as the percentage of total stations that exceed each AQG. To gauge how far stations are to compliance, the median of the percentage differences with each AQG across all non-compliant stations is also calculated (median relative distance to compliance).

Non-compliance was already substantial with AQGs^{v2005}, being only below 50% for NO_2^{AN} (8%) and SO_2^{24H} (37%). With AQGs^{v2021}, non-compliance steeply increases for all more stringent AQGs, particularly for the AN metrics. NO_2^{AN}, PM_{10}^{AN} and $PM_{2.5}^{AN}$ see dramatic increases both in non-compliance (from 8%, 50% and 77% to 88%, 85% and 98%), and in the median relative distances to compliance (from 16%, 26% and 41% to 120%, 41% and 160%). For the entirely new guidelines, non-compliance is high for O_3^{PS} and NO_2^{24H} (97% and 90%), but very low for CO^{24H} (1%). For the AQGs^{v2021} which were unchanged/relaxed, non-compliance for O_3^{8H} stays high at 93%, and for SO_2^{24H} falls to 16%.

Non-compliance varies across station types, most notably for NO_2 and PM_{10}, from 41%–57% at rural background stations to 77%–99% at all other types.

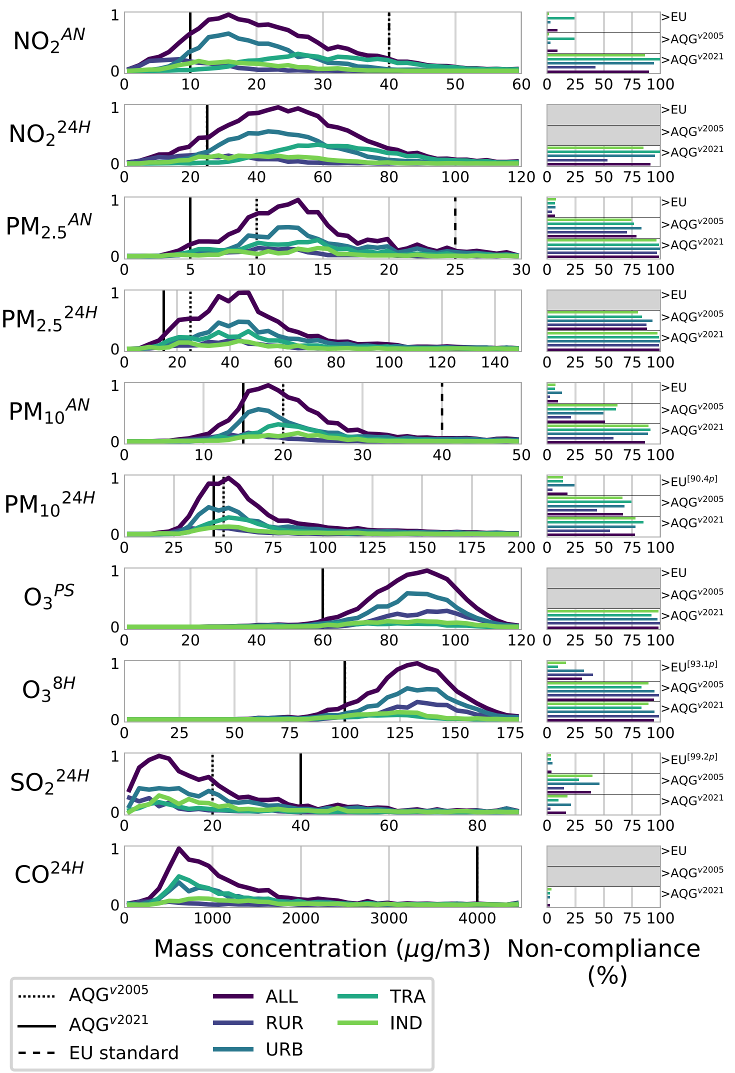

Figure 1. Normalised distribution of calculated AQG metrics, across European stations, during BAU (average of 2017–2019). Distributions are given per station type: ALL = all stations, RUR = rural background, URB = urban background, TRA = traffic, IND = industrial. Bar charts show percentage station non-compliance, per station type, with $AQGs^{v2005}$, $AQGs^{v2021}$ and EU standards.

The massive increase in non-compliance is observed across all countries for NO_2^{AN} (figure 2, rightward arrows). Changes in non-compliance with $PM_{2.5}^{AN}$ and PM_{10}^{AN} are heterogeneous by country, but eastern European countries that heavily use coal for electricity generation and in residential sectors [5] further increase their median relative distances from compliance (>300%).

3. Effect of emission reductions on non-compliance: lessons from COVID-19 lockdowns

Unprecedented emission reductions would clearly be needed to comply with $AQGs^{v2021}$, and some lessons can be extracted from the impact on non-compliance due to COVID-19 lockdowns, when emissions drastically fell [6]. In 2020 (supplementary figures 2 and 3), the strongest reduction in non-compliance concerns $PM_{10}^{AN,\,24H}$ (−18%, −23%), SO_2^{24H} (−13%) and $NO_2^{AN,\,24H}$ (−6%, −5%), while non-compliance changes by less than 1% for all other $AQGs^{v2021}$. The larger improvement for PM_{10} is mainly due to the smaller preexisting median relative distance to compliance (40%–41%) compared to NO_2 (107%–120%). When focusing only on the most stringent 3-month COVID-19 period (15 March–15 June), reductions in non-compliance are much more significant for $NO_2^{AN,\,24H}$ (−23%, −37%), however more than 50% of stations still remain non-compliant (66%, 53%), giving scale to the challenge in meeting NO_2 $AQGs^{v2021}$. There are also more significant reductions for PM_{10}^{24H} and $PM_{2.5}^{24H}$ (−30%, −6%) but for all other $AQGs^{v2021}$ the non-compliance is similar to that for the entirety of 2020.

The EU Directive 2016/2284 sets out emission reduction commitments for 2030, however it is highly unlikely the scale of these reductions will meaningfully help meet $AQGs^{v2021}$, with emission reductions during lockdowns being actually greater or near

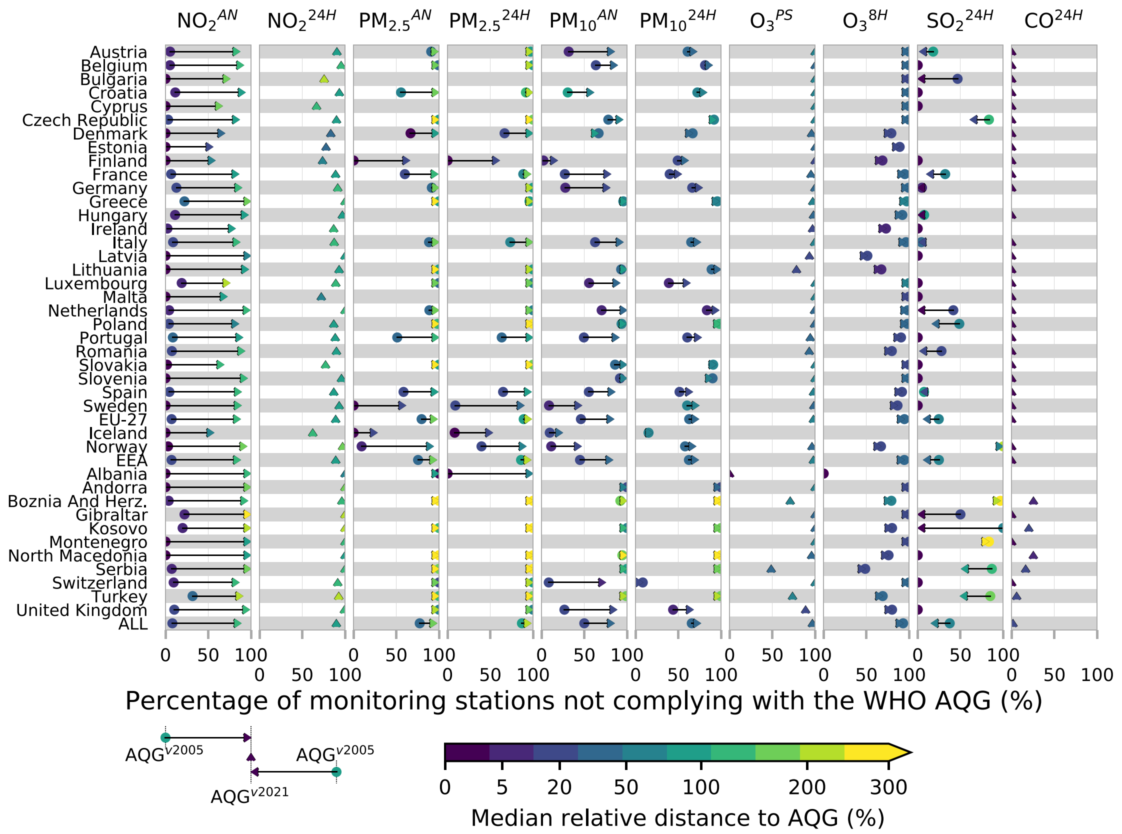

Figure 2. Percentage station non-compliance with AQGs^{v2005} versus AQGs^{v2021}, per European country, during BAU (average of 2017–2019). The change in non-compliance is indicated by the arrow. Colours indicate the median relative distances across non-compliant stations to the respective AQGs. Specific fractions and percentages of station non-compliance are given per country in supplementary tables 2 and 3.

equivalent to the proposed 2030 targets for the majority of pollutants [6]. Profound and radical action will be required. For NO_x, with a contribution of 38% to total emissions in the EU (supplementary figure 4), road traffic will continue to be the targeted sector for reductions. Large cities are trying to reduce the amount of circulating vehicles, but the measures implemented so far have proved to be insufficient to meet even less-stringent EU standards in certain cities [7]. Radical measures such as zero-emissions zones (e.g. as trialled in some London boroughs), or the ban on the sale of fossil fuel vehicles (i.e. EU Directive 2019/1161) would be needed to enact sufficient change. For PM_{10}, which is mainly directly emitted, the relative contribution of pollutant activities to total emissions varies significantly by country, meaning the response to any lockdowns is difficult to unpack, e.g. Italy did not experience any reduction in non-compliance during 2020 with $PM_{10}^{AN,\,24H}$, as the fall in transport emissions is compensated by an increase in residential combustion emissions (supplementary figure 4). $PM_{2.5}$ in urban areas is 70% secondary in origin [8], with a large contribution attributable to regional agricultural NH_3 emissions [9], and urban volatile organic compounds (VOCs) from the use of solvent products [10]. Thus its smaller reduction during 2020 is partly because these emissions were not affected by lockdown restrictions. Efficacious management of O_3 is incredibly challenging due its non-linear secondary formation and its capacity to be transported over long distances. With falling NO_x, VOCs will play an increasingly important role over the coming decades as O_3 production becomes increasingly dependent on VOC availability (as evidenced during COVID-19 lockdowns [11]), however current VOC chemical understanding is relatively embryonic, with observations also lacking. All in all, only a holistic management of VOCs, NO_x, and NH_3, can be expected to reduce the distance to compliance for O_3 and $PM_{2.5}$ AQGs^{v2021}.

4. Implications for new EU standards

Meeting the AQGs^{v2021} is estimated to prevent ∼66% of premature deaths attributed to $PM_{2.5}$ exposure in Europe [12]. These numbers will naturally apply greater pressure on the EU to align with the AQGs^{v2021}. EU standards have consistently lagged decades behind the AQGs, most notably for PM, with current EU standards (Directive 2008/50/EC) for $PM_{2.5}^{AN}$ and PM_{10}^{AN} being 2.5/2 times the AQGs^{v2005} and 5/2.7 times the AQGs^{v2021}, respectively (supplementary table 1). Despite this, countries still are frequently exceeding limits. For even more ambitious standards to be effective, they should be accompanied by strong supporting measures so that the transition does not leave anyone behind. This is particularly important for countries with lower income, which are typically exposed to higher pollution levels but depend on polluting energy sources, or those disproportionately affected by natural emission sources (e.g. deserts) [13]. Although a radical decrease in emissions implies substantial abatement costs, it has been demonstrated that the net economic benefit (e.g. through increased labour productivity) would be many magnitudes higher [14]. Some air pollutants are also short-term climate forcers (e.g. black carbon) and a number of win-win mitigation policies can improve both air quality and mitigate climate change at a potentially lower cost of intervention [15]. The legislative proposal for the revision of the EU's standards is scheduled at the tail-end of 2022, and all of these factors need to be carefully considered by the EU before any new standards are set.

The value of clean air has never been so keenly felt from both a health and climate perspective. As the global population begins to emerge from being house-bound during the COVID-19 pandemic, countries across Europe will need to employ radical measures if they wish to protect their citizens from unnecessary harm.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: 10.5281/zenodo.5591885.

Acknowledgments

This research has received funding from the Agencia Estatal de Investigacion (AEI) (MITIGATE, PID2020-116324RA-I00/AEI/10.13039/501100011033), European Research Council (#773051, FRAGMENT), and the AXA Research Fund. We also acknowledge Red Temática ACTRIS España (CGL2017-90884-REDT), H2020 ACTRIS IMP (#871115), and PRACE and RES for awarding access to Marenostrum4 Supercomputer based at the Barcelona Supercomputing Center.

Conflict of interest

The authors declare that there are no conflicts of interest.

Author contributions statement

C P G-P conceived the idea for publication, D B drafted the manuscript, D B processed the observations, H P calculated the statistics and created the figures. All authors reviewed the manuscript.

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