Public Health Impacts of Industrial Decarbonization

by

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Introduction

Decarbonizing the industrial sector presents formidable challenges. The bulk of greenhouse gas (GHG) emissions from industrial production is carbon dioxide (CO_2), which is released not only when burning fossil fuels for heat and power generation but also by specific production processes (e.g. cement clinker or ammonia). Moreover, CO_2 is not the only GHG emanating from industrial production. Other GHGs such as methane, nitrous oxides, HFCs, PFCs, SF_6 and NF_3 all derive from industrial activities. As a consequence, decarbonizing industry is expected to be very costly.

However, curbing industrial GHG emissions is likely to generate ample co-benefits in terms of human health. On the one hand, this is because CO_2 is jointly emitted with numerous air pollutants that either cause health damages directly or are precursors to ozone and fine dust ($PM_{2.5}$) which have dangerous health consequences. On the other hand, some of the above mentioned GHG emissions are known to have detrimental health effects at local and regional scales, in addition to aggravating climate change at the global scale. Therefore, reducing industrial GHG emissions and related co-emissions will likely improve air quality and hence public health.

The goal of this paper is to quantify such public health benefits of decarbonization scenarios for selected industries, and attribute contributions of the various pollutant species to those overall health benefits.

Data

Our analysis is based on a novel dataset linking air pollution emissions from the European Pollutant Release and Transfer Register (E-PRTR)[1] and GHG emissions from the European Union Transaction Log (EUTL) which we built in de Preux, Kassem and Wagner (2022). This unique dataset comprises 6,000 stationary emitters located in more than 30 European countries all of which are regulated under the European Union Emissions Trading Scheme (EU ETS). Mandatory emissions reporting comprises up to 50 different air pollutants at any given facility,

[1] See https://ec.europa.eu/environment/industry/stationary/e-prtr/legislation.htm

subject to reporting thresholds. Focusing on ETS-regulated facilities allows us to work with more precise CO_2 emissions data than are available from E-PRTR, where the reporting threshold for CO_2 is high. This dataset contains information on annual emissions of CO_2, other GHGs and more than 90 co-pollutants overall. We use this to compute two key ingredients for our analysis; (i) GHG emissions in a base year (2015) and (ii) specific pollution intensities for each pollutant and each installation, expressed as mass of co-pollutant emitted per ton of CO_2 equivalent. By way of illustration, Tables 1-3 report emissions of CO_2 and other GHGs (in kg) as well as the main precursors to $PM_{2.5}$ pollution in the cement, fertilizer and metal industries in 2015.

Decarbonization and co-emissions

We consider decarbonization scenarios for specific industries that are intensive in GHG emissions, including, but not limited to, the industrial production of steel, cement, and fertilizers. A naive decarbonization scenario maps a percentage reduction in CO_2 emissions for an industrial installation of a given type into the corresponding reduction in co-pollution which is governed by the installation-specific pollution intensities. This is isomorphic to a reduction in the economic activity level, multiplied by the average pollution intensity per unit of output or per ton of CO_2.

More sophisticated decarbonization scenarios take into consideration the specific technical decarbonization options that currently are -or may soon become- commercially viable in a given industry. A straightforward example in steel production is to replace a blast furnace by an electric arc furnace powered by renewable electricity, which is expected to reduce CO_2 emissions and fossil-fuel related co-pollutants on site. In the fertilizer industry, different decarbonization scenarios will have very different implications for co-pollutant emissions, depending on whether grey hydrogen is replaced by blue hydrogen (where the CO_2 from cracking and energy feedstocks is captured and stored, but co-pollution is released) or green hydrogen (where no pollutants are being released). In the context of such scenarios, it is imperative to control for possible differences between marginal and average co-pollution intensities in order to obtain reliable estimates of co-pollution emissions. We use panel data on pollution intensities to explore such non-linearities.

Atmospheric dispersion, population exposure, and public health impacts

A well-known challenge with quantifying the health co-benefits of decarbonization policies derives from the fact that the place of emission is not necessarily equal to the place of impact. Topography, weather, and pre-existing air pollution suspended in the local atmosphere all influence in major ways how the emissions of primary pollutant species, once released from the smokestack, translate into ambient concentrations of secondary pollutants such as ozone and $PM_{2.5}$. To gauge the impact of industrial decarbonization scenarios on human exposure to air pollution, it is necessary but not sufficient to know the location of polluters (geo-coded industrial sites in our dataset) and the polluted (highly population density on a 1km-by-1km grid for Europe). A chemical transport model is needed to quantify how changes in point-source emissions map to ambient pollution concentrations on a grid, taking due account of the highly non-linear atmospheric transport and chemical conversion processes that govern this mapping.

We compute ambient concentrations using a nested GEOS-Chem Adjoint model that was recently developed for the European domain (Gu et al., 2022). The model is calibrated to 2015 weather and emissions data. Based on primary pollution emissions of, among others, NO_x, SO_2, and NH_3 it generates exposure to secondary $PM_{2.5}$ on a grid (0.25° × 0.3125°) for the European domain.

Moreover, thanks to adjoint modeling, this model allows for source appointment of secondary $PM_{2.5}$ health effects at no additional computational cost.[2] Source appointment is crucial for the counterfactual policy analyses we propose because it provides a direct mapping from local changes in emissions to public health, summarized in a single but highly policy relevant metric: the total number of pre-mature deaths associated with the prevailing $PM_{2.5}$ concentration levels in each grid cell. This is defined as the total number of $PM_{2.5}$-related premature deaths in all the European countries listed in the Global Health Data Exchange[3] and for health outcomes[4] that can be affected by $PM_{2.5}$ pollution suggested by the Global Burden of Disease Study (GBD) 2019 (Murray et al., 2020). Figure 1 displays the geographic distribution of premature mortality predicted by the model at baseline.

Our analysis will proceed in two steps: First, the effects of different decarbonization scenarios on total premature mortality due to fine dust will be evaluated using the computationally inexpensive source attribution provided by the adjoint model. Second, for a selected counterfactual scenario of point-source emissions one full model run will be performed in order to analyze the geographic distribution of the health impacts on the grid (as in Figure 1).

Policy relevance

This work is highly relevant for policy makers weighing the costs and benefits of industrial decarbonization. Decarbonizing the production of steel or ammonia will have major implications for the economic geography of global value chains, shifting the competitive advantage to regions where carbon-free energy is inexpensive and thus threatening to move parts of the downstream value chain in the same direction, away from their historical locations. Against this backdrop, policy makers have begun to implement decarbonization policies as industrial policy, with an explicit objective to prevent such industries from moving overseas (cf. the Inflation Reduction Act). By providing first estimates of the co-benefits of industrial decarbonization, grounded in detailed establishment data and sophisticated atmospheric modeling, our study helps policy makers to compare the net benefits of such policies with those of alternative policy options.

[2] Without adjoint modeling, this would require a full model run for each decarbonization scenario, which takes about ten weeks.
[3] https://ghdx.healthdata.org/
[4] Chronic obstructive pulmonary disease, ischemic heart disease, lung cancer, type-2 diabetes, and stroke.

References

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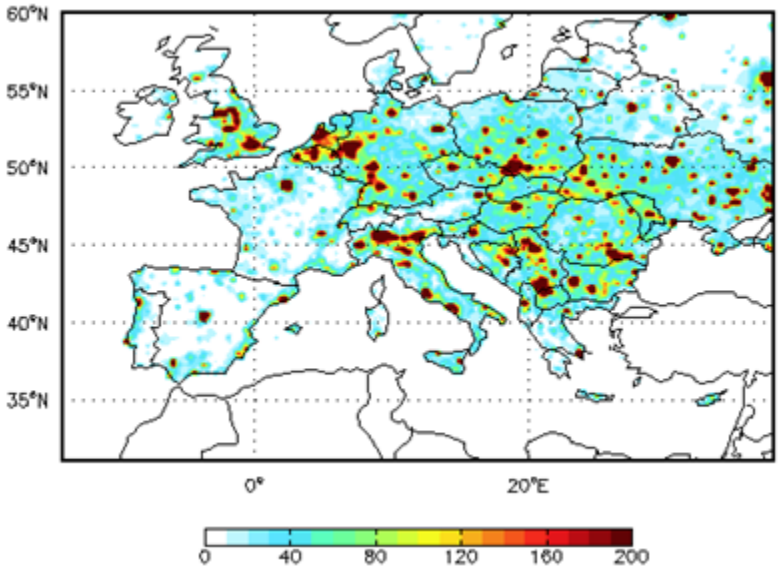
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Conflict of Interest

The authors state that they have no ties to the energy industry nor to any of the industries that might be impacted by industrial decarbonization.

Tables and Figures

Figure 1: Premature deaths due to PM2.5 in 2015



Source: Gu et al. (2022).

Table 1: Cement Industry in 2015 (Facility level, in kg)

Variables	Facilities	Mean	Std. dev.	Min	Max
GHGs					
CO_2	322	438,501.60	362,040.70	96.00	2,040,000.00
CH_4	3	335.00	348.19	128.00	737.00
N_2O	16	18.69	4.14	11.30	29.20
HFCS	1	0.31	0.00	0.31	0.31
Co-Pollutants					
NO_x	234	796.91	681.65	108.00	5,690.00
SO_x	70	462.14	323.05	150.00	1,800.00
PM_{10}	20	98.61	51.25	51.90	239.00
CO	137	2,675.85	3,427.47	515.00	29,300.00

Table 2: Fertilizer Industry in 2015 (Facility level, in kg)

Variables	Facilities	Mean	Std. dev.	Min	Max
GHGs					
CO_2	26	635,959.30	866,733.50	784.00	3,550,000.00
CH_4	3	1,865.67	1,557.88	347.00	3,460.00
N_2O	25	319.03	342.92	11.30	1,070.00
Co-Pollutants					
NO_x	22	687.82	899.14	112.00	3,610.00
SO_x	6	806.50	556.69	190.00	1,660.00
PM_{10}	10	259.59	204.75	58.40	610.00
CO	2	1,410.00	268.70	1,220.00	1,600.00

Table 3: Metal Industry in 2015 (Facility level, in kg)

Variables	Facilities	Mean	Std. dev.	Min	Max
GHGs					
CO_2	301	556,581.10	1,590,094.00	116.00	11,400,000.00
CH_4	11	428.36	263.07	121.00	868.00
SF_6	2	0.14	0.10	0.07	0.21
N_2O	11	98.53	106.41	11.60	361.00
HFCS	38	0.67	0.83	0.12	4.00
Co-Pollutants					
NO_x	120	965.24	1,652.80	101.00	6,650.00
SO_x	52	2,226.85	2,568.31	164.00	9,710.00
PM_{10}	41	500.95	622.11	51.30	2,810.00
CO	80	26,560.89	44,533.57	508.00	178,000.00