Public Health Co-benefits of Decarbonizing Industrial Production in Europe

Laure de Preux\textsuperscript{1}  Yixuan Gu\textsuperscript{2}  Daven K. Henze\textsuperscript{3}  Ulrich J. Wagner\textsuperscript{2}

\textsuperscript{1}Imperial College London
\textsuperscript{2}University of Mannheim
\textsuperscript{3}University of Colorado Boulder

The Economics of Decarbonizing Industrial Production: NBER Conference
December 8, 2023
STILL PRELIMINARY

HEAL Project
Industrial GHG Emissions and Co-pollution

- 12 Gt of CO$_2$-equivalent annually emitted worldwide (20%)

- Public Health Benefits of Decarbonizing Industry:
  - Direct benefits of climate change mitigation
  - Health co-benefits of reducing air pollution due to
    - co-pollutants jointly emitted with CO$_2$ from fossil fuel use
    - co-pollutants of CO$_2$ process emissions
    - non-CO$_2$ GHGs (CH$_4$, N$_2$O, HFCs, PFCs, SF$_6$ and NF$_3$)

- Goal of this paper is to **quantify**
  - health benefits of reduced PM$_{2.5}$ pollution due to industrial decarbonization (past and future)
  - contributions of different industries and pollutant species
  - distributional impacts

- Local nature of co-benefits provides a rationale for targeted subsidies to carbon intensive industries. How much? And where?
We focus on industrial activities regulated in the EU Emissions Trading Scheme (EU ETS)

Health co-benefits depend on
1. co-pollution intensity
2. location
3. atmospheric dispersion
4. population density

Figure: EU ETS Facilities and Population Density
Methods and Data
Research Design: Micro-founded Integrated Assessment

Summary:

1. Decarbonization Scenario

2. Facility-level Emissions of Air Pollutants: Location, Scale, Mix

3. Atmospheric Pollution Dispersion and Population Exposure

4. Public Health Burden in terms of Mortality Impacts
Steps 3 & 4: New Chemical Transport Model for Europe

- Nested GEOS-Chem adjoint model (Gu et al., 2023)

- Model input:
  Primary pollutants NO\textsubscript{x}, SO\textsubscript{2}, NH\textsubscript{3}, OC, BC, SOAP

- Model outputs
  - Population exposure to PM\textsubscript{2.5} on a 0.25°×0.3125°-grid
  - PM\textsubscript{2.5} related premature deaths using dose-response from Global Burden of Disease Study 2019 (Murray et al., 2020):

\[
J_{PM_{2.5}} = \sum_{L} \sum_{A} \sum_{k \in D} \sum_{(I,J) \in k} (POP_{I,J,A} \times MOR_{I,J,A,L} \times AF_{I,J,A,L})
\]

where \(AF_{I,J,A,L} = \frac{RR_{I,J,A,L} - 1}{RR_{I,J,A,L}}\) and \(L \in \{\text{COPD, IHD, LRI, LC, T2D, stroke}\}\)

- Source appointment (adjoint):
  Compute sensitivity of premature deaths to specific pollution source without additional computational costs
PM$_{2.5}$ exposure, population, and health burden in Europe

Source: Gu et al. (2023a)

- 449,813 PM$_{2.5}$-related premature deaths in 2015 (relative to total pop. 598.97m)
- 59% due to anthropogenic NO$_x$, NH$_3$, SO$_2$, OC, BC, SOAP
- Between 2005-15, reduced industrial emissions avoided 4,000 premature deaths to industrial emissions
Step 2: Microdata on Emissions of CO$_2$ and Air Pollutants

1. European Union Transaction Log (EUTL)
   - Register of all ETS installations
   - Verified emissions and permit allocations

2. European Pollutant Release and Transfer Register (E-PRTR)
   - Pollutant releases to air, water and land
   - 91 Pollutants, between 1 and 50 per facility (s.t. reporting thresholds)

Entity linked across data (De Preux, Kassem and Wagner, 2023)

- >8,000 EUTL installations (48.7 percent) matched to EPRTR facilities
- Matched installations account for 95.5 percent of EU ETS emissions
- Annual data from 2007-17
Step 1: Decarbonization Scenarios

1. Recent trends in CO₂ and co-pollution emissions 2008-2015
2. Naive decarbonization by 80%
3. Cost-effective (at current ETS prices) decarbonization of Portland cement
Recent Trends in Industrial Emissions
Emissions reductions under the cap were mostly driven by combustion activities (main part of ‘other’)

Note: Combustion activities includes many industrial boilers
Three largest industries have reduced emissions by about 15%

In line with causal effect of ETS price on energy related emissions (Colmer, Martin, Muuls, Wagner, 2023)

Note: Increased emissions from bulk chemicals, ammonia due to 2013 ETS changes
Cement and refining reduced NO$_x$ and SO$_x$ emissions by almost 40%, respectively

Not entirely driven by decarbonization
Changes in Carbon Emissions, 2008-15 (log scale, balanced sample)
Changes in PM$_{2.5}$ precursor emissions, 2008-15 (logs, balanced)

(a) Carbon emissions

(b) Cement

(c) Iron & Steel

(d) Refining
Health Impacts of Decarbonization Scenarios
Scenario 1: Avoided mortality due to recent emissions reductions

Associated PM$_{2.5}$ related premature deaths 2008-15

<table>
<thead>
<tr>
<th>Industry</th>
<th>Level in 2008</th>
<th>Change 2008 to 2015</th>
<th>Imputed Change 2008-15 w/ pollution intensity from median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>2,205</td>
<td>-738</td>
<td>-347</td>
</tr>
<tr>
<td>Steel</td>
<td>946</td>
<td>-237</td>
<td>-264</td>
</tr>
<tr>
<td>Refining</td>
<td>1,889</td>
<td>-741</td>
<td>-198</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5,040</td>
<td>-1,715</td>
<td>-696</td>
</tr>
</tbody>
</table>

- Significant health effects. Cement is most harmful industry
- Imputation: Scales co-emissions in proportion to observed carbon abatement
  ⇒ Observed mortality reductions in mortality only partially due to decarbonization
Decomposing Change in PM$_{2.5}$ related premature deaths, 2008-15

<table>
<thead>
<tr>
<th>Industry</th>
<th>Level in 2008</th>
<th>Change 2008-15</th>
<th>Decarbonization Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>observed</td>
<td>imputed (2008)</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>2,205</td>
<td>-33%</td>
<td>-17%</td>
</tr>
<tr>
<td>Steel</td>
<td>946</td>
<td>-25%</td>
<td>-17%</td>
</tr>
<tr>
<td>Refining</td>
<td>1,889</td>
<td>-39%</td>
<td>-11%</td>
</tr>
<tr>
<td>Total</td>
<td>5,040</td>
<td>-34%</td>
<td>-15%</td>
</tr>
</tbody>
</table>

- Largest decarbonization contribution from steel where health impact is smallest.
- Largest health benefit in refining where the contribution of decarbonization is smallest.
- Next: Use 2015 pollution intensities to abstract from such other impacts.
Scenario 2: 80% Reduction in Emissions and Co-emissions

▶ Naive approach: Scale co-emissions in proportion to large decarbonization.
▶ Useful to gauge potential magnitude of health benefits different industries

▶ Likely consistent with:
  ▶ output change
  ▶ (large) energy efficiency improvements
  ▶ electrification or
  ▶ hydrogen-based production

▶ Not necessarily consistent with:
  ▶ Carbon Capture and Storage
  ▶ fuel substitution,
  ▶ major process innovations
80% Decarbonization: Avoided Premature Deaths due to PM$_{2.5}$

<table>
<thead>
<tr>
<th>Industry</th>
<th>NOX (Deaths)</th>
<th>SOX (Deaths)</th>
<th>NH$_3$ (Deaths)</th>
<th>Total (Deaths)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>1,000</td>
<td>300</td>
<td>20</td>
<td>1,520</td>
</tr>
<tr>
<td>Steel</td>
<td>500</td>
<td>100</td>
<td>10</td>
<td>610</td>
</tr>
<tr>
<td>Refinery</td>
<td>1,500</td>
<td>450</td>
<td>30</td>
<td>2,080</td>
</tr>
<tr>
<td>Total</td>
<td>3,000</td>
<td>1,050</td>
<td>60</td>
<td>4,110</td>
</tr>
</tbody>
</table>

Avoided Deaths per kilo ton:
- NH$_3$: 20.3
- NOX: 4.9
- SOX: 2.5

Emissions-weighted average of marginal impacts across industries.
80% Decarbonization: Avoided Premature Deaths due to PM$_{2.5}$

Avoided Deaths per kiloton:
- NH$_3$: 20.3
- NO$_x$: 4.9
- SO$_x$: 2.5

Emissions-weighted average of marginal impacts across industries

Associated deaths with an 80% reduction in emissions in 2015
Marginal Mortality Impacts of Pollutants by Industry

Between 2008 and 2015 (95% CI)
Marginal Health Impacts per Mt of CO$_2$e by Source Country

Emissions from cement, steel and refining in 2015. Vertical lines are means.
Scenario 3: Decarbonizing Cement Production

Levers for decarbonizing Portland Cement that are profitable at 80 Euros per tCO2e or less: (Glenk et al., 2023)

1. Reducing Clinker to Cement ratio:
   ▶ optimized grinding of cement
   ▶ addition of new supplementary cementitious materials (SCMs) and of recycled cement
   ▶ Air quality (AQ) impact is positive (lower fossil fuel use)

2. Fuel Switching:
   ▶ Biomass: AQ impact depends on specific fuel and pollution control equipment
   ▶ Waste: AQ impact depends on alternative disposal (incineration vs. land fill)

3. Carbon Capture and Storage with LEILAC.
   ▶ We disregard LEILAC and other CCS technologies (likely no AQ benefit).
Cost-effective Decarbonization of Portland Cement Production

Compute pollution reduction factor following Fenell et al. (2021, *Joule*)

\[
\frac{CO_2}{CO_2_{base}} = \frac{Clinker}{Clinker_{base}} (1 - \text{Digitization})(1 - \text{EnEff})(1 - \text{Hydrogen})(1 - \text{AltFuel}) \tag{1}
\]

We follow their assumptions and assume:

- Lower clinker requirement: from 0.7 to 0.6 (low) or 0.5 (high)
- Digitization improves efficiency by 10%
- Energy efficiency improvements of 5%
- Hydrogen share = 0
- Alternative fuel share: low 10%, high 50%

Back-of-Envelope Calculation

- Reduction in fuel based emissions reduction by 33% (low) or 69% (high)
- Avoided premature deaths from cement production 547 (low) or 1,145 (high) p.a.
- Monetized benefits (VSL at €2.7 m) of €1.5 bn and €3.1 bn
Conclusion and Outlook

- Industrial decarbonization offers sizable PM$_{2.5}$ related health co-benefits in Europe
- Magnitude depends on which industries decarbonize, and where
- Cement & clinker production is a prime candidate, given size, pollution intensity, and economics of readily available decarbonization levers
- Analysis *still preliminary*
- Distributional analysis of health burden is feasible but computationally expensive.
Thank You!