OXFORD ECONOMICS

NATIONAL ASSOCIATION OF Manufacturers

U.S. AIR QUALITY STANDARDS AND THE MANUFACTURING SECTOR

A REPORT FOR THE NATIONAL ASSOCIATION OF MANUFACTURERS

APRIL 2023

SeventyFour/Shutterstock.com

TABLE OF CONTENTS

Executive summary	4
1. Introduction	10
1.1 The purpose of this report	10
1.2 Introducing fine particulate matter pollution	11
1.3 The structure of this report	11
2. Manufacturing's economic exposure to PM2.5 air quality Standard changes	16
2.1 Introducing PM2.5 air quality standards	16
2.2 Abating emissions	22
3. Environmental impact of U.S. vs. global manufacturing	24
3.1 Theory and previous research	24
3.2 Estimated environmental implications	26
Appendix 1 – Detailed results	32
Appendix 2 – Detailed methodology	34

EXECUTIVE SUMMARY

For more than half a century, the United States has set and enforced standards for air quality to protect the general public from the potentially harmful effects of air pollution. Today, these standards take the form of the National Ambient Air Quality Standards (NAAQS), which are a range of concentrations of specific pollutants in the ambient environment set by the Environmental Protection Agency (EPA), above which levels are considered to pose a risk to human health. As time has gone by, these standards have been changed, and more stringent regulations have been adopted. The EPA has recently proposed further tightening of air quality standards relating to PM2.5.[1]

Air pollution has many sources including electricity generation, motor vehicles, manufacturing, agriculture, natural sources, international sources and more. Industrial activity represents one of many sources and is a large contributor in some of the major industrial districts that will be affected by tighter air quality standards. Historically, the emissions of industrial sectors have significantly decreased over time because of increased manufacturing efficiency, new clean technologies, and the contraction of some heavily polluting sectors.[2] It is anticipated that the manufacturing industry will face increased pressure to do its part in further reducing emissions and will therefore be increasingly impacted by any future tightening of air quality standards.

Tougher air quality standards will therefore have an impact on manufacturers within areas that are subject to stricter thresholds. There are various potential implications of this, depending on the extent of this pressure and the nature of manufacturers' operations. One is that they must further invest in new technologies to reduce, or abate, the emissions associated with their operations. In other cases, this may not be technologically, practically, or economically viable, meaning that companies may have to downsize, relocate, or shut down their operations to comply with tightening emissions standards. Any downsizing, relocation, or shutdown of manufacturers' operations would have related implications for future business investment, workers. and the communities they operate in, as well as the suppliers and customers that rely on their operations. Existing literature has found that environmental regulations impose costs on manufacturers and that these costs are reflected in manufacturers' decisions on investment and plant location. In particular, there is evidence of companies being less likely to open new facilities in areas with stricter regulations and investing less in facilities in such areas.[3]

U.S. manufacturing industries are often environmentally cleaner than the global average. Understanding this relationship is key to developing a full appreciation of the sector's environmental impact. If environmental regulations cause U.S. manufacturing output to contract, this will lead to a greater reliance on importing products manufactured overseas. This could have the unintended effect of increasing air pollution and greenhouse gas (GHG) emissions globally.

[1] On January 6th, 2023, the EPA announced its proposed decision to revise this standard from the current 12 µg/m3 level to a level within the range of 9 to 10 µg/m3. We note, however, that the EPA's proposal solicits comments on a range of potential standards, the lowest of which is the 8 µg/m3 limit called for by some environmental groups. See EPA, *Proposed Decision for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter (PM)*, 2023.

[2] See *EPA National Emissions Inventories*.

[3] Gray, W. B., *Environmental regulations and business decisions*, 2015. IZA World of Labor 2015: 187. Gray, W.B. and Shadbegian, R.J., *Environmental Regulation, Investment Timing, and Technology Choice*, 1998. The Journal of Industrial Economics Vol. 46, No. 2.

THE MANUFACTURING SECTOR'S ECONOMIC EXPOSURE FROM A NEW PM2.5 AIR QUALITY STANDARD

Manufacturers are likely to be a significant focus of policies to reduce emissions of pollutants in the U.S., with the stringency of air quality standards likely to be a key factor in determining the strength of this focus.[4] Quantifying these impacts in terms of changes to technical standards or tonnes of emissions often makes them seem abstract, doing little to illuminate the scale to which industries could be exposed given they are not as familiar as headline economic statistics. As such, looking at the scale of reductions required to meet a new PM2.5 standard by sector and state, **we translate this into an economic metric of manufacturing's "economic exposure"**—the portion of manufacturing that could potentially be impacted by changes required to meet the more stringent standard.[5] This is not a projection of the economic cost of air quality standard changes because, along with the potential for manufacturers to shrink or close their operations, we expect there to be alternative options such as investing in technologies to abate these emissions. Instead, this demonstrates the scale and distribution of the manufacturing activity that will need to adapt in some way to changes to PM2.5 standards.

The scale of economic exposure of the manufacturing sector to different levels of the primary PM2.5 standard is analysed at the current three-year annual average of 12 µg/m3 level (micrograms per cubic meter air) and at the lower 8 µg/m3 threshold. Taking the structure and value of U.S. manufacturing in 2021 to illustrate the scale of the reach of this standard, **we estimate that the 8 µg/m3 air quality standard would create an economic exposure of $87.4 billion annual contribution to GDP (or 2.4% of manufacturing) and 311,600 manufacturing jobs (1.9%).**

California is the state whose manufacturing industry is most exposed, with several counties already exceeding the 12 µg/m3 standards and therefore requiring significant improvements in air quality to meet any stricter standards. As such, the manufacturing activity in California exposed to a possible 8 µg/m3 air quality standard has a GVA of $31.6 billion (6.2% of the total manufacturing GVA in the state) and is associated with 119,000 jobs (7.1% of manufacturing jobs in California). The states of Michigan and Illinois are also expected to be significantly exposed in relative terms. 5.9% ($7.3 billion) and 4.9% ($6.7 billion) of their manufacturing sectors (in GVA terms), respectively, are exposed to a possible 8 µg/m3 limit. The large size of the manufacturing sector in Texas also means that its 2.8% exposure represents a large exposure in absolute value terms, with this exposure totalling $15.6 billion in GVA terms and being associated with 29,000 jobs.

This economic exposure is highly concentrated in a small number of industrial centers. Ten counties across the entire country account for 53% of the total national economic exposure to a possible 8 µg/m^3 limit, despite these counties accounting for only 9% of the U.S. population and 10% of its economy. This economic exposure is estimated to cover an average of 20% of the manufacturing industry in these counties. The potential economic consequences associated with more stringent PM2.5 standards are therefore highly concentrated in a small number of locations.

[4] Our analysis defines the manufacturing sector according to a definition provided by the NAM. This definition includes traditional manufacturing (NAICS codes 31-33) and key manufacturing supply chain inputs including forestry and logging (NAICS code 113), extractive industries (NAICS code 211, 212 and 213), and other stationary industrial sources, namely heavy construction (NAICS code 237), rail and pipeline transportation (NAICS codes 482 and 486), warehousing and storage (NAICS code 493), and waste management and remediation (NAICS code 562).

[5] Our analysis implicitly assumes that only manufacturing activity in counties in which the EPA currently monitors air quality will be affected by tightened standards. Around one-third of all counties in the U.S. are monitored, and more than 80% of the U.S.'s population lives in a monitored county. This reflects the fact that the EPA tends to place monitors of areas "of relatively high population and/or areas believed to have relatively higher pollutant concentrations", meaning that there is unlikely to be significant additional economic exposure in counties that are not currently monitored.

In particular, **most of the economic exposure is concentrated in major centers of industry and population** because of the large amount of industrial activity, traffic and other causes of emissions in these areas. **While some industries may avoid economic exposure by moving their activities away from these locations, for other manufacturers this is likely to be more difficult**, with industrial clusters offering benefits for their operations. In either case, **the proposed standards give a clear incentive for companies to organize their operations in a way that does not result in clustering around populations centers**, despite the added benefits that come from this clustering as industries can operate more efficiently.

In addition to its own activity, the **exposed parts of the manufacturing sector will support GDP and jobs in the wider economy** through their **supply chain spending** (which we refer to as the sector's 'indirect' economic exposure). We analyse this using input-output modelling. There is uncertainty inherent in this estimation because these suppliers might already be directly affected by the more stringent PM2.5 standard, meaning that we derive a **range of estimates** for the indirect economic exposure. We estimate that the part of the US manufacturing sector that is exposed to an 8 $\mu g/m^3$ standard **supports between $75 billion and $110 billion in GDP and between 540,500 and 662,300 jobs in the US through its supply chain spending.** Notably, this is not a prediction of the likely impact of a tighter PM2.5 standard, as exposed manufacturers may have the option to invest to abate their emissions instead of shrinking or closing down, and their suppliers may be able to sell to other customers.

Finally, when an area is designated as being in nonattainment, it remains so for a period of time. While an area is designated as in nonattainment, **the growth of emitting industries may be restricted** – either because of direct controls or because investment in productive capital or new facilities in the area is deterred. We analyse the value of potentially restricted growth of manufacturing industries in the nonattainment counties identified in our analysis during the 2024-2031 period that counties outside of attainment will be expected to reach attainment, based on Oxford Economics forecasts of state-level industrial growth, and using the simplifying assumption that PM2.5 emissions vary in line with GVA over that time period. From this, we estimate that, **the potentially exposed growth would be of a scale of approximately $138.4 billion of GVA (in 2021 prices) and associated with 501,000 jobs in 2027.** However, importantly for the purpose of this analysis and interpretation of this estimate, we make the strong implied assumption that manufacturing does not change its environmental efficiency (i.e. become less polluting) over the decade between 2021 and 2031. Another key caveat around this estimate is that some of the restriction of growth in nonattainment counties may be compensated for by additional growth in other areas (for instance, if investment is directed away from nonattainment areas towards attainment areas the economic growth and employment may be created elsewhere).

ENVIRONMENTAL IMPACT OF U.S. VS. GLOBAL MANUFACTURING

The portion of the U.S. manufacturing sector that is exposed to tightened standards would have a range of options for responding to those standards, including abating its emissions or contracting activities in affected locations. Some of the exposed manufacturing production may shift to outside the U.S., though the extent to which this might occur in response to tightened standards is uncertain.

Fully contextualizing the environmental footprint of U.S. manufacturers requires us to develop a deeper understanding of how U.S. emissions compare to international peers. Existing evidence illustrates that the U.S. manufacturing sector is less damaging to the environment than the global average, especially when compared to less-developed economies.[6]

Using Oxford Economics' Global Sustainability Model (GSM), we compare the environmental impact of five manufacturing sectors based in the U.S. to those sectors globally. These sectors were selected both because of the scale of the economic exposure they have to a tighter PM2.5 standard and the variety of the sectors in order to provide a broad perspective. Namely, they are extractive industries, petrochemical manufacturing, non-metallic mineral manufacturing, metals manufacturing and computer, electronic products and electrical equipment manufacturing. This analysis includes both their direct impacts and the indirect contributions from their global supply chains. It considers the following environmental impacts: air pollution in terms of emissions of PM2.5, nitrogen oxides (NOx) and volatile organic compounds (VOCs) (key air pollutants), and greenhouse gas emissions.

The comparative analysis finds that the sectors analyzed are mostly less pollution-intensive in the U.S. than they are globally, with the U.S. estimated to be less PM2.5-intensive than the sector in the rest of the world in each of the five sectors analysed. Similarly, the U.S. sector was found to be less NOx-intensive, by between a fifth and two-thirds, than the corresponding sector in the rest of the world in each of the five sectors considered. In addition, the analysis finds that all of the sectors considered have lower GHG emissions intensities in the U.S. than the global average for that sector. In four of the five sectors analysed, the U.S. sector is estimated to be less VOC-intensive (in two cases, less than half as VOC-intensive) than the corresponding sector in the rest of the world.

[6] Climate Leadership Council, *America's Carbon Advantage*, 2020.

PopTika/Shutterstock.com

1. INTRODUCTION

1.1 THE PURPOSE OF THIS REPORT

The United States (U.S.) has a long history of establishing and enforcing air quality standards. The enactment of the Clean Air Act of 1970 led to the establishment of national standards for air quality, known as National Ambient Air Quality Standards (NAAQS).[7] These standards have evolved over time, with the Environmental Protection Agency (EPA) responsible for researching and setting these standards that control air permitting. In recent decades, the U.S.'s air quality regulations have seen substantial falls in air pollution levels, including 37%, 16% and 40% decreases in the national average levels of PM2.5, ozone and NO_2 respectively between 2000 and 2021 and a larger, 85% decrease in SO_2 levels over the same period.[8] Emissions of PM2.5 from stationary industrial sources fell by around one-third between 2008 and 2017.[9] Nonetheless, there remains concern in some quarters about the health impacts of air pollution in the U.S. The EPA has recently proposed to further tighter air quality standards around PM2.5.[10]

The EPA seeks to implement air quality standards through a range of measures that target the sources of emissions, including electricity generation, motor vehicles, paved and unpaved roads, and forest fires. Industrial sectors, including manufacturing, are therefore only one element of the equation. However, they play a significant role, in particular in industrial and population centers, and it is therefore believed that they will be expected to do their part in reducing emissions going forward. As such, we believe that manufacturing industries will be a focus of State Implementation Plans (developed by states and submitted to the EPA for approval), which are primarily responsible for setting out how standards will be met.

Industrial sectors that generate targeted emissions in counties exceeding the standards are likely to be required to further reduce their emissions in that area. The scale of a given sector's exposure to potential changes in the standard for PM2.5 and the proportion of a given state's manufacturing sector that is exposed will depend on the amount of economic activity from manufacturing sectors within counties over the standard.

The first purpose of this report is to assess the proportional reduction in emissions potentially required and the corresponding value of economic activity in the manufacturing sector that could be impacted, which we term the manufacturing sector's "economic exposure".

The manufacturing sector's economic exposure is estimated based on the economy in 2021; that is, this economic exposure is calculated using 2021 data (the latest available data) for gross value added (GVA) and employment. The estimates of economic exposure are not a prediction of economic impact, as companies will have a range of options to limit their emissions other than reducing their output; however, it allows us to contextualize the scale of the exposed industries in well-understood economic quantifications. We also estimate the economic value of the supply chain spending of exposed manufacturers, as well as the value of growth of manufacturers that could be restricted in nonattainment areas under a tighter PM2.5 standard. We also discuss the cost of abating these emissions by incorporating new technologies.

[7] EPA, *Evolution of the Clean Air Act*.
[8] EPA, *National Air Quality: Status and Trends of Key Air Pollutants*.
[9] Oxford Economics analysis of *EPA National Emission Inventories* data.
[10] On January 6th, 2023, the EPA announced its proposed decision to revise this standard from the current 12 μg/m3 level to a level within the range of 9 to 10 μg/m3. We note, however, that the EPA's proposal solicits comments on a range of potential standards, the lowest of which is the 8 μg/m3 limit called for by some environmental groups. See EPA, *Proposed Decision for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter (PM)*, 2023.

The second purpose of this report is to examine how U.S. manufacturers compare to those internationally in terms of the environmental impact of the goods that they produce. This offers some insight into how U.S. production of various key manufactured goods compares to the rest of the world. We also examine possible cost implications of the U.S. refining petroleum abroad, given the extent to which this activity would be affected by the PM2.5 standard being changed.

Our analysis in this report focuses on the manufacturing sector, as defined by the NAM. This definition includes traditional manufacturing (NAICS codes 31-33) and key manufacturing supply chain inputs including forestry and logging (NAICS code 113), extractive industries (NAICS code 211, 212 and 213), and other stationary industrial sources, namely heavy construction (NAICS code 237), rail and pipeline transportation (NAICS codes 482 and 486), warehousing and storage (NAICS code 493), and waste management and remediation (NAICS code 562).

1.2 INTRODUCING FINE PARTICULATE MATTER POLLUTION

When we assess the economic exposure of the manufacturing sector to more stringent ambient air quality standards, our analysis focusses on PM2.5—fine particulate matter—emissions and standards. The measurements of these ambient air levels are made at monitoring stations that providing data on emissions in counties across the country.

PM2.5 is particulate matter measuring 2.5 micrometers or smaller, with this form of particulate matter considered to be the most hazardous to human health. The primary standard is based on an annual mean, averaged over three years. In our analysis we therefore calculate this mean over the 2019-2021 period.

These are the three most recent years for which data were available at the time of writing; it is not the case that Covid-19 lockdowns saw large drops in PM2.5 concentrations in monitored counties relative to 2019. As such we did not feel the need to use an alternative time period. The current standard has an annual mean of 12 μg/m^3 (micrograms per cubic meter air); however, the EPA has proposed to tighten this standard.[11,12] We therefore examine scenarios based on the existing 12 μg/m^3 standard and an 8 μg/m^3 standard, the lowest of the potential standards on which the EPA solicited comment in its proposal, which has been called for by some environmental groups.[13]

1.3 THE STRUCTURE OF THIS REPORT

This report is structured as follows:

- **Chapter 2** details our estimation of the economic exposure of the U.S. manufacturing sector to possible changes to the PM2.5 standard.
- **Chapter 3** explores the relative environmental footprints of U.S. and international manufacturing.
- **Appendix 1** provides detailed breakdowns of our estimates of manufacturing's economic exposure to possible changes to the PM2.5 standard.
- **Appendix 2** presents a detailed methodology.

[11] EPA, *NAAQS Table*.
[12] EPA, *Proposed Decision for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter (PM)*, 2023.
[13] Environmental groups called for an 8 μg/m3 threshold in a *letter* to President Joe Biden.

GLOSSARY OF TERMS

Abatement: Abatement is the process through which companies invest in technologies and other solutions to reduce the emissions generated by their activities. The cost of abatement is estimated using marginal abatement costs curves (MACCs), that model the process of abatement whereby organizations are assumed to prioritize low-cost solutions, before more expensive ones are implemented.

Economic exposure: In order to contextualize the value of a given emissions reduction, this report presents the manufacturing sector's "economic exposure", which represents the value of GVA or employment in the manufacturing sector that would be impacted if they were to be reduced by the same proportion. This is a useful way to assess the scale of the emissions reductions that are needed, as well as where in the economy they fall. However, it should not be interpreted as a prediction of economic impact or harm as companies will face other options such as abatement.

Employment: The number of people estimated to work in a given area or sector, primarily used as a measurement of economic exposure in this report. It is measured on a "headcount" basis, meaning that it includes every individual employed at a given time (or the average number employed over a period of time), rather than being scaled to a full-time equivalent. Our approach is comparable to headline employment statistics.

Environmental Protection Agency (EPA): The United States Environmental Protection Agency is the executive agency of the U.S. federal government tasked with environmental protection. It is in charge of setting and enforcing environmental standards.

Global Sustainability Model (GSM): The Global Sustainability Model is Oxford Economics' proprietary software which models the environmental impact of industries and their supply chains. The model is rooted in a global input-output model, which traces the supply chains of industries in countries all over the world, tracing how they buy and sell from each other, and support final demand. The GSM builds on this by applying environmental intensities to the output of each industry in each country to model the environmental impacts of their activities.

Greenhouse gases (GHGs): Greenhouse gases are the gases responsible for trapping heat in the environment and causing climate change. The most prevalent GHG is carbon dioxide (CO_2), followed by methane (CH_4), nitrous oxide (N_2O), and a range of fluorinated gases.[14]

Greenhouse Gas Protocol Scopes 1, 2, and 3: The Greenhouse Gas Protocol provides comprehensive global standardised frameworks to measure GHG emissions.[15] The GHG Protocol defines different "scopes" for a company's emissions.

- Scope 1 emissions are the direct emissions from the operation of a company or industry's own facilities and assets.
- Scope 2 emissions are the indirect emissions that are made by other organizations that provide electricity and heat to the company or industry, i.e., the energy sector.
- Scope 3 emissions are the indirect emissions from which are sources that are not owned or controlled by the company, but which are nonetheless a consequence of the company's activities. In this analysis we include estimates of Scope 3 value chain emissions.

[14] EPA, Overview of Greenhouse Gases.
[15] Greenhouse Gas Protocol, About Us.

Gross value added (GVA): Gross value added is a measure of economic activity within a given area, industry, or organization. It equates to the value of goods or services that are created, minus the cost of any goods or services purchased. Gross Domestic Product (GDP) can be calculated by aggregating GVA across all industries nationally and adjusting for taxes and subsidies on products. As such, a given economic impact can be expressed in terms of the gross value added contribution to GDP.

National Ambient Air Quality Standards (NAAQS): NAAQS are the air quality standards set by the EPA, from a requirement established in the Clean Air Act. In this report we focus on the primary standards which are intended to protect public health. They are reviewed and potentially changed over time. Our scenarios are based on assessing the implications of a potential change to these standards for PM2.5.

Nitrogen oxides (NO_x): Nitrogen oxides (NOx) are a family of poisonous, highly reactive gases that can have natural, biogenic and industrial sources. NOx is emitted by automobiles, trucks and various non-road vehicles (e.g., construction equipment, boats, etc.) as well as industrial sources such as power plants, industrial boilers, cement kilns, and turbines. It plays a major role in the reactions with volatile organic compounds (VOCs) that produce ground-level ozone, particularly on hot summer days.[16]

Ozone: Tropospheric, or ground-level ozone, is a form of pollution that is harmful to human health when breathed in and is sometimes known as "smog". It is not emitted directly into the air; rather, it is created by chemical reactions between nitrogen oxides (NOx; see above) and volatile organic compounds (VOCs; see below). Limiting ozone creation is therefore achieved by reducing the pollutants that create it.

Particulate matter (PM2.5 and PM10): Particulate matter is a combination of solid particles and liquid droplets in the air, created by a range of sources including natural and industrial activities. PM2.5 is fine particulate matter measuring 2.5 micrometers and smaller. PM10 represents particles measuring 10 micrometers and smaller. Particulate matter's small size means that it is inhalable, meaning it can be harmful to health.

Volatile organic compounds (VOCs): Volatile organic compounds (VOCs) are compounds of carbon that are produced in the manufacture or use of products and participate in atmospheric photochemical reactions. In this report we focus on outdoor volatile organic compounds, which react with nitrogen oxides (NOx) to produce ground-level ozone.

[16] EPA, *Nitrogen Oxides (NOx) Control Regulations*.

Stock Connection Blue/Alamy Stock Photo

2. MANUFACTURING'S ECONOMIC EXPOSURE TO PM2.5 AIR QUALITY STANDARD CHANGES

2.1 INTRODUCING PM2.5 AIR QUALITY STANDARDS

This section presents evidence on the economic exposure of the U.S. manufacturing sector to changes in the primary PM2.5 NAAQS. Throughout, it considers the implications of full enforcement of the primary PM2.5 standard under the current 12 μg/m³ standard and an 8 μg/m³ standard. These two standards represent, respectively, the status quo and the most stringent standard on which the EPA solicited comment in its recent announcement on the reconsideration of the NAAQS for particulate matter.[17] The latter limit is focussed on in more depth in this chapter. Full results for both scenarios are presented in Appendix 1. The methodology for the analysis is set out in Appendix 2.

We begin by discussing the frequency and distribution of exceedances of these air quality standards over the three-year period from 2019 to 2021 (recalling that the primary PM2.5 NAAQS relates to the three-year average of annual average concentrations of PM2.5).[18] It then examines the economic exposure of the manufacturing sector to each standard and considers state-level and sectoral patterns (within manufacturing) in this exposure.

2.1.1 Frequency and distribution of air quality standard exceedances

Considering the average across the three-year period from 2019 to 2021, the current 12 μg/m³ standard for PM2.5 was recorded as being exceeded in 20 counties—in some cases quite considerably. These counties together represent less than 1% of all U.S. counties, though they contain approximately 7% of the U.S.'s population. If an 8 μg/m³ standard had been in place during that period, 200 counties containing 38% of the U.S.'s population would have been recorded as being in exceedance of that standard. The scale of the exceedances of the different PM2.5 standards is summarized in Fig. 1.

Focussing on the locations of these exceedances, three-fifths of the counties recorded as being in above the current 12 μg/m³ between 2019 and 2021 are in California. Further, California was the state with the most counties that were recorded with PM2.5 levels that would have been above an 8 μg/m³ standard, with just under 15% of the total (200).

Fig. 1: Comparison of high-level implications of different PM2.5 standards

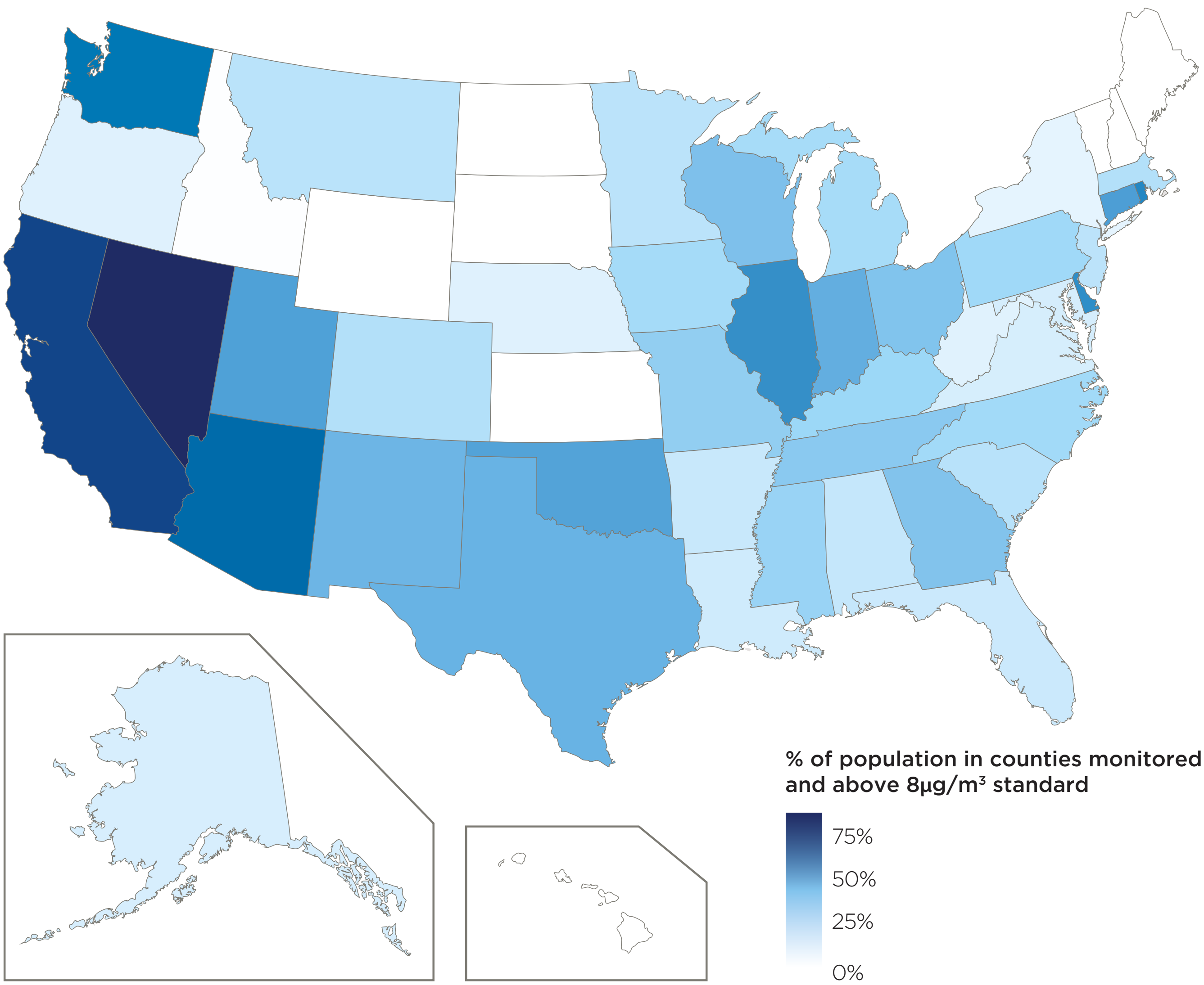
	Number of counties monitored and above the air quality standard, 2019-2021	Percentage of all U.S. counties monitored and above the air quality standard, 2019-2021	Percentage of U.S. population living in counties monitored and above the air quality standard, 2019-2021[19]
12 μg/m³	20	1%	7%
8 μg/m³	200	6%	38%

Source: Oxford Economics analysis of EPA data

[17] EPA, Reconsideration of the National Ambient Air Quality Standards for Particulate Matter, 2023.
[18] Our analysis focuses only on monitored counties. Around one-third of U.S. counties are monitored, with more than four-fifths of the U.S. population living in a monitored county. The EPA places monitors in areas "of relatively high population and/or areas believed to have relatively higher pollutant concentrations". As such, there is unlikely to be significant additional economic exposure in counties that are not currently monitored.
[19] Based on population estimates for the 50 states and the District of Columbia for July 2021 from the U.S. Census Bureau.

Alongside California, the EPA data show that Indiana, Georgia, and Texas were the other states with more than 10 counties recorded with PM2.5 levels that would have been above an 8 µg/m³ standard. In some states, a high proportion of counties would have been non-compliant even if the absolute number of non-compliant counties would not have been high (because there are relatively few counties in those states); for instance, four of Arizona's 15 counties (approximately 27%) were recorded with PM2.5 levels that would have exceeded an 8 µg/m³ limit.

Fig. 2: Share of population in counties monitored and above an 8 µg/m3 PM2.5 standard in 2019-2021, by state[20]



Source: Oxford Economics analysis of EPA data

[20] The District of Columbia, which is monitored and above an 8 µg/m³ PM2.5 standard in 2019-2021, is not shown in this chart.

2.1.2 Overall economic exposure of manufacturing to PM2.5 air quality standards

The manufacturing sector's "economic exposure" to a tighter PM2.5 standard refers to the portion of manufacturing that could potentially be impacted by changes required to meet the more stringent standard. This is not a projection of the economic cost of these air quality standard changes for manufacturer; while some manufacturers may shrink or close their operations, we expect there to be alternative options such as investing in technologies to abate these emissions. Nonetheless, existing research has found that environmental regulations impose costs on firms that can influence firms' investment and plant location decisions, and that higher abatement costs can be associated with less investment in productive capital. This is discussed further in section 2.2 below.

Considering a reduction in the PM2.5 standard to 8 µg/m^3 and looking at the magnitude of air quality standard exceedances and comparing that to the economic footprint of the manufacturing sector, we find a total economic exposure of $87.4 billion, equal to 2.4% of the U.S. manufacturing sector's GVA. The number of manufacturing jobs associated with this exposed activity is 311,600, or 1.9% of all U.S. manufacturing employment.

Given that, as noted above, the current 12 µg/m^3 standard is exceeded—in some cases quite significantly—in a number of counties, there is also economic exposure to full enforcement of a 12 µg/m^3 standard. This exposure of $12.2 billion (0.3% of U.S. manufacturing GVA) is associated with 36,200 jobs (0.2% of U.S. manufacturing employment).

Fig. 3: Summary of manufacturing sector's economic exposure to different PM2.5 air quality standards[21]

	Manufacturing's economic exposure, GVA ($ billions)	Manufacturing's economic exposure, GVA, % of total U.S. manufacturing GVA	Manufacturing's economic exposure, employment	Manufacturing's economic exposure, employment, % of total U.S. manufacturing employment
12 µg/m^3	12.2	0.3%	36,200	0.2%
8 µg/m^3	87.4	2.4%	311,600	1.9%

Source: Oxford Economics analysis of EPA, BEA and BLS data

2.1.3 State-level economic exposure of manufacturing to PM2.5 air quality standards

The share of manufacturing GVA exposed under an 8 µg/m^3 standard for PM2.5 varies appreciably by state. This variation is visible in Fig. 4, with some states seeing significant shares of the manufacturing industries exposed and others having zero exposure, often because no counties are found to be above the air quality standard. California is the state with the highest exposure in the manufacturing sector, with the manufacturing sector's economic exposure equal to 6.2% of the state's manufacturing GVA, an exposure of $31.6 billion in GVA associated with 119,000 jobs. There are a number of counties in California that were recorded as being well over an 8 µg/m^3 limit for PM2.5 between 2019 and 2021 (and indeed a handful that are significantly above the existing 12 µg/m^3 standard). These counties, many of which are highly populous, contain large industrial centers.

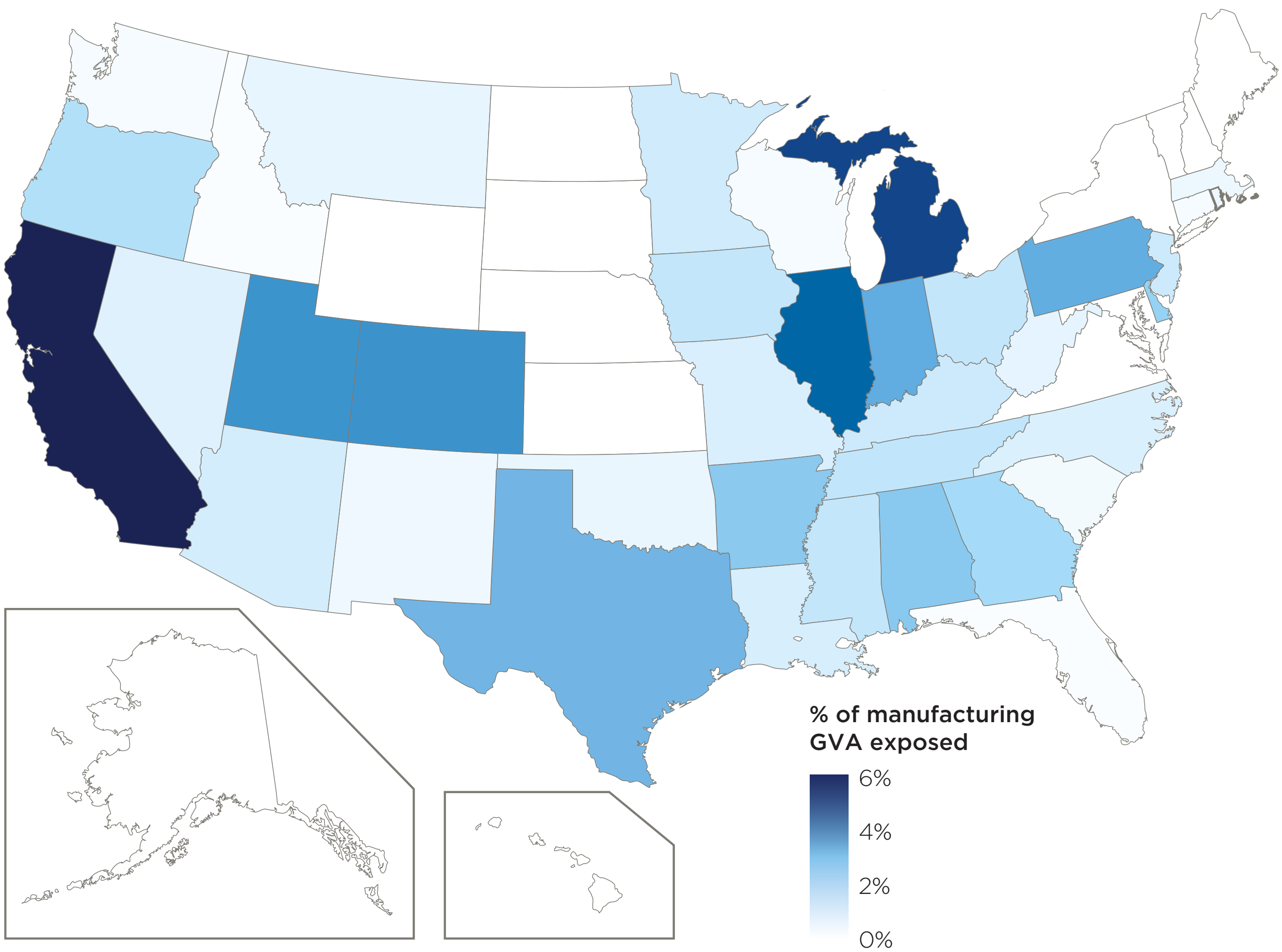
[21] Percentages rounded to nearest 0.1%. Absolute numbers rounded to nearest 100.

Texas's manufacturing sector experiences the second-largest economic exposure in value terms, totalling $15.6 billion and associated with 29,000 jobs.[22] Texas's manufacturing sector's exposure is equal to 2.8% of the state's manufacturing GVA. Texas differs from California in that in Texas, none of its counties is as far above the current standards. However, appreciable reductions would be required in a couple of major industrial clusters.

In the Great Lakes states (Michigan, Illinois, Indiana, and Pennsylvania) and in Utah and Colorado, the above-average exposure of the manufacturing sector is driven mostly by one, or a handful, of populous counties containing concentrations of industrial activity where the tighter air quality standard would be exceeded to an appreciable extent (but not to the same extent as the most non-compliant Californian counties).

Across all these states, the largest economic exposure for the manufacturing sector therefore most often comes because states contain a small number of counties that would be above a lower 8 μg/m^3 standard and have large manufacturing clusters and urban centers, leading to both the most significant exceedances and the most concentrated economic exposure in the manufacturing industry.

Fig. 4: Share of manufacturing GVA exposed to an 8 μg/m3 standard for PM2.5, by state



Source: Oxford Economics analysis of EPA data

[22] Comparing Texas and California, Texas's manufacturing sector's exposure in GVA terms is much higher relative to its exposure in jobs terms than is the case in California. This reflects the fact that Texas's manufacturing sector's exposure is concentrated in relatively high productivity industries.

2.1.4 Key sectoral patterns

Certain manufacturing sectors are more exposed than others to a lower PM2.5 air quality standard. The extent to which a manufacturing sector is economically exposed to a lower PM2.5 air quality standard depends not only on the extent to which it emits PM2.5, but also where it tends to be located.

Industries that tend to be located away from population centers or industrial clusters will tend to have lower economic exposure since, because of an absence of other contributing sources, they are less likely (all else being equal) to be in a county that exceeds the air quality standard.

Conversely, manufacturing sectors that tend to be located in or close to cities and to other industries will tend to have a higher economic exposure, since monitored counties tend to be areas "of relatively high population and/or areas believed to have relatively higher pollutant concentrations".[23] The manufacturing sectors with the highest economic exposure (in GVA terms) are in primary metal manufacturing, food manufacturing, and petroleum and coal products manufacturing. These sectors have a large amount of activity in counties that are monitored and that are in exceedance of the hypothetical 8 μg/m^3 standard.

Food manufacturing likely tends to be located in or close to cities in order to have access to large amounts of labor, as well as a large nearby market. Oil refineries and steel plants, meanwhile, require large amounts of water for cooling, so locating close to a port offers a nearby supply of water as well as providing access to transportation links to serve their broad markets. These facilities therefore are likely to cluster near ports along with other industries seeking the same benefits from such a location, creating clusters of manufacturers with significant economic exposure to more stringent PM2.5 air quality standards. All of these forms of clustering offer potential productivity and efficiency benefits to firms, with the economic exposure they face potentially threatening these benefits.

2.1.5 Supply chain impacts of exposed manufacturing

Manufacturers purchase goods and services from other firms both within and outside the manufacturing sector. This supply chain expenditure by manufacturers supports GDP and jobs in the wider economy. These GDP and job impacts are known as the manufacturing sector's indirect economic impact. This indirect impact will also exist for the companies exposed to more stringent PM2.5 air quality standards.

Using input-output modelling, we estimate the indirect economic footprint of the portion of the U.S. manufacturing sector that is exposed to an 8 μg/m^3 standard for PM2.5. In estimating this impact, there is uncertainty around the extent to which companies in the exposed manufacturers' supply chains are themselves exposed to the tighter air quality standard. For this reason, we present a range of estimates (based on different assumptions around this uncertainty). Manufacturing firms exposed to an 8 μg/m^3 standard are estimated to support between $75 billion and $110 billion and between 540,500 and 662,300 jobs in the U.S. through their supply chain spending, which we can view as their indirect economic exposure.

As with the estimates above, these estimates are not a prediction of the impact of a tighter PM2.5 air quality standard. Instead of contracting or closing down, exposed manufacturers may be able to abate their emissions. In addition, the firms in the exposed manufacturers' supply chains may be able to replace lost demand from those manufacturers by selling to other firms. Nonetheless, these estimates indicate how activity in the rest of the economy is connected to the exposed portions of the manufacturing sector.

[23] EPA, *Who decides where monitors get placed?*.

2.1.6 Potential restricted growth in manufacturing

The analysis above is focused on the economic exposure of the manufacturing sector to a tighter PM2.5 air quality standard based on its size in 2021. However, when an area is designated as in nonattainment, it remains so for a period of time. Initially, an area classified as in nonattainment with respect to the PM2.5 NAAQS is expected to return to attainment "as expeditiously as practicable, but not later than the end of the sixth calendar year after designation".[24]

While an area is in nonattainment, the growth of industries in that area may be restricted, either because of direct controls or because investment is reduced (either because it is "crowded out" by spending on abating emissions or because investment is directed to other areas; see below). We understand that this process is expected to take place between 2024 and 2031 and have therefore modeled the potentially restricted growth over this period.[25]

Drawing on forecasts of GVA growth for each industry in each state, we model how emissions would evolve to 2031 to estimate the growth in industrial GVA that would not be able to occur in nonattainment areas between 2024 and 2031 based on restrictions due to their PM2.5 emissions levels in 2021. We assume that growth in the economic output of an industry implies a commensurate growth in that industry's PM2.5 emissions, therefore no additional economic growth would be able to occur where a county is in nonattainment. Notably, this approach adopts a strong implied assumption that the manufacturing sector does not become more environmentally efficient in its operations before 2031, for instance through improved processes or investments in new technology which would allow for growth in economic output without an associated increase in emissions.

Furthermore, this approach does not account for the potential for growth to shift from nonattainment areas to areas in attainment, whereby the restricted growth due to the tighter air quality standards may be offset by increased growth in other locations due to the redirection of investment.

With these assumptions and caveats, we estimate that the 8 $\mu g/m^3$ PM2.5 air quality standard would expose manufacturing sector growth in areas of nonattainment on the scale of approximately $138.4 billion of GVA and 501,000 jobs between 2024 and 2031. While this is not a forecast of growth that will be lost in exposed manufacturing industries, given the significant caveats already described, this estimate highlights the potential scale of effects of a tighter PM2.5 standard on the manufacturing sector in areas of nonattainment.

[24] EPA, *Fine Particulate Matter National Ambient Air Quality Standards: State Implementation Plan Requirements*.
[25] We assume that governors would submit designations in 2024, one year after promulgation of a new standard in 2023. The EPA would then finalize designations in 2025, implying an attainment date at end-2031 (except for those areas for which this date is determined to be not practicably attainable).

2.2 ABATING EMISSIONS

As noted above, manufacturers will have a range of options for reducing their emissions of PM2.5 beyond just contracting. There exist a number of technologies that can be implemented to reduce the emissions intensity of industrial processes. Doing so, however, has a cost, as the requisite technologies will need to be purchased and fitted. The cost of *abating* emissions in this way varies by technology and according to the extent of emissions reduction required—typically, emissions are initially relatively cheap to abate (reflecting the existence of "low-hanging fruit") but become more expensive as larger proportional reductions are required. As such, different industries will face different costs per unit of emissions reduction when trying to abate their emissions.

Evidence from the EPA estimates that the cost to the manufacturing sector of abating its emissions to the degree modelled in the analysis above would be substantially less than the total value of the manufacturing sector's economic exposure estimated above.[26] This underscores the point that the estimates of economic exposure presented above are not forecasts of the economic cost for manufacturers of adapting to any new air quality standards. However, in some cases abatement may not be technologically or economically feasible (given that even relatively small costs can be significant in the face of competitive pressure). In such cases, manufacturers may have to contract or shut down their operations in order to comply with tightening emissions standards, potentially moving operations elsewhere. Also, investments in new facilities or in productive capital may be deterred. This would have knock-on effects on the companies in their supply chain and on customers as well as the impact on the local economy, as well as threatening to reduce the benefits that firms get from clustering in these industrial centres.

Existing literature has found that environmental regulations impose costs on manufacturers that can influence manufacturers' investment decisions and choice of plant location. There is evidence of firms being less likely to open new facilities in areas with stricter regulations and investing less in facilities in such areas.[27] Literature suggests two mechanisms for a facility facing higher abatement costs being associated with less investment in productive capital in that facility: firstly, that abatement investment "crowd out" productive investment, and secondly, that firms redistribute investment in favor of facilities with smaller abatement costs.[28] As such, if exposed manufacturers choose to abate emissions rather than contracting or shutting down, this may nonetheless impact output in the future.

[26] EPA, Regulatory Impact Analysis for the Proposed Reconsideration of the National Ambient Air Quality Standards for Particulate Matter, 2022, ES-14 Table ES-5.
[27] Gray, W. B., Environmental regulations and business decisions, 2015. IZA World of Labor 2015: 187., W.B. and Shadbegian, R.J., Environmental Regulation, Investment Timing, and Technology Choice, 1998. The Journal of Industrial Economics Vol. 46, No. 2.
[28] Gray, W.B. and Shadbegian, R.J., Environmental Regulation, Investment Timing, and Technology Choice, 1998. The Journal of Industrial Economics Vol. 46, No. 2.

3. ENVIRONMENTAL IMPACT OF U.S. vs. GLOBAL MANUFACTURING

Chapter 2 presented estimates of the scale of manufacturing activity that could be impacted by more stringent air quality standards for PM2.5. Affected manufacturers will have a range of options for how they respond to any changes in this standard, including abating emissions by implementing new technologies as well as contracting. Some of the exposed manufacturing production might shift outside the U.S. As such, while the EPA is concerned with regulating the environmental performance of industries in the U.S., it is worth considering how these industries compare to their peers globally, both directly and through the entirety of their global supply chains. This chapter considers how the environmental impact of U.S. manufacturing compares with the impact of manufacturing elsewhere. This comparison contextualizes the environmental impact of U.S. manufacturing and offers insight into the environmental impact that would materialize if the same output were produced outside the U.S.

The chapter begins by discussing the theoretical background behind this comparison. It then presents findings from previous research comparing the environmental impacts of different countries' manufacturing sectors. It then presents our estimates of the relative environmental impacts of production in the U.S. and producers in the rest of the world for five sectors: extractive industries; metals, metal product, and machinery manufacturing; petrochemicals manufacturing; computer and electrical equipment manufacturing; and non-metallic mineral manufacturing. The environmental impacts that we focus on are emissions of key air pollutants—namely, PM2.5, NOx and VOCs[29]—and greenhouse gas emissions, with the latter being a key area of focus in environmental policy more broadly.

3.1 THEORY AND PREVIOUS RESEARCH

Manufacturing produces a range of environmental impacts in addition to emissions of air pollutants. Like other industries, the manufacturing sector requires energy for a range of purposes, including heating materials to high temperatures and operating machinery. This energy is often derived from fossil fuels, whose combustion produces greenhouse gases. Manufacturing also, like other industries, entails the use of natural resources whose overuse can result in scarcity. The pattern of environmental impacts that manufacturing has will depend on various factors, including the type of manufacturing, where that manufacturing occurs, and the nature of any inputs—in particular, electricity sources.

More economically developed countries typically have more stringent environmental regulations than less economically developed ones, and tend to have had such regulations for longer, allowing industries to adapt to them. In addition, wealthier countries are likely to have greater capacity (in both the private and the public sector) to invest in technologies that reduce the environmental impacts of production processes. As such, one would expect the manufacturing sectors of more economically developed countries to tend to have a lesser negative impact on the environment than those of less economically developed countries.

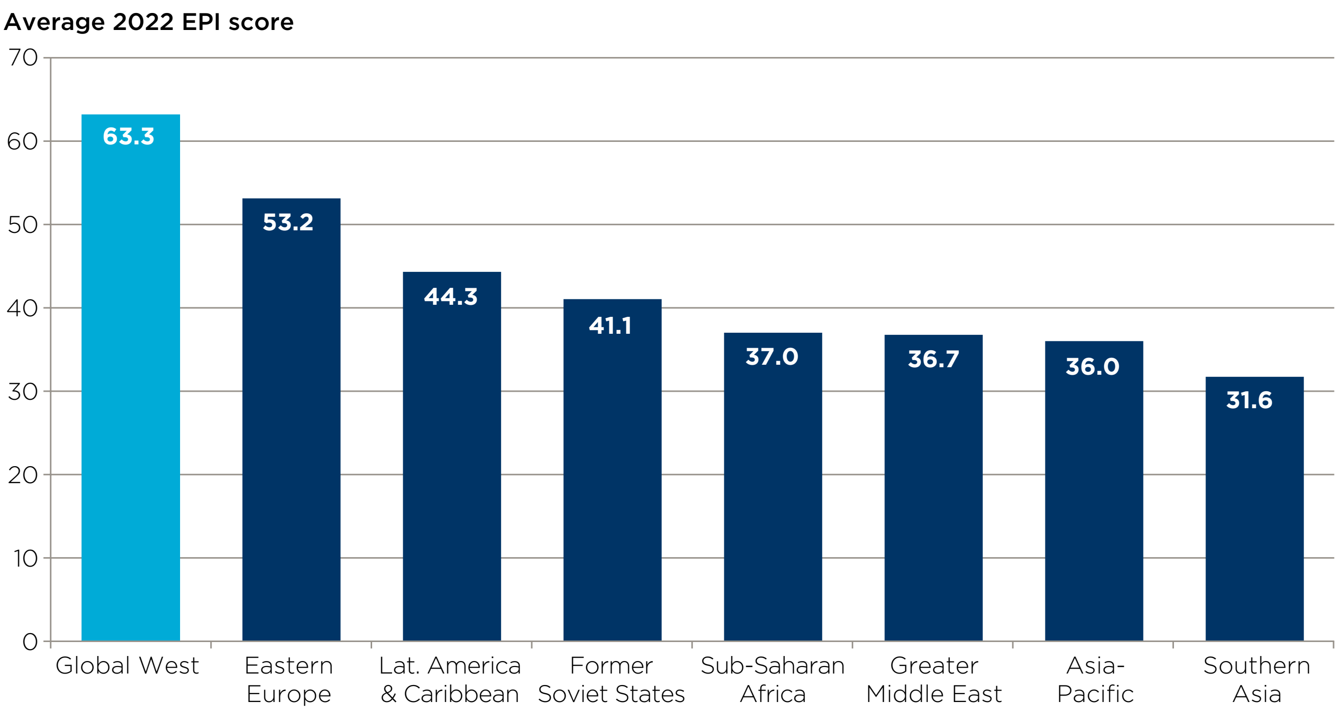
[29] In line with the EPA's regulatory definition of VOCs, we do not include methane as a VOC for the purposes of this analysis due to its negligible photochemical reactivity. The estimates of VOC amounts in this chapter therefore refer to NMVOCs.

The 2022 Environmental Performance Index[30] (EPI) measures countries' performance on climate change, environmental health, and ecosystem vitality. As expected, wealthier countries tend to perform better in the EPI than less wealthy ones, reflecting typically more stringent environmental regulations and generally greater financial resources with which to invest in clean technologies. Fig. 5 below shows the average score in the 2022 EPI by regional group; the Global West, of which the U.S. is part, has the highest average score.

The U.S. lies in the top quartile of countries globally, placing 43rd out of the 180 countries ranked (though it ranks 20th out of the 22 countries in the Global West). It also outperforms several key manufacturing nations including China (which placed 160th), India (180th), and South Korea (63rd), as well as neighbors Canada (49th) and Mexico (73rd).

A 2020 Climate Leadership Council report found, taking into account firms' global supply chains, that U.S. manufacturing is more carbon-efficient (that is, it generates a smaller carbon footprint in producing the same or similar output) than the world average and a number of important manufacturing nations, including Brazil, Russia, India, China, and its North American neighbors Canada and Mexico.[31] The report found that U.S. manufacturing was slightly less carbon-efficient than EU manufacturing on the whole, though in some parts of manufacturing the reverse was true. EU countries, however, account for a relatively small portion of U.S. imports, and the report found that 75% of the U.S.'s goods imports came from less carbon-efficient countries. Substituting from U.S.-based manufacturing to importing products from abroad might therefore see the GHG emissions involved in manufacturing these products rise.

Fig. 5: Average score in 2022 Environmental Performance Index, by regional group



Source: Oxford Economics, using data from Martin Wolf, John Emerson, Daniel Esty, Alex de Sherbinin, Zachary Wendling, et al. *2022 Environmental Performance Index*, 2022.

[30] Martin Wolf, John Emerson, Daniel Esty, Alex de Sherbinin, Zachary Wendling, et al., *2022 Environmental Performance Index*, 2022.
[31] Climate Leadership Council, *America's Carbon Advantage*, 2020.

3.2 ESTIMATED ENVIRONMENTAL IMPLICATIONS

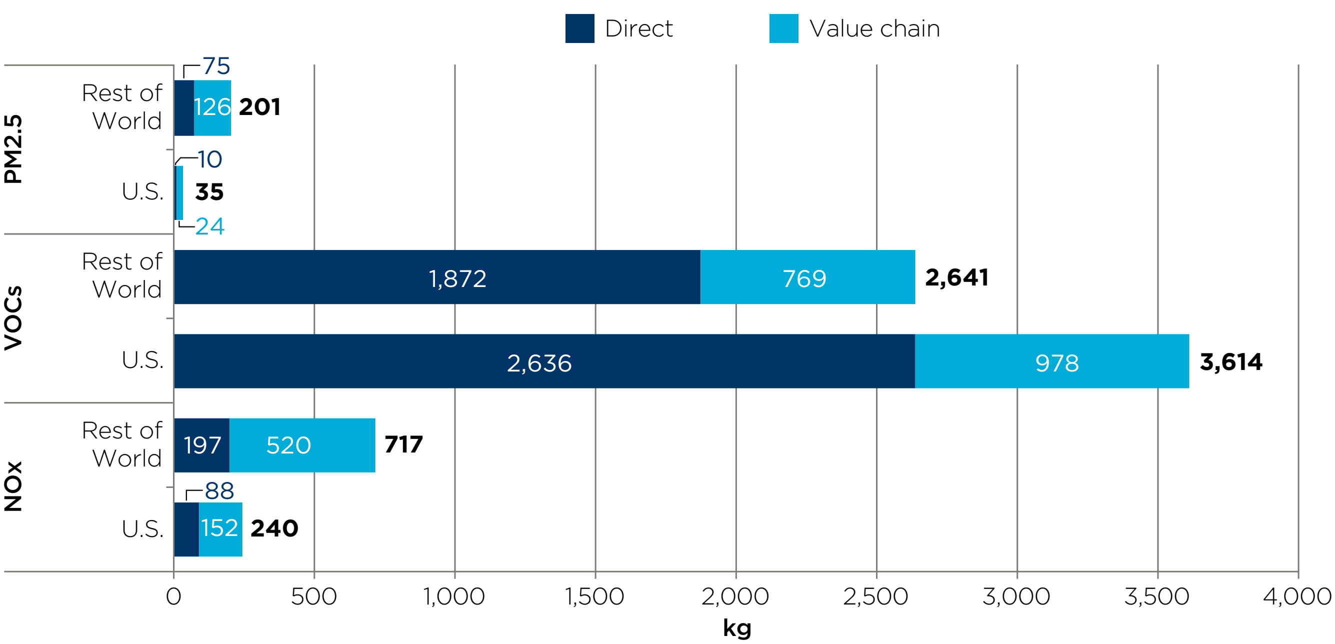
This section compares the environmental impacts, in terms of air pollution and greenhouse gas emissions, of a given amount of output being produced in the U.S. with the impacts of the same amount of output being produced elsewhere, for five sectors. For each sector, the amount of production that occurs in each country when production occurs outside the U.S. is based on the output of that sector in each country in 2021. It should be noted that output produced in the U.S. and that produced in the rest of the world may be different in character even within the same sector; for instance, in the extractive industries, the types of products extracted to produce a given amount of output are likely to differ in the U.S. when compared to the rest of the world.

3.2.1 Extractive industries

The extractive industries (NAICS codes 211, 212 and 213) in the U.S. produce significantly less PM2.5 and NOx in producing a given amount of output than the sector in the rest of the world does (approximately one-sixth and one-third as much respectively). The U.S. industries' emissions in producing a given amount of output are lower in terms of both their own emissions and through those "embedded" in their supply chains (Fig. 6). The extractive industries in the U.S. are estimated to produce approximately one-third more VOCs in producing a given amount of output than the sector in the rest of the world. Emissions of VOCs from extraction include "fugitive" emissions from leaks or irregular releases and the level of fugitive emissions associated with extraction is likely to be dependent on the type of extraction (for instance, whether coal seam gas or conventional natural gas is being extracted). This difference in VOC emissions may reflect differences in the type of extraction that occurs in the U.S. as compared to in the rest of the world.

In addition, the GHG footprint associated with the U.S. extractive industries producing a given amount of output is

Fig. 6: Emissions of air pollutants from producing $1 million (PPP) of output in the extractive industries, U.S. and rest of the world, 2021



Source: Oxford Economics

Note: numbers may not sum to totals due to rounding.

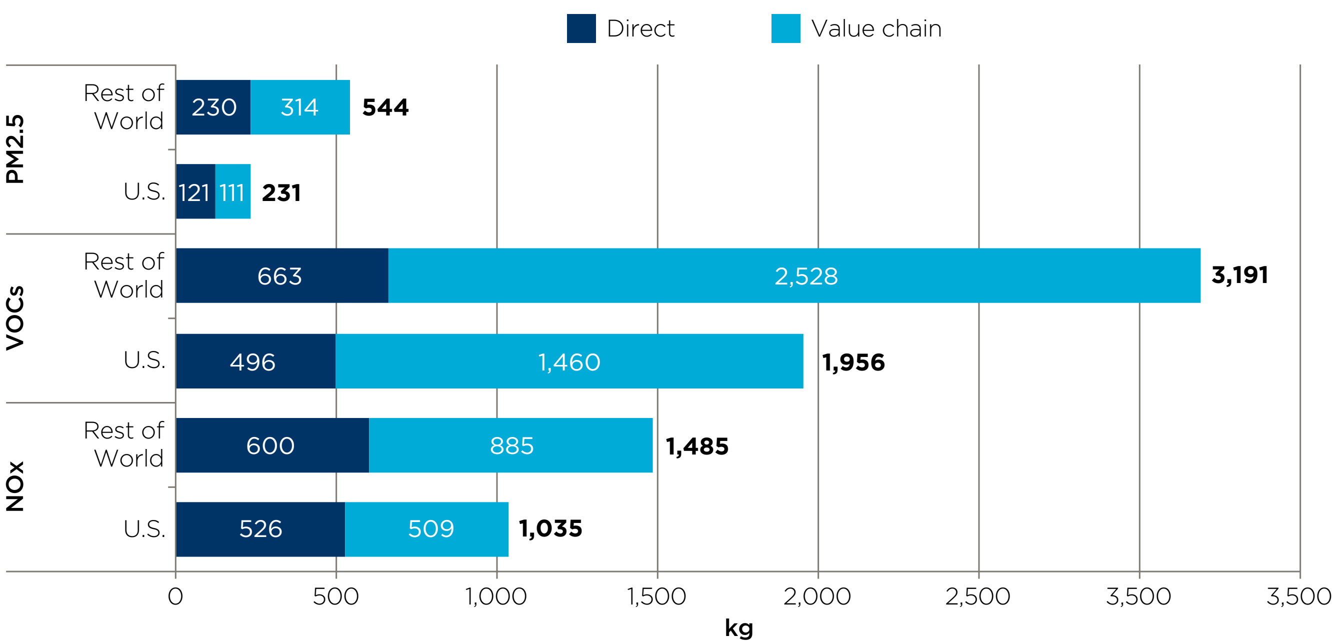
smaller, at around 530,000kg per $1 million (PPP) of output, than that associated with the sector in the rest of the world producing the same amount of output, with the latter being around 670,000kg per $1 million (PPP) of output. While the emissions produced from the U.S. extractive industries' own activities in producing a given amount of output are slightly larger (at 381,000kg compared to 369,000kg), this is outweighed by the U.S. extractive industries having fewer emissions "embedded" in their purchases from their supply chain (around 150,000kg for the U.S., compared to over 300,000kg for the rest of the world). It should be noted that scope 1 emissions for the extractive industries include fugitive emissions and, as discussed above, the extent of fugitive emissions will depend on the type of extraction.

3.2.2 Petrochemical manufacturing

The U.S. petrochemical manufacturing sector (NAICS codes 324, 325, and 326) produces significantly less PM2.5, NOx and VOCs in producing the same amount of output as the sector in the rest of the world (Fig. 7), emitting an estimated 43%, 70% and 61% as much of these pollutants respectively in producing the same amount of output. This reflects both lower emissions intensity in the U.S. sector's own activities and, especially, lower emissions intensity in its supply chain. Both in the U.S. and in the rest of the world, this sector is the amongst the most pollution-intensive of the five industries examined here.

Comparing the GHG emissions associated with the U.S. petrochemical manufacturing sector producing a given amount of output with those associated with the same amount of production happening elsewhere, the U.S. sector has the smaller GHG footprint. For each $1 million (PPP) of output, the U.S. sector emits just under 455,000kg of GHGs, while the sector in the rest of the world produces more than 665,000kg. The U.S. sector's scope 1 emissions are nearly 25% smaller, and it has significantly smaller estimated scope 3 emissions (those associated with its purchases from its supply chain).

Fig. 7: Emissions of air pollutants from producing $1 million (PPP) of output in the petrochemical manufacturing sector, U.S. and rest of the world, 2021



Source: Oxford Economics

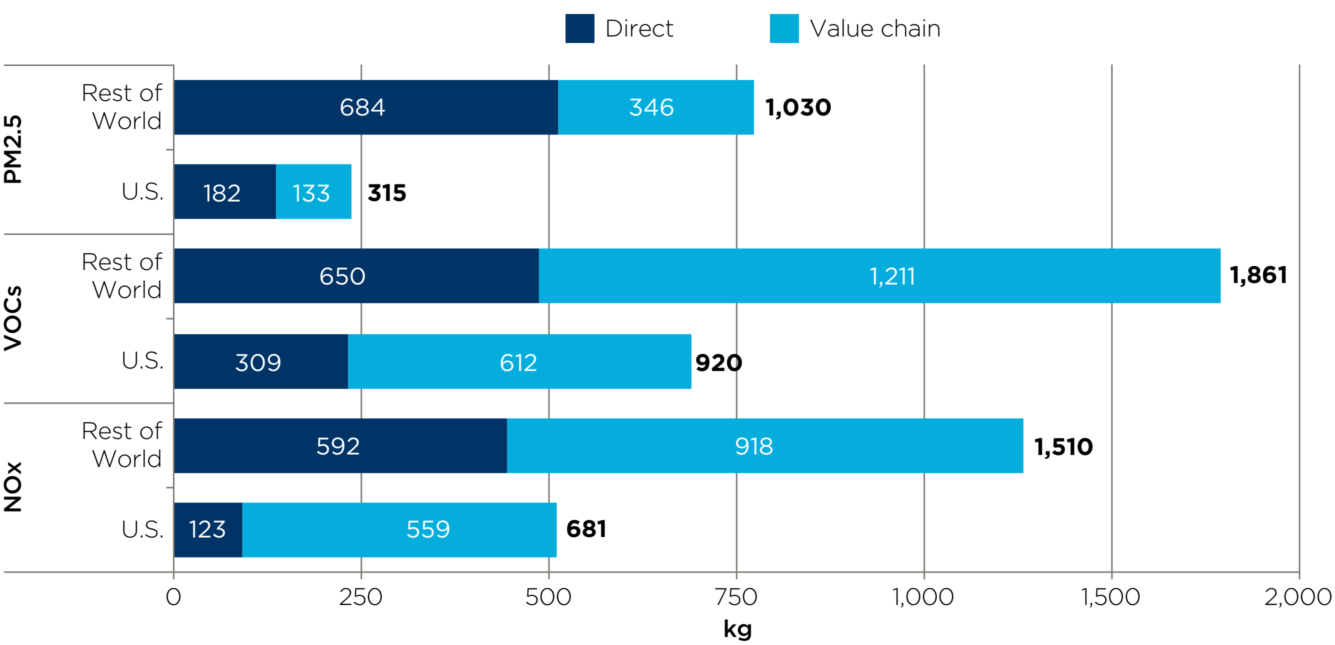
Note: numbers may not sum to totals due to rounding.

3.2.3 Non-metallic mineral product manufacturing

U.S. non-metallic mineral product manufacturing (NAICS code 327) produces far less PM2.5, VOCs, and NOx than the corresponding sector in the rest of the world when producing a given amount of output—around 31%, 49%, and 45% as much of the three pollutants respectively. Both in the U.S. and in the rest of the world, the sector's direct emissions account for a relatively high proportion of its total footprint for these pollutants (compared to several of the other industries considered in this analysis). Non-metallic mineral product manufacturing includes the manufacturing of a range of materials including cement, glass, and lime, and differences in the relative importance of these subsectors in different countries may contribute to international differences in pollution intensities.

Moreover, the production of a given amount of non-metallic mineral products in the U.S. is associated with fewer GHG emissions than the production of the same amount in the rest of the world. To produce $1 million (PPP) of output, the U.S. sector emits approximately 986,000kg of GHGs while the sector in the rest of the world produces more than 1,440,000kg GHGs (considering supply chains in both cases). The U.S. sector is less emissions-intensive both overall and in terms just of scope 1 emissions. That is, the U.S. sector is responsible for fewer GHG emissions both through its own activities and in its supply chain. This may reflect the areas of non-metallic mineral product manufacturing that U.S. activity is concentrated in. Cement manufacturing is responsible for around a quarter of all global manufacturing emissions, and China is responsible for a majority of global cement emissions, while the U.S. is responsible for around 2.6%.[32]

Fig. 8: Emissions of air pollutants from producing $1 million (PPP) of output in the non-metallic mineral product manufacturing sector, U.S. and rest of the world, 2021



Source: Oxford Economics

Note: numbers may not sum to totals due to rounding.

[32] *Climate TRACE*.

3.2.4 Metals, metal product and machinery manufacturing

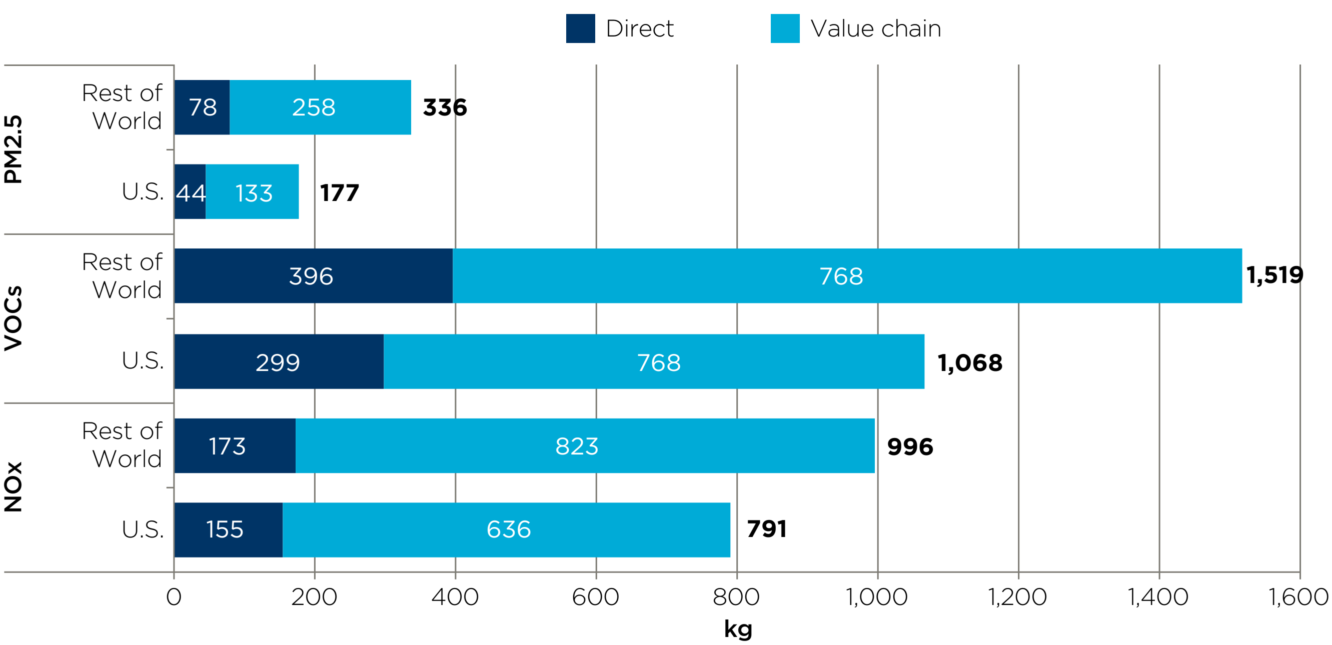
Production in the U.S. metals, metal product and machinery manufacturing sector (NAICS codes 331, 332 and 333) is less intensive in terms of the emission of PM2.5, VOCs and NOx than production by that sector in the rest of the world. The U.S. sector is estimated to be more than 20% less intensive with respect to NOx emissions than sector in the rest of the world and nearly 30% less intensive in terms of VOCs than the sector in the rest of the world. The relative difference in pollution intensities is greatest in the case of PM2.5, with the U.S. sector being estimated to be around 47% less PM2.5-intensive than the sector in the rest of the world.

In producing a given amount of output, the U.S. metals, metal product, and machinery manufacturing sector has a smaller carbon footprint than the sector in the rest of the world. For each $1 million (PPP) of output, the sector in the U.S. (including its supply chain) emits around 472,000kg of GHGs while the sector in the rest of the world (and its supply chain) emits over 570,000kg. While the U.S. sector's emissions from its own operations and from its purchases of electricity are higher (when producing a given amount of output), its significantly lower scope 3 emissions outweigh this.

3.2.5 Computer, electronic products and electrical equipment manufacturing

In producing a given amount of output, the U.S. computer, electronic product, and electrical equipment manufacturing sector (NAICS codes 334 and 335) is estimated to produce less than half as much PM2.5, NOx and VOCs than the sector in the rest of the world. In addition to having significantly less pollution-intensive activities itself, the U.S. sector has a significantly less pollution-intensive supply chain. This partly reflects lower pollution-intensity in the U.S.'s basic metals sector than in basic metals manufacturing in the rest of the world, as described

Fig. 9: Emissions of air pollutants from producing $1 million (PPP) of output in the metals, metal product and machinery manufacturing sector, U.S. and rest of the world, 2021



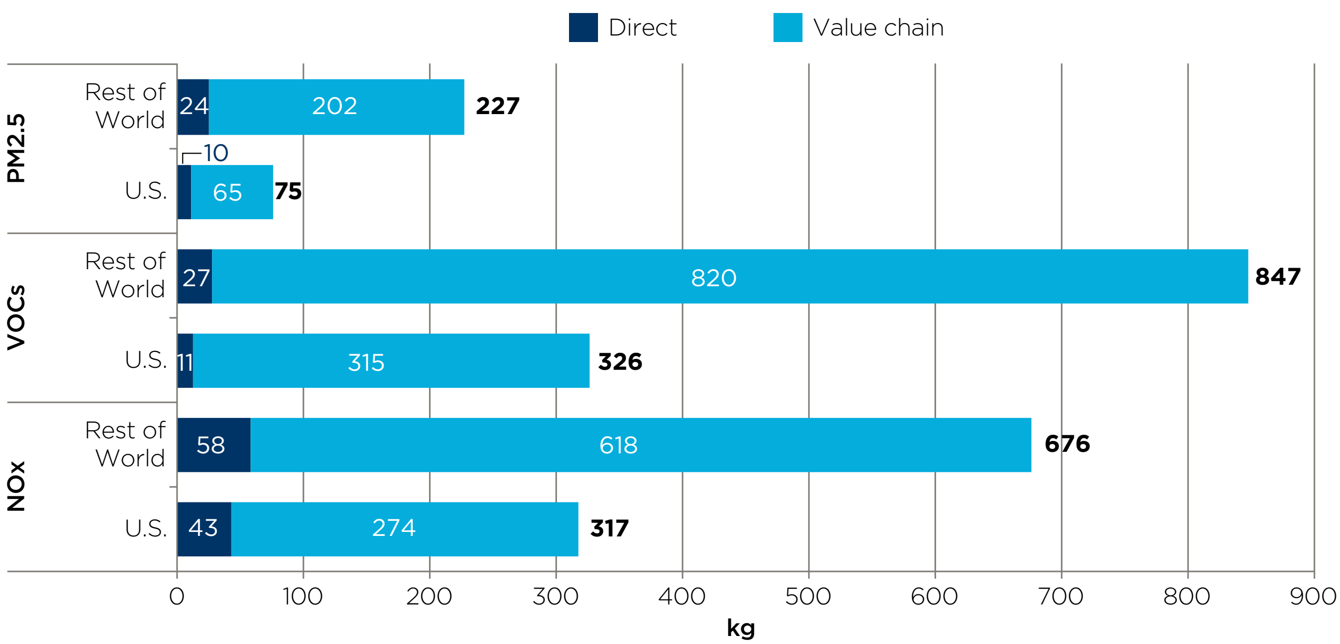
Source: Oxford Economics

Note: numbers may not sum to totals due to rounding.

above. Both in the U.S. and in the rest of the world, the sector's footprint in terms of emissions of these pollutants is driven mostly by its supply chain rather than its own activities.

In both the U.S. and the rest of the world, the computer, electronic product, and electrical equipment manufacturing sector is the least GHG-intensive of the five sectors considered in this chapter. Nonetheless, the total GHG footprint of producing a given amount of output in this sector in the rest of the world is more than 50% greater than that of doing so in the U.S., at over 335,000kg per $1 million (PPP) of output for the sector in the rest of the world versus over 200,000kg for the U.S. sector. The estimated scope 3 emissions associated with a given amount of production outside the U.S. are roughly double those associated with that amount of production by the sector in the U.S.; this outweighs the U.S. sector's larger scope 1 emissions.

Fig. 10: Emissions of air pollutants from producing $1 million (PPP) of output in the computer, electronic products and electrical equipment manufacturing sector, U.S. and rest of the world, 2021



Source: Oxford Economics

Note: numbers may not sum to totals due to rounding.

APPENDIX 1 – DETAILED RESULTS

Manufacturing's economic exposure to an 8 μg/m³ limit for PM2.5

	Manufacturing's economic exposure, GVA ($ billions)	Manufacturing's economic exposure, GVA, % of manufacturing total	Manufacturing's economic exposure, employment (thousands)	Manufacturing's economic exposure, employment, % of manufacturing total
All states	87.4	2.4%	311.6	1.9%
AK	0.0	0.0%	0.0	0.0%
AL	1.2	2.4%	4.4	1.3%
AR	0.6	2.4%	3.6	1.9%
AZ	0.5	0.9%	1.3	0.5%
CA	31.6	6.2%	119.0	7.1%
CO	2.3	3.7%	3.2	1.4%
CT	0.1	0.3%	0.3	0.1%
DC	0.0	0.0%	0.0	0.0%
DE	0.1	2.2%	0.2	0.6%
FL	0.1	0.1%	0.7	0.1%
GA	1.5	1.9%	7.6	1.4%
HI	0.0	0.0%	0.0	0.0%
IA	0.6	1.4%	3.9	1.5%
ID	0.0	0.1%	0.2	0.2%
IL	6.7	4.9%	28.4	4.2%
IN	3.7	3.0%	13.6	2.2%
KS	0.0	0.0%	0.1	0.0%
KY	0.6	1.1%	2.5	0.8%
LA	0.6	0.9%	1.1	0.5%
MA	0.3	0.4%	1.8	0.7%
MD	0.0	0.0%	0.0	0.0%
ME	0.0	0.0%	0.0	0.0%
MI	7.3	5.9%	26.9	4.1%
MN	0.7	1.0%	2.7	0.7%
MO	0.4	0.8%	1.8	0.5%
MS	0.3	1.3%	1.4	0.7%
MT	0.0	0.5%	0.3	0.8%
NC	0.9	0.8%	4.0	0.7%
ND	0.0	0.0%	0.0	0.0%
NE	0.0	0.0%	0.0	0.0%
NH	0.0	0.0%	0.0	0.0%
NJ	0.8	1.1%	1.0	0.3%
NM	0.1	0.4%	0.5	0.8%
NV	0.1	0.7%	1.2	1.0%
NY	0.0	0.0%	0.0	0.0%
OH	1.9	1.3%	10.6	1.3%
OK	0.3	0.5%	0.5	0.2%
OR	0.7	1.6%	4.9	2.1%
PA	4.5	3.0%	23.4	3.2%
RI	0.0	0.4%	0.2	0.5%
SC	0.1	0.3%	0.8	0.2%
SD	0.0	0.0%	0.0	0.0%
TN	1.0	1.4%	4.6	1.1%
TX	15.6	2.8%	29.0	2.0%
UT	1.4	3.7%	2.4	1.3%
VA	0.0	0.0%	0.0	0.0%
VT	0.0	0.0%	0.0	0.0%
WA	0.2	0.3%	1.3	0.4%
WI	0.2	0.3%	1.9	0.4%
WV	0.2	0.6%	0.4	0.5%
WY	0.0	0.0%	0.0	0.0%

Manufacturing's economic exposure to a 12 μg/m3 limit for PM2.5

	Manufacturing's economic exposure, GVA ($ billions)	Manufacturing's economic exposure, GVA, % of manufacturing total	Manufacturing's economic exposure, employment (thousands)	Manufacturing's economic exposure, employment, % of manufacturing total
All states	12.2	0.3%	36.2	0.2%
AK	0.0	0.0%	0.0	0.0%
AL	0.0	0.0%	0.0	0.0%
AR	0.0	0.0%	0.0	0.0%
AZ	0.1	0.3%	0.2	0.1%
CA	11.6	2.3%	33.3	2.0%
CO	0.0	0.0%	0.0	0.0%
CT	0.0	0.0%	0.0	0.0%
DC	0.0	0.0%	0.0	0.0%
DE	0.0	0.0%	0.0	0.0%
FL	0.0	0.0%	0.0	0.0%
GA	0.0	0.0%	0.0	0.0%
HI	0.0	0.0%	0.0	0.0%
IA	0.0	0.0%	0.0	0.0%
ID	0.0	0.0%	0.0	0.0%
IL	0.0	0.0%	0.0	0.0%
IN	0.0	0.0%	0.1	0.0%
KS	0.0	0.0%	0.0	0.0%
KY	0.0	0.0%	0.0	0.0%
LA	0.0	0.0%	0.0	0.0%
MA	0.0	0.0%	0.0	0.0%
MD	0.0	0.0%	0.0	0.0%
ME	0.0	0.0%	0.0	0.0%
MI	0.0	0.0%	0.0	0.0%
MN	0.0	0.0%	0.0	0.0%
MO	0.0	0.0%	0.0	0.0%
MS	0.0	0.0%	0.0	0.0%
MT	0.0	0.0%	0.0	0.0%
NC	0.0	0.0%	0.0	0.0%
ND	0.0	0.0%	0.0	0.0%
NE	0.0	0.0%	0.0	0.0%
NH	0.0	0.0%	0.0	0.0%
NJ	0.0	0.0%	0.0	0.0%
NM	0.0	0.0%	0.0	0.0%
NV	0.0	0.0%	0.0	0.0%
NY	0.0	0.0%	0.0	0.0%
OH	0.0	0.0%	0.0	0.0%
OK	0.0	0.0%	0.0	0.0%
OR	0.3	0.6%	2.0	0.9%
PA	0.2	0.1%	0.7	0.1%
RI	0.0	0.0%	0.0	0.0%
SC	0.0	0.0%	0.0	0.0%
SD	0.0	0.0%	0.0	0.0%
TN	0.0	0.0%	0.0	0.0%
TX	0.0	0.0%	0.0	0.0%
UT	0.0	0.0%	0.0	0.0%
VA	0.0	0.0%	0.0	0.0%
VT	0.0	0.0%	0.0	0.0%
WA	0.0	0.0%	0.0	0.0%
WI	0.0	0.0%	0.0	0.0%
WV	0.0	0.0%	0.0	0.0%
WY	0.0	0.0%	0.0	0.0%

APPENDIX 2 – DETAILED METHODOLOGY

ESTIMATES OF MANUFACTURING'S ECONOMIC EXPOSURE TO TIGHTER AIR QUALITY STANDARDS FOR PM2.5

Our estimates of the manufacturing sector's economic exposure to more stringent air quality standards for PM2.5 drew on air quality and pollutant emissions data from the EPA as well as economic data from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). We did not model the economic exposure of the broader economy and other sectors such as electricity generation, motor vehicle use and agriculture to tighter air quality standards.

Counties in industrial and population centers have monitoring stations that measure ambient air quality, which are compared to the relevant NAAQS standards. Approximately one-third of U.S. counties (around 1,000 out of 3,143 counties), accounting for more than 80% of the U.S. population, have monitoring stations in them. The EPA tends to place monitors in areas "of relatively high population and/or areas believed to have relatively higher pollutant concentrations".[33] As such, there is unlikely to be significant additional economic exposure in counties that are not currently monitored.

EPA data in monitored counties were used to identify counties that would have been above the different air quality standards for PM2.5 considered in 2019 to 2021. Data on industrial emissions were then used to identify the industries that were the significant industrial contributors to pollution in those counties identified as exceeding the standard. The percentage reduction in emissions by these contributors that was required was then calculated. This was done by assuming that in order to reduce pollutant levels by a given percentage in order to reach compliance with the standard, industrial emissions would be required to reduce by that percentage, and that all of the reduction in industrial emissions would occur in industries identified as significant contributors in a given county (with significant industries including all of those contributing at least 5% of total industrial emissions). Primary emissions of PM2.5 were the focus of this analysis. This gave percentage emissions reductions required for each sector in each county. From these, the percentage reduction in emissions required for each sector in each state were derived.

The percentage reductions in emissions required for each sector in each state were then translated into estimates of "economic exposure" for the manufacturing sector. Economic exposure is a measure of the scale of the economy that could potentially be impacted by changes in industrial activities to meet the more stringent standards and is not a forecast of the economic cost of adapting to any new air quality standards. The manufacturing sector was defined as per a definition provided by the NAM, and included traditional manufacturing (NAICS codes 31-33) and key manufacturing supply chain inputs including forestry and logging (NAICS code 113), extractive industries (NAICS code 211, 212 and 213), and other stationary industrial sources, namely heavy construction (NAICS code 237), rail and pipeline transportation (NAICS codes 482 and 486), warehousing and storage (NAICS code 493), and waste management and remediation (NAICS code 562).

[33] EPA, *Who decides where monitors get placed?*.

The manufacturing sector's economic exposure was estimated by applying the percentages that each manufacturing sector's emissions would be required to reduce by to estimates of each manufacturing sector's GVA and employment in each state. The estimates were sourced from the BEA and BLS. Quantifying economic exposure at the state level ensures that it is being assessed at the same level as the State Implementation Plans for reducing emissions are produced. 2021 estimates of state-level GVA and employment for each sector were used.

In order to estimate the GDP and jobs supported in the U.S. by the supply chain spending of the exposed portion of the manufacturing sector, Oxford Economics' proprietary Global Sustainability Model (described further below) was used to estimate the economic footprint of the exposed portion of the manufacturing sector and identify its indirect economic impact in the U.S. in terms of jobs and GVA. Where the exposed portion of manufacturing purchases from the U.S. manufacturing sector, there is uncertainty about the extent to which that supplier is itself an exposed manufacturer (which would entail double-counting). A range of estimates were therefore derived by computing the indirect economic impact assuming either 0% or 100% overlap.

The last element of the economic exposure analysis was concerned with the value of growth in manufacturing sectors in counties identified as exceeding an 8 μg/m^3 standard for PM2.5, which could be restricted under such a limit. The analysis looked at the period between 2024, when it is assumed that governors would submit designation recommendations, and 2031, assuming that the EPA would finalize designations in 2025 and, as noted above, nonattainment areas are expected to reach attainment by the end of the sixth calendar year after designation. To derive this estimate, we used Oxford Economics' forecasts of industrial GVA growth in each state and make the simplifying assumption that an industry's PM2.5 emissions evolve in line with its GVA over the period being analysed. The change in industrial emissions in each industrial sector between 2024 and 2031 was then calculated on this basis. The net change in industrial emissions in each county was then calculated. In counties where a net increase in industrial emissions was predicted between 2024 and 2031, it was assumed that each sector would have to forego emissions growth proportionally such that industrial emissions did not increase above 2021 levels in net terms – meaning that counties where emissions were estimated to fall between 2021 and 2024 were thereby given "headroom" for 2024 to 2031 accordingly.

The emissions growth restricted was then aggregated up to the state level for each sector. These state-level estimates of restricted emissions growth were then calculated as a fraction of state-level total PM2.5 emissions for each industry in 2021. Utilizing the assumption that GVA and emissions move together, this fraction was applied to the 2021 estimate of state-level industry GVA for each manufacturing sector to derive an estimate of the GVA associated with the restricted growth. An estimate of the jobs associated with the potentially restricted growth was then derived in a similar way based on the 2021 estimate of employment in each sector, scaling to account for forecasted changes in labor productivity in each sector and state between 2021 and 2031.

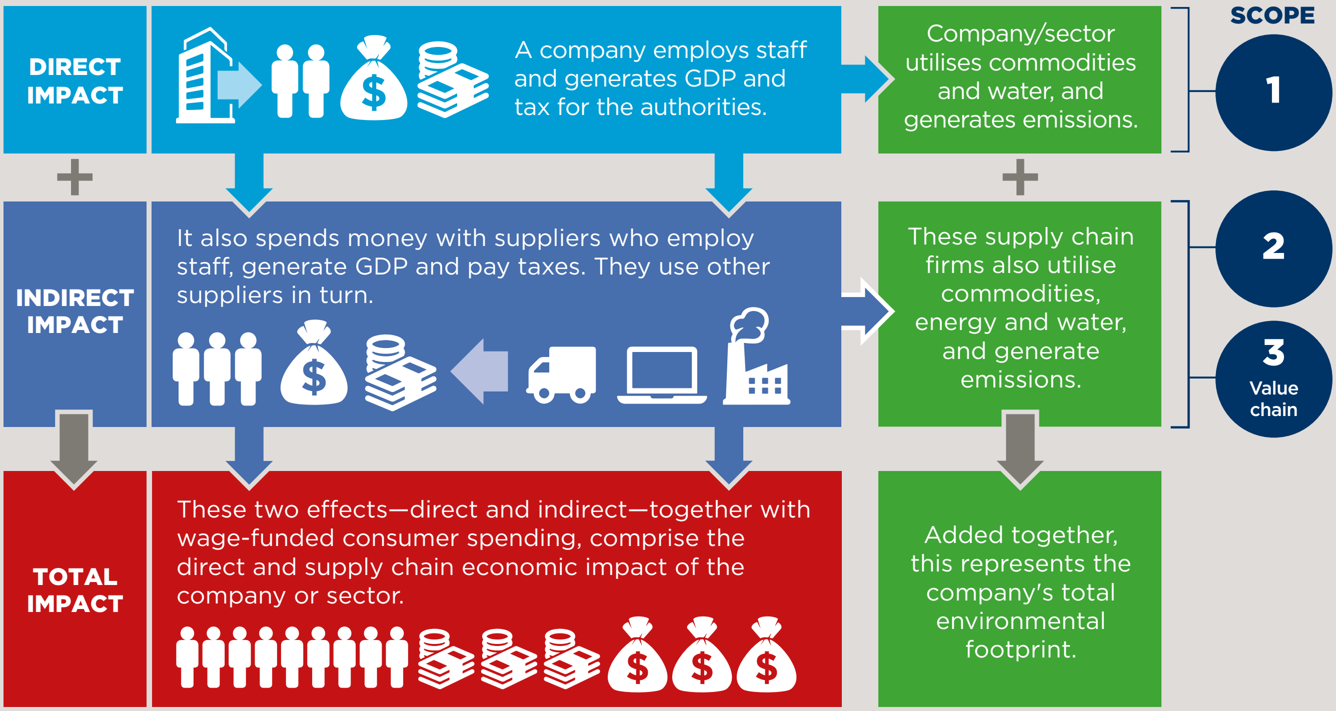
ENVIRONMENTAL PERFORMANCE OF U.S. VS. GLOBAL MANUFACTURING

The next element of our analysis was a comparison of the relative environmental performance of U.S. manufacturing in five key manufacturing sectors. The five sectors represent a diversity of activity and were as follows: extractive industries (NAICS codes 211, 212 and 213); metals, metal product and machinery manufacturing (NAICS codes 331, 332 and 333); petrochemicals manufacturing (NAICS codes 324, 325 and 326); computer and electrical equipment manufacturing (NAICS codes 334 and 335); and non-metallic mineral manufacturing (NAICS code 327).

This analysis draws on Oxford Economics' Global Sustainability Model (GSM). The GSM analyzes the ways that global industries interact, allowing us to understand how supply chains involve trade between different sectors both domestically and internationally, generating a broad economic footprint. It then maps that economic footprint to an associated environmental footprint using data on how specific sectors in different countries generate emissions or consume resources. The figure below illustrates this mapping.

This analysis modeled the environmental impact of producing a given amount of output—$1 million—both in the U.S. and internationally. The production outside the U.S. was allocated to countries based on their output of the relevant products in 2021, using production data from Oxford Economics' databanks. To equate production volumes in the U.S. and international scenarios, the value of the output in each country was then scaled to account for differences in purchasing power between countries, based on PPP and non-PPP exchange rates from Oxford Economics' databanks.

Fig. 11: Measuring environmental footprints using the GSM



The emissions of PM2.5, NOx and VOCs are quantified in terms of their direct and indirect impact. The direct impact includes all emissions or consumption by companies within the sector themselves. The indirect impact includes all activities within their supply chain.

Greenhouse gas emissions were also estimated, given their salience in environmental policy. Greenhouse gas emissions were quantified in line with the Greenhouse Gas Protocol scopes 1, 2, and 3 estimates.

Scope 1 refers to the direct emissions from the operation of a company or industry's own facilities and assets.

Scope 2 refers to the indirect emissions that are made by other organizations that provide electricity and heat to the company or industry, i.e., the energy sector.

Scope 3 value chain refers to the indirect emissions that occur in the company or industry's upstream supply chain as a result of the goods and services it purchases. Our analysis quantifies GHG emissions in CO_2 equivalent terms, which accounts for the different potencies of different greenhouse gases.

OXFORD ECONOMICS

Oxford Economics was founded in 1981 as a commercial venture with Oxford University's business college to provide economic forecasting and modeling to UK companies and financial institutions expanding abroad. Since then, we have become one of the world's foremost independent global advisory firms, providing reports, forecasts, and analytical tools on more than 200 countries, 100 industries, and 8,000 cities and regions. Our best-in-class global economic and industry models and analytical tools give us an unparalleled ability to forecast external market trends and assess their economic, social, and business impact.

Headquartered in Oxford, England, with regional centers in New York, London, Frankfurt, and Singapore, Oxford Economics has offices across the globe in Belfast, Boston, Cape Town, Chicago, Dubai, Dublin, Hong Kong, Los Angeles, Mexico City, Milan, Paris, Philadelphia, Stockholm, Sydney, Tokyo, and Toronto. We employ 450 staff, including more than 300 professional economists, industry experts, and business editors—one of the largest teams of macroeconomists and thought leadership specialists. Our global team is highly skilled in a full range of research techniques and thought leadership capabilities from econometric modeling, scenario framing, and economic impact analysis to market surveys, case studies, expert panels, and web analytics.

Oxford Economics is a key adviser to corporate, financial, and government decision-makers and thought leaders. Our worldwide client base now comprises over 2,000 international organizations, including leading multinational companies and financial institutions; key government bodies and trade associations; and top universities, consultancies, and think tanks.

April 2023

Oxford Economics
4 Millbank,
London
SW1P 3JA, UK

Tel: +44 203 910 8000

Cover Photo

kckate16/Shutterstock.com

Panuwat Phimpha/Shutterstock.com

OXFORD ECONOMICS

Global headquarters
Oxford Economics Ltd
Abbey House
121 St Aldates
Oxford, OX1 1HB
UK
Tel: +44 (0)1865 268900

London
4 Millbank
London, SW1P 3JA
UK
Tel: +44 (0)203 910 8000

Frankfurt
Marienstr. 15
60329 Frankfurt am Main
Germany
Tel: +49 69 96 758 658

New York
5 Hanover Square, 8th Floor
New York, NY 10004
USA
Tel: +1 (646) 786 1879

Singapore
6 Battery Road
#38-05
Singapore 049909
Tel: +65 6850 0110

Europe, Middle East and Africa

Oxford
London
Belfast
Dublin
Frankfurt
Paris
Milan
Stockholm
Cape Town
Dubai

Americas

New York
Philadelphia
Boston
Chicago
Los Angeles
Toronto
Mexico City

Asia Pacific

Singapore
Hong Kong
Tokyo
Sydney

Email:
mailbox@oxfordeconomics.com

Website:
www.oxfordeconomics.com

Further contact details:
www.oxfordeconomics.com/about-us/worldwide-offices