Impact of Air Pollution on Human Capital

Kenan Karakulah, Glenn-Marie Lange, Yewande Awe, and Shun Chonabayashi

Main Messages

- In 2019, outdoor and household air pollution jointly accounted for 6.7 million premature deaths globally. The majority of these were caused by human exposure to fine inhalable particles or fine particulate matter, also known as PM$_{2.5}$. While noting that no safe level of exposure to air pollution exists, analysis shows that at the global level, per capita human capital would have increased by about US$290 in 2018 if there were no premature deaths from air pollution.

- At the regional level, the loss of human capital resulting from premature deaths attributable to air pollution ranged from 0.1 percent in North America and Europe and Central Asia to 1.4 percent in South Asia in 2018. The impact was higher in low-income and lower-middle-income countries than in high-income countries.

Introduction

Air pollution is one of the world’s leading risk factors for health and the cause of illness and premature death from diseases such as lung cancer, ischemic heart disease, chronic obstructive pulmonary disease, stroke, and pneumonia. In this analysis, air pollution includes ambient particulate matter with a diameter of less than 2.5 microns (PM$_{2.5}$), household PM$_{2.5}$ from the burning of solid fuels, and ambient ozone pollution. In 2019, air pollution was responsible for 6.7 million deaths globally, which accounted for about 11.8 percent of total deaths that year. Following high systolic blood pressure and smoking, air pollution was the third leading risk factor for death in 2019 (figure 8.1).
The majority of deaths related to air pollution are caused by human exposure to fine inhalable particles or fine particulate matter of 2.5 microns or less in diameter (PM$_{2.5}$) (see box 8.1). As shown in figure 8.2, outdoor air pollution in cities and rural areas was estimated to cause some 4.1 million premature deaths globally in 2019. The combination of declining air quality, increasing rates of urbanization, and population aging has contributed to a rise in the number of deaths from ambient PM$_{2.5}$ each year. Household air pollution from solid fuels was the leading risk factor for premature deaths from exposure to air pollution until 2009. However, the number of premature deaths resulting from household air pollution from solid fuels has been constantly decreasing, while premature deaths from ambient PM$_{2.5}$ have been increasing. Household air pollution from solid fuels was estimated to cause about 2.3 million premature deaths globally in 2019, while ambient ozone pollution was estimated to cause about 0.4 million premature deaths globally in 2019.

Map 8.1 illustrates disability-adjusted life years (DALYs) attributable to air pollution by country. The share of DALYs attributable to air pollution is quite high in South Asia, East Asia, Sub-Saharan Africa, the Middle East and North Africa, and the Balkans, while it is quite low in North America, Northern Europe, and Western Europe. According to Gordon et al. (2017), the people who are most affected by air pollution are children and the elderly, particularly in low- and middle-income countries.
Inhalable, fine particles, also known as PM$_{2.5}$, are the most detrimental air pollutants to human health. PM$_{2.5}$ comes from both natural and anthropogenic origins: in the former case, for example, desert dust or sea spray, and in the latter case, burning of fossil fuels, transport, burning of agricultural residues, or solid fuels. Most deaths that are attributed to outdoor PM$_{2.5}$ air pollution globally are caused by cardiovascular disease. Global estimates of the health burden of air pollution typically assume that all PM$_{2.5}$ particles are equally toxic. In other words, no distinction is made between PM$_{2.5}$ from different sources or between the chemical species present in PM$_{2.5}$ mass. Particles in low- and middle-income countries usually have very different sources and compositions from particles in high-income countries. Therefore, the health effects per unit mass of PM$_{2.5}$ are likely different in low- and middle-income countries from those in high-income countries, which form the basis of present global and regional assessments of health impacts (Thurston et al. 2021).

Recent analytical work by the World Bank shows that the toxicity of PM$_{2.5}$ is dependent on the source and chemical constituents or species of the PM$_{2.5}$ particles (Thurston et al. 2021). Trace constituents from PM$_{2.5}$ and PM$_{2.5}$ mass from fossil fuel combustion are among the greatest contributors to PM$_{2.5}$ toxicity. Of the fossil fuel combustion particles, coal- and traffic-related PM$_{2.5}$ were found to be most consistently associated with cardiovascular mortality, especially ischemic heart disease or heart attacks, as a result of short- and long-term exposure to PM$_{2.5}$ particles. Notably, sulfate or particulate sulfur (a trace constituent of PM$_{2.5}$ and a marker of coal burning) is among the most, if not the most, important constituents of PM$_{2.5}$ associated with additional hospital admissions and mortality. Overall, the cardiovascular disease risks of sulfate, elemental carbon (another trace constituent of PM$_{2.5}$, and a marker of diesel-fueled vehicle emissions), and PM$_{2.5}$ from coal combustion are larger than that of PM$_{2.5}$ mass in general. The targeting of these sources (coal burning and diesel-fueled vehicles) as a matter of priority in World Bank client countries has important implications for reducing premature death and morbidity and the associated damage to human capital in low- and middle-income countries. Ambient air pollution control efforts in low- and middle-income countries need to account for the contributing sources of PM$_{2.5}$ and the toxicity of the PM$_{2.5}$ from each source category. Reducing pollution from these sources can be expected to return greater cardiovascular disease health benefits per unit mass of PM$_{2.5}$ reduced than if PM$_{2.5}$ mass continues to be addressed equally, irrespective of source and composition.

With respect to PM$_{2.5}$ of natural origins, a separate World Bank report finds that there is evidence of an association between long-term exposure to dust and its markers and cardiovascular and respiratory mortality (Ostro, Awe, and Sánchez-Triana 2021). Although the association is not as strong as those observed for sulfate and elemental carbon, the findings indicate that absent further evidence, it is reasonable to assume that the health risk per microgram of natural dust is generally similar to that of the constituents of particulate matter, with the exceptions of sulfate and elemental carbon.
The adverse effects of air pollution on human capital include premature mortality and ill health (morbidity), which affect labor productivity and economic growth (India State-Level Disease Burden Initiative Air Pollution Collaborators 2020). The potential impacts of air pollution are wide-ranging, including but not limited to deaths from carbon monoxide poisoning and respiratory and heart-related health problems stemming from pollution exposure, damaging children’s health and survival, diminishing labor productivity because of worsening cognitive performance, and
reducing students’ ability to benefit from education (Lavy, Ebenstein, and Roth 2014; Shehab and Pope 2019; Zhang, Chen, and Zhang 2018).

Estimates of premature mortality have been made by the Global Burden of Disease Study (noting some caveats, see box 8.2), and the benefits of reducing premature mortality can be calculated. But calculating the impact on morbidity and the benefits from reducing air pollution for human capital is more challenging. First, it is challenging to measure the precise effects of air pollution on labor productivity and cognitive performance although the deaths stemming from air pollution are observable. In addition, deaths caused by air pollution can take place in different time periods depending on the form and impact of the air pollution. While an intense carbon monoxide intake could cause a sudden death, persistent exposure to low levels of carbon monoxide could cause death in months or years. The available global data do not include information on the duration of exposure to air pollution before death occurs. Furthermore, the literature documenting the effects of air pollution on human productivity

**BOX 8.2 Challenges in Estimating Global Mortality Attributable to Air Pollution**

Notwithstanding that it is well known that PM$_{2.5}$ is the most detrimental air pollutant to human health, there are significant uncertainties that remain to be addressed in estimating global mortality attributable to air pollution. Among the most important is the extrapolation of the integrated exposure-response function, based primarily on studies in Europe and North America, to the rest of the world where the mixture and concentrations of PM$_{2.5}$ are very different. Another major uncertainty is the question of the toxicity of blowing dust. Clearly, for specific countries and regions, the treatment of the toxicity of dust can have an important impact on the mortality estimates.

A recent World Bank report assessed the methodological aspects underlying changing the Global Burden of Disease estimates for ambient air pollution. The report found that while there have been significant improvements, notably in exposure methodology, the lack of ground-level air quality monitors in several regions—the Middle East and North Africa, Sub-Saharan Africa, and South Asia—has resulted in poorer predictions of PM$_{2.5}$ relative to other regions (Ostro et al. 2018).

In regions where air quality data obtained from ground-level monitors are not available, global estimates of the mortality burden of ambient air pollution have used satellite-derived measurements to predict ambient ground-level concentrations of PM$_{2.5}$. Satellite-derived measurements have been used successfully in regions such as Europe, North America, and Organisation for Economic Co-operation and Development countries, where established and strong air quality monitoring networks exist for calibrating satellite measurements. However, based on selected pilot studies in nine cities in low- and middle-income countries, separate World Bank analytical work found that the use of satellite-derived measurements for predicting ambient air quality is not reliable. The measurements resulted in large errors, ranging from 21 to 85 percent in satellite-based estimates of daily average PM$_{2.5}$ concentrations at a given location in a city (Alvarado et al. 2019; World Bank 2021a).
is limited. This chapter reflects only the direct effect of air pollution on premature mortality, because of limited data on productivity impacts.

This chapter builds on chapter 9 in the 2018 edition of *The Changing Wealth of Nations* (Lange, Wodon, and Carey 2018), which provided a measure of the loss, or depreciation, of human capital associated with premature deaths from exposure to air pollution. The previous work informed the treatment of air pollution–related damage in the measurement of adjusted net saving, but it noted that future work would need to address the impact of air pollution on human capital—which this chapter aims to accomplish.

### Incorporating the Impact of Air Pollution into the Human Capital Calculations

This chapter estimates the impact of air pollution exposure on human capital by measuring the difference between human capital under actual pollution conditions and the hypothetical value of human capital if there were no premature deaths from air pollution. This approach captures just one aspect of the impacts of air pollution on human health—the most severe outcome, premature death. Although there are other channels through which air pollution exposure may have an impact on human capital, such as reduced productivity and labor force participation, this work focuses only on the impact of premature deaths using readily available data from the Global Burden of Disease Study.

As the human capital methodology suggested, survival rate is a critical parameter in the human capital calculations, since the probability of surviving one more year determines the population who will be in the workforce one more year. The survival rates used in the human capital calculations combine all causes of death, including premature mortality resulting from air pollution. To estimate the impact of air pollution in the human capital calculations, premature deaths resulting from air pollution are separated from the total number of deaths. Deaths are considered as air pollution–related if they are associated with any air pollution risk factors in the Global Burden of Disease Study data, including household air pollution from solid fuels, ambient particulate matter pollution, and ambient ozone pollution. Once the number of deaths caused by air pollution is excluded from the total number of deaths, the change in the death rates improves the survival rates. The survival rates are calculated as

\[
\nu_{a+1}^\text{base} = 1 - \text{death}_a^{\text{all causes}},
\]

\[
\nu_{a+1}^\text{air pollution} = 1 - \text{death}_a^{\text{excl. air pollution}},
\]

where \( \text{death}_a \) is the death rate of age \( a \), and \( \nu_{a+1} \) is the probability of surviving one more year of age \( a \).

Therefore, the stock of human capital is calculated using the adjusted survival rates, as explained in chapter 7. The difference between the base
human capital stock and the adjusted human capital stock is considered the hypothetical value of human capital if there were no premature deaths caused by air pollution.

\[
\Delta HC = HC_{\text{no air pollution}} - HC_{\text{with air pollution}}. 
\]

(8.3)

It is important to note that mortality is valued within the framework of the human capital methodology, which uses a discounted lifetime income approach. The cost of premature deaths caused by air pollution represents the discounted value of the forgone labor income that sufferers of fatal illness would have earned over their remaining working lives had they not died. This income-based measure is different from a welfare-based approach to valuing mortality, and the welfare-based estimate can be magnitudes higher.

**Estimates of the Impact of Air Pollution on Human Capital**

At the global level, it is estimated that the cost of premature deaths caused by air pollution—including ambient particulate matter, household PM$_{2.5}$ from cooking with solid fuels, and ambient ozone—on per capita human capital was about US$290 in 2018 (table 8.1). In other words, globally

<table>
<thead>
<tr>
<th>TABLE 8.1 Loss of Per Capita Human Capital Because of Premature Deaths Attributable to Air Pollution, by Income Group and Region, in US Dollar Terms, 1995–2018</th>
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<tbody>
<tr>
<td><strong>2018 US$</strong></td>
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<tr>
<td><strong>Income group and region</strong></td>
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<tr>
<td>Low-income</td>
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<tr>
<td>Lower-middle-income</td>
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<td>Upper-middle-income</td>
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<td>High-income: non-OECD</td>
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<tr>
<td>High-income: OECD</td>
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<tr>
<td><strong>Region</strong></td>
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<tr>
<td>East Asia and Pacific</td>
</tr>
<tr>
<td>Europe and Central Asia</td>
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<tr>
<td>Latin America and the Caribbean</td>
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<tr>
<td>Middle East and North Africa</td>
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<td>North America</td>
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<tr>
<td>South Asia</td>
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<tr>
<td>Sub-Saharan Africa</td>
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<tr>
<td>World</td>
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</table>

Source: World Bank staff calculations.

Note: OECD = Organisation for Economic Co-operation and Development.
per capita human capital would have increased by about 0.3 percent in 2018 if there were no premature deaths resulting from exposure to air pollution (figure 8.3 and figure 8.4). The estimates of the impact of eliminating air pollution suggest that there was a slight improvement in air quality at the global level from 1995 to 2018. The impact of the elimination of air pollution on human capital was 0.4 percent in 1995 and 0.3 percent in 2018 (table 8.2).

At the regional level, loss of human capital because of premature deaths from exposure to air pollution is quite variable, ranging from 0.1 percent in North America to 1.4 percent in South Asia in 2018. Since air pollution is quite high in South Asia, Sub-Saharan Africa, and the Middle East and North Africa, reducing air pollution will have a significant impact on human capital in the countries in these regions. Per capita human capital in South Asia could improve by US$208 if there were no premature deaths resulting from exposure to air pollution. Similarly, per capita human capital in Sub-Saharan Africa and the Middle East and North Africa is estimated to improve by US$105 and US$213, corresponding to increases of 0.9 and 0.7 percent, respectively. The loss of per capita human capital resulting from premature deaths from exposure to air pollution is estimated at only 0.1 percent in North America and Europe and Central Asia (table 8.1 and table 8.2).

The estimates of the loss of per capita human capital because of premature deaths attributable to air pollution point out that the loss was greater than 1 percent in lower-middle-income and low-income countries, while the loss was only 0.1 percent in high-income Organisation for Economic Co-operation and Development (OECD) countries in...
2018 (table 8.1 and table 8.2). This indicates that the change in per capita human capital resulting from decreased air pollution becomes relatively smaller as total human capital increases because of economic growth. In addition, countries that suffer from air pollution are mostly lower-middle-income and low-income countries. The loss in per capita human capital in lower-middle-income countries and low-income countries is estimated at US$199 and US$58, respectively (table 8.1). In US dollar terms, the highest loss is US$675, which is estimated for high-income non-OECD countries because of some countries in the Middle East and North Africa.

At the country level, the loss of per capita human capital resulting from premature deaths attributable to air pollution is highest in the Solomon Islands, estimated at about 5.0 percent loss of per capita human capital in 2018. The loss of per capita human capital in Papua New Guinea and Pakistan was also quite high, at 2.2 and 1.9 percent, respectively (figure 8.5). These results are not surprising since the shares of air pollution–related premature deaths in the Solomon Islands, Papua New Guinea, and Pakistan are among the highest worldwide.

China and India need special focus in terms of reducing air pollution–related deaths. More than 1 million deaths are attributable to air pollution in each of these countries. In other words, about 12 percent of deaths in India and China are attributable to air pollution. As figure 8.5

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<tr>
<td><strong>Income group</strong></td>
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<tr>
<td>Low-income</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>0.5</td>
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<tr>
<td>Lower-middle-income</td>
<td>1.3</td>
<td>1.4</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Upper-middle-income</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>High-income: non-OECD</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>High-income: OECD</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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</tr>
<tr>
<td><strong>Region</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>East Asia and Pacific</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Europe and Central Asia</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Latin America and the Caribbean</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Middle East and North Africa</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>North America</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>South Asia</td>
<td>1.6</td>
<td>1.7</td>
<td>1.6</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>World</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
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</table>

Source: World Bank staff calculations.
Note: OECD = Organisation for Economic Co-operation and Development.
illustrates, about a 1.4 percent loss of per capita human capital is estimated in India and 0.5 percent in China because of premature deaths from exposure to air pollution in 2018. Although the numbers of deaths are close in these countries, the impacts of reducing air pollution–related deaths are quite different. The reason is that the magnitude of reducing or eliminating air pollution is smaller as income level increases. As illustrated in figure 8.5, the magnitude of the loss of per capita human capital because of premature deaths stemming from exposure to air pollution is higher in low-income and lower-middle-income countries.

**Conclusion**

Air pollution is one of the world’s leading health risk factors after high systolic blood pressure and smoking. In addition to premature deaths, air pollution has diverse adverse effects, including but not limited to worsening cognitive performance, reducing labor productivity, damaging children’s health, and reducing students’ ability to benefit from education. Additionally, there are airborne pollutants other than PM$_{2.5}$ that are harmful to health (box 8.3).

Although air pollution has some significant productivity effects on human capital, it is difficult to measure the precise effects of air pollution
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on labor productivity and cognitive performance. Therefore, this chapter has provided the impact of air pollution exposure as the gap between human capital estimated under actual pollution conditions and the hypothetical value of human capital if there were no premature deaths from exposure to air pollution in 146 countries throughout 1995–2018.

The estimates suggest that the loss of per capita human capital globally because of premature deaths attributable to air pollution was about 0.3 percent in 2018. On average, the percentage loss of per capita human capital is greater for lower-middle-income countries, highlighting the importance of improving air quality management in developing countries where one of the many benefits would include higher human capital.

In addition, COVID-19 has exacerbated the premature deaths from exposure to air pollution. A significant fraction of worldwide COVID-19 mortality is attributable to the long-term exposure to ambient fine particulate air pollution (Cole, Ozgen, and Strobl 2020; Pozzer et al. 2020). In addition, some recent research shows that higher historical PM$_{2.5}$ exposures are positively associated with higher country-level COVID-19

**BOX 8.3 More Research Is Needed on the Health Impacts of Air Pollution**

Air pollution is associated with many detrimental but less researched health impacts and conditions (Sánchez-Triana et al. 2015; World Bank 2020; World Bank 2021b), such as infant mortality (Heft-Neal et al. 2018), low birth weight (Ezziane 2013), preterm delivery (Liu et al. 2019), mental health problems (Shin, Park, and Choi 2018), neurological impairment (Xu, Ha, and Basnet 2016; Zhang, Chen, and Zhang 2018) including dementia in later life (Carey et al. 2018), type 2 diabetes (Bowe et al. 2018), and irreversible eyesight loss (Chua et al. 2021). Dose-response functions have been established for PM$_{2.5}$ and the following health outcomes: (1) ischemic heart disease, (2) lung cancer, (3) chronic obstructive pulmonary disease, (4) strokes, and (5) acute respiratory infections in children. However, further research is needed to establish exposure-response functions, which will enable the estimation of the health burden of air pollution associated with additional health conditions.

In addition to PM$_{2.5}$, other airborne pollutants are harmful to health, including, among others, ozone, lead, mercury, and pesticides. For example, lead is particularly toxic to children even in small amounts and can compromise their ability to grow up to become productive members of their societies. Lead poisoning in children causes damage to the brain and nervous system, slowed growth and development, and learning and behavior problems. Furthermore, there is no known safe level of lead exposure in children. More research is needed to better understand the relationships between exposure to these pollutants and specific health outcomes. In addition, there is a need for air quality monitoring efforts in developing countries that include measurements for these pollutants. The shortcomings in air quality monitoring in developing countries pose additional challenges. Furthermore, there is a need to understand, through source apportionment analyses in specified locations (regions and countries), the contributions of these pollutants to the air quality that people in those locations are exposed to.
mortality rates (Wu et al. 2020). Furthermore, people with underlying health conditions, such as respiratory illness caused by exposure to air pollution, might have a higher risk of death following COVID-19 infection (Yamada, Yamada, and Mani 2021). Because of data limitations, this chapter has not provided estimates of the loss of human capital because of COVID-19 mortality, but if detailed data become available, this analysis can be incorporated into future work.

Future work could also explore the potential productivity gains from reducing air pollution and its impact on human capital. Future editions of The Changing Wealth of Nations could also provide a more detailed breakdown of the impact of air pollution on human capital, disaggregated by indoor and outdoor air pollution. In addition, information on the duration of exposure to air pollution before death occurs could improve this analysis. Deaths caused by air pollution can take place in different time periods depending on the form and impact of the air pollution.

Note

1. DALY is a composite metric that combines the years of life lost because of premature death and the years lived with disability.

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