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Equitable energy transitions for a healthy future: combating air pollution and climate change

Yifang Zhu and colleagues argue that equitable energy transitions are critical to improving public health and reducing health inequalities

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Energy systems—the entire network of processes, technologies, and infrastructure involved in producing, converting, distributing, and consuming energy—are the largest single source of greenhouse gas emissions. The emissions come mainly from the combustion of fossil fuels, which also contribute to ambient air pollution.¹ Alarming, nearly the entire global population (99% of 8.2 billion) resides in areas that fail to meet the World Health Organization's air

quality guidelines, with low and middle income countries experiencing the highest levels of fine particulate matter (PM_{2.5}).² Adding to this concern, WHO estimates that 3.6 billion people live in areas highly susceptible to climate change.³ Both air pollution and climate change pose threats to human health that can be addressed through coordinated and synergistic measures (fig 1).

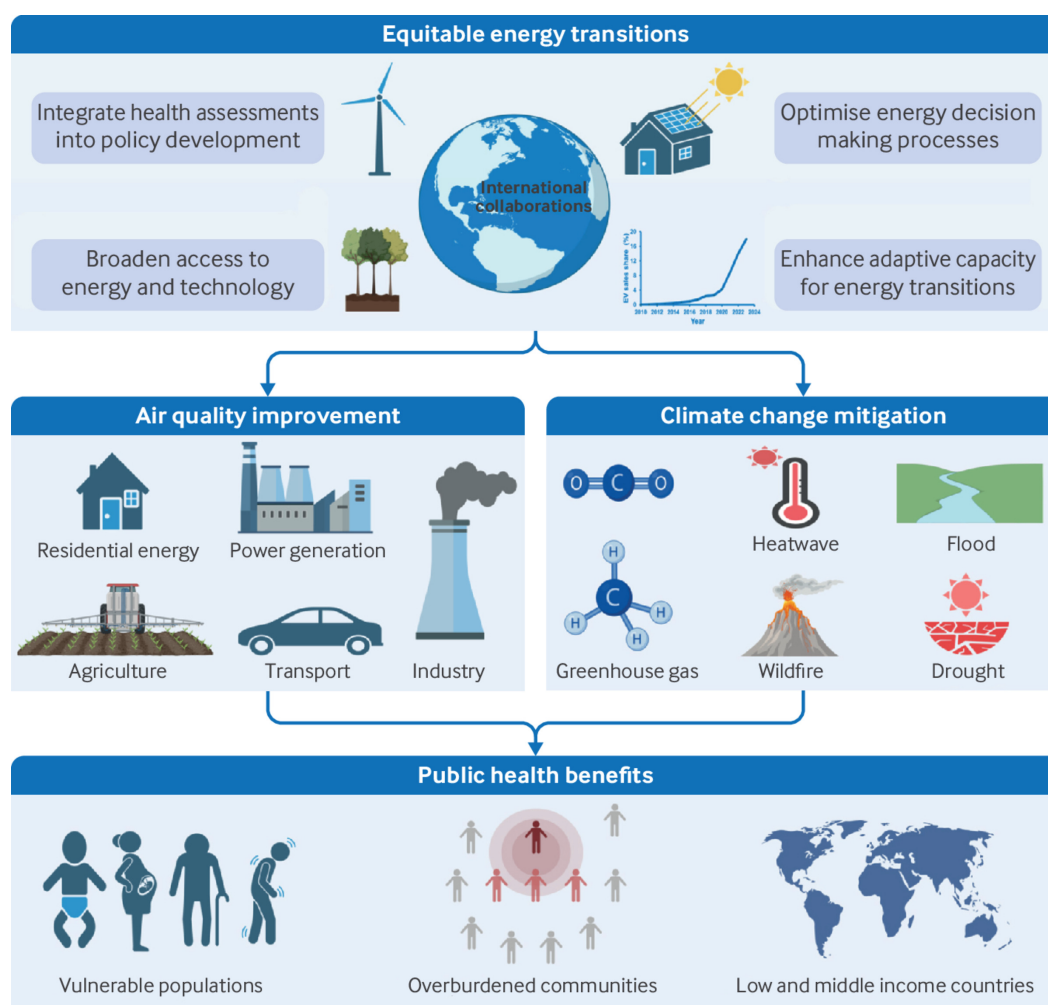


Fig 1 | The nexus of equitable energy transitions, air quality, climate change, and public healthEnergy transitions, such as phasing out fossil fuels and adopting renewable energy sources (eg, solar, wind, hydro, wave, tidal, and geothermal), are effective strategies to reduce air pollution and improve health. These transitions also contribute to the United Nations' goal of achieving carbon neutrality by 2050. Energy transitions, however, need to be equitable, which means that everyone should have access to energy that is affordable, safe, sustainable, and capable of supporting a decent lifestyle. Equitable energy transitions should also empower individuals to participate in, and lead, energy decision making processes with the authority to enact change.⁴ Action is urgent as "health is at the mercy of fossil fuels"⁵

Health effects of climate change and air pollution

Climate change is arguably the greatest global health threat of the 21st century. Its health effects are extensive, including direct exposure to extreme weather events, disruption of food and healthcare systems, and increases in both communicable and non-communicable diseases. Additionally, climate change affects mental health, cultural practices, and social stability.⁶ Earlier analyses predicted an excess of around 250 000 deaths a year would be attributable to climate change by 2050, but these estimates probably underestimated the possible effects of ecosystem disruption, declines in agriculture output, and widespread secondary economic impacts.³ In recent years, the frequency, intensity, and duration of extreme weather events—such as heatwaves, wildfires, droughts, floods, and typhoons—have increased globally. A global modelling study estimated that more than five million additional deaths annually were attributable to abnormal hot and cold temperatures between 2000 and 2019.⁷ Geographical differences were evident, with more than half of these deaths occurring in Asia.⁷

Combustion dependent activities—such as residential energy use, industry, power generation, agriculture, transport, and open fires—are major contributors to greenhouse gas emissions and leading sources of outdoor air pollution, contributing to 76% of global PM_{2.5} exposure.⁸ Among these, residential energy use, including domestic heating, cooking, and waste disposal, contributes the most to ambient PM_{2.5}, particularly in densely populated regions of South Asia, East Asia, and Africa.

Exposure to air pollution, particularly PM_{2.5}, is consistently linked to increased health risks throughout the life course, including adverse birth outcomes, autism spectrum disorder, respiratory and cardiovascular diseases, diabetes, depression, cognitive decline and dementia, and premature death.⁹ Certain groups are more vulnerable than others, including children, pregnant women, older people, those with pre-existing heart and lung diseases, and people in low socioeconomic neighbourhoods and communities.⁹ The 2024 State of Global Air Report reveals that air pollution was the second leading risk factor for premature mortality worldwide in 2021, resulting in some 8.1 million deaths, exceeded only by high blood pressure.¹⁰ The highest burden of disease from air pollution was in South Asia and Africa.

Increasing evidence suggests that co-exposure to air pollution and extreme weather events may result in synergistic health effects, amplifying their individual health risks.¹¹ Moreover, the health risks associated with air pollution and climate change are not evenly distributed, leading to substantial inequalities in exposures and health burdens. Even when aggregate pollution is reduced, health inequalities persist.¹² People from ethnic minority groups, vulnerable populations, and lower income groups are particularly affected, showing the need for targeted policies and interventions to protect these populations.

Benefits and risks of energy transitions

The shift to clean energy offers opportunities and benefits, particularly for low and middle income countries, including improved electricity access, job creation, economic growth, and reductions in air pollutants and greenhouse gas emissions.¹³ The benefits of energy transitions on environmental health determinants, such as air quality and climate, have been conceptually examined. For instance, aggressive transition to electric and hydrogen fuel cell vehicles, combined with decarbonised electricity and hydrogen in China, could greatly reduce emissions from both vehicles and

power plants. This approach brings substantial air quality, climate, and health co-benefits.¹⁴ Another study estimated that if India moves from traditional biomass and coal energy sources to renewable electricity, it could reduce carbon dioxide, sulfur dioxide, nitrogen oxides, and black carbon emissions by 67%, 87%, 89%, and 99%, respectively, compared with the projected 2070 business-as-usual levels.¹⁵ These results suggest that energy transitions can achieve a synergy between improved air quality and climate benefits. Little research, however, has explicitly considered the public health effects and potential inequalities associated with the ongoing energy transition.¹⁶

Take electrification of transport as an example. Policy makers worldwide have committed to transitioning from internal combustion engine vehicles to electric vehicles (EVs) to achieve air quality and climate mitigation goals. This commitment is reflected in the rising sales of EVs, with nearly 14 million new registrations globally in 2023. As a result, the total number of EVs on the roads today has reached 40 million. EVs made up 18% of all car sales in 2023, increasing from 14% in 2022 and just 2% in 2018, indicating a rapidly maturing market.¹⁷ Unlike conventional petrol and diesel vehicles, EVs produce no exhaust emissions, presenting an opportunity to improve air quality, reduce greenhouse gas emissions, and yield health benefits. Low and middle income countries, however, may face unequal access and systemic injustices that hinder the widespread adoption of EVs. For instance, although, sub-Saharan Africa has made notable progress in electrification of transportation, with collaboration between governments and the private sector improving the accessibility of EVs to the public, the region still has the lowest EV adoption rate globally.¹⁸ Energy experts from Nigeria, Kenya, Ethiopia, South Africa, and Cameroon point out key tensions: balancing energy transition with access, aligning policy design with implementation, and expanding EV adoption while ensuring sufficient power generation to support growth.¹⁹ Much of the existing EV infrastructure depends on power generation from fossil fuel sources, which is now on the verge of being phased out as part of Africa's power supply transformation.¹⁹

EVs, however, are not entirely environmentally benign. They still generate particles from brake and tyre wear emissions, which vary based on vehicle weight, brake pad types, and regenerative braking intensity.²⁰ Studies in Los Angeles show that overburdened communities—including minority, low income, tribal, and indigenous populations that often experience higher environmental exposures, cumulative impacts, or greater vulnerability to environmental hazards—experience 40% more pollutant reduction from the transition to EVs than other communities because they live close to major roadways.²¹ However, the brake and tyre wear emissions, particularly those from heavy duty trucks, still disproportionately affect overburdened communities.²² A study in Los Angeles finds that brake and tyre wear contributes as much as, or even more than, exhaust to ambient PM_{2.5}.²³ Similarly, the UK National Atmospheric Emissions Inventory reports that vehicle and road surface wear particles account for 60% of primary PM_{2.5} emissions from road transport.²⁴ Increasing research has revealed that brake and tyre wear is the dominant source of metal particles (eg, barium, copper, zinc, lead, chromium, and antimony).²⁵ These particles contribute to greater toxicity, as measured by oxidative stress potential, which is higher in overburdened communities.²⁶ Furthermore, the health effects associated with brake and tyre wear particles are independent of, and in some cases larger than, those from NO₂ in vehicle exhaust.²⁷

Additionally, tyre wear particles may contribute to the dispersion of microplastics into the air and water. Emerging research indicates

that microplastics are entering human bodies, but their effects on human health remain uncertain.²⁸ Potential technological solutions, such as regenerative braking, advanced brake pad materials, and low rolling resistance tyres, could reduce emissions to ambient air.²⁹ Moreover, key activities in the EV life cycle—including the mining and processing of lithium and cobalt, vehicle manufacturing and assembly, recharging and operation, and battery waste management and reuse—can contribute to local pollution, health risks, and global inequalities.³⁰

Ensuring equity

Achieving equitable energy transitions requires the fair distribution of both the benefits and the costs, aiming to reduce inequalities rather than exacerbate them. Barriers to equitable energy transitions range from limited resources, technologies, and infrastructure to a lack of information, incentives, and international agreements or collaborations tailored to specific circumstances. Existing studies, however, focus mainly on economic benefits and environmental impacts, often overlooking the effects of energy transitions on different communities, especially vulnerable groups, leading to an insufficient emphasis on equity. As energy systems evolve, it is important to consider the health implications of these shifts to ensure an equitable transition, inform current strategies, and predict future outcomes. Research gaps, however, remain in understanding the depth of inequalities associated with the energy transition, identifying where and who is most affected, determining what measures are needed to support individuals, communities, and countries during the shift, designing and implementing effective policies, and enabling individuals to participate in and lead energy decision making processes.

These gaps call for an integrated understanding of these complex interactions and inequalities from health, natural, and social science perspectives. Ongoing and future research and policy efforts should focus on several key priorities. First, health assessments associated with air quality and climate changes should be integrated into cost-benefit analyses when developing new energy transition policies. This approach helps quantify the burdens and benefits of the energy transition, as well as to understand how they differ among various groups within society. For example, although zero emission vehicles offer climate, air quality, and health benefits, they cannot fully address pollution in overburdened communities as near roadway PM_{2.5} levels remain a problem because of brake and tyre wear emissions, especially from large trucks.²²

Second, policies and practices should be implemented to prioritise cleaner air around schools, playgrounds, parks, hospitals, and care homes. Implementing low emission zones in urban areas of Germany, Japan, and the UK has been shown to improve health outcomes related to air pollution, with the most consistent effects observed in cardiovascular disease.³¹

Third, it is important to broaden access to renewable energy and energy efficiency technologies, particularly in low and middle income countries. This requires methodological innovations, including expanding the deployment of renewable energy technologies, enhancing energy efficiency, addressing waste generation and disposal, and improving the accessibility of these technologies.

Fourth, under-represented groups must be included in decision making processes, prioritising collaboration with local communities most affected by past and current energy inequities and co-developing solutions that address systemic barriers. There are several successful examples of community engagement with policy implications in high income countries, but it is less common in

lower income countries. In the UK, the Breathe London Community Sensing Network (www.breathelondon.org), funded by the Mayor of London in 2020, deploys over 100 sensors across schools, hospitals, and other sites to engage citizens on air quality and advance a zero pollution future. Similarly, the Los Angeles 100% Renewable Energy Study outlines 11 community guided energy equity strategies, including co-developing programmes, tailored outreach and education, specialised training, and debt relief initiatives.³²

Finally, efforts should be made to enhance adaptive capacity, enabling individuals and communities to navigate the economic, social, and cultural shifts brought about by energy transitions. Practical measures might include deploying low-cost sensors and fostering citizen science initiatives to monitor and address air pollution near major energy transition facilities, such as hydrogen hubs, vehicle charging stations, and lithium mines. Moreover, international agreements and collaborations are vital for ensuring an equitable transition, especially in low and middle income countries and communities with limited financial and institutional resources. To ensure an equitable energy transition, active participation is essential from stakeholders at all levels. This includes national and subnational governments, communities, organisations, and individuals, all working collaboratively to address the social, economic, and environmental dimensions of the transition.

Key messages

- Air pollution and climate change are two critical global challenges affecting human health
- Equitable energy transitions can synergistically improve air quality and mitigate climate change
- Targeted research and policy, combined with international collaborations, are necessary to ensure equitable energy transitions
- Efforts should be made to engage and support vulnerable individuals, communities, and countries affected by energy transitions

Contributors and sources: YY is a postdoctoral scholar focusing on the nexus of air pollution, climate change, and human health. MJ is an internationally recognised expert in geographic information science for exposure assessment and spatial epidemiology. TZ's primary research focus is on atmospheric chemistry and environmental health, and he is a member of both the Chinese Academy of Sciences and the Chinese Academy of Medical Sciences. FJK's research spans all aspects of air pollution, from toxicology to science policy. YZ has research interests in climate change, air pollution, environmental exposure assessment, and aerosol science and technology. YY, MJ, and YZ conceived the article, YY and YZ drafted the manuscript, MJ, TZ, and FJK revised the manuscript. All authors approved the final version. YZ is the guarantor.

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