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Commentary

Electric vehicle adoption delivers public health and environmental benefits

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Large-scale electric vehicle (EV) deployment powered by renewable electricity has the potential to drastically change the environmental impacts of road transportation. The transportation sector is a major contributor to global greenhouse gas (GHG) emissions [1,2], air pollution, and related health impacts [3]. Renewable-powered EVs substantially decrease fossil fuel consumption and are a pivotal technology to reduce transportation's climate burden while also substantially improving air quality and public health. However, while EV deployment has rapidly increased in recent years, the current fleet of 16.5 million EVs in 2021 is still just a fraction of the estimated 300 million needed by 2030—consistent with EVs reaching 60% of new car sales—to meet a net zero emissions scenario by mid-century, according to the International Energy Agency [4]. The number of heavy-duty EVs in the fleet has increased in recent years, but light-duty vehicles, which were responsible for a majority of global road transportation GHG emissions in 2020 [5], still account for almost the entire global EV stock [6]. China dominates the production and sales of EVs, with more than half of all EVs on the road worldwide in China [4].

The International Energy Agency estimates that EVs could avoid 460 Mt of CO_2-equivalent (CO_2e) emissions in 2030 under stated government policies and up to 580 Mt if more ambitious pledges are included [6]. While rapid EV deployment is critical to meet decarbonization targets, it also has the potential to generate large human health benefits, mostly due to reduced mortality attributable to fine particulate matter ($PM_{2.5}$) [7–10]. Studies for the United States [7] and China [8–10] have estimated that, in some cases, the health benefits of light-duty vehicle electrification could even exceed climate benefits from reduced GHG emissions. The health impacts of emissions of air pollutants vary according to population exposure. As EVs shift emissions from the tailpipe to power plants, large health benefits generally ensue because tailpipe emissions typically occur in densely populated urban areas, where a much larger population is exposed to them [7]. Health impacts of vehicle tailpipe emissions per mile driven can vary by orders of magnitude depending on where vehicles drive [11]; hence, much larger health benefits accrue when EV deployment occurs in densely populated urban areas. EV deployment has been estimated to achieve an average of $8,600 in health benefits per vehicle across the 53 largest U.S. metropolitan areas, with up to $15,000 in the New York city metropolitan area [7].

It is crucial that this EV transition is accompanied by a decarbonization of the power sector since renewable-powered EVs are needed to achieve more ambitious GHG cuts and substantially increase health benefits. EVs powered by current grid mixes that rely largely on coal, such as in some regions in China and India, lead to very modest GHG cuts or, in some cases, even increased GHG emissions [9,12–14]. EV adoption can also increase emissions of primary $PM_{2.5}$ and some precursor gases, such as SO_2, under current grid mixes that still rely heavily on coal power plants [7–9]. A study [9] conducted in China highlighted that at least a 40% share of renewable energy in the electricity grid is needed for EVs to effectively reduce CO_2 and air pollutant emissions (the current share is 32% [15]). Power plants typically cause a smaller health impact per mass emitted due to smaller population exposure compared to tailpipe emissions in large urban areas [7]. Therefore, EV deployment, occurring typically in urban areas, might still achieve health benefits under current grids [7,9,10,12]. However, the distributional impacts of coal-powered EVs are profound and should not be ignored. Large health benefits in urban areas might still accrue, but at the expense of increased exposure of some populations, typically rural, to harmful coal power plant air pollution—a large transfer of health impacts from vehicle users to nonusers [16].

Environmental impacts of EVs also depend on charging behavior as a massive increase in EV numbers can result in a substantial surge in power demand, exacerbating peak loads of electricity consumption and posing challenges for electricity grid operation [17,18]. These challenges depend on the location and schedule of EV charging, including whether charging occurs during peak or off-peak hours and whether charging is rapid or slow, which affect the electricity mix used to meet EV demand

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and hence its emissions [17,18]. Assuming no changes in driving behavior, the peak demand for electricity from fossil fuels would potentially increase by up to 25% over expected 2035 levels in the United States if half of the cars in use were electric [18]. While in the United States, EVs lead to climate and health benefits regardless of the grid mix [7], in China, unmanaged EV charging can have negative consequences and increase GHG emissions when using fast charging, negating much of the benefits of expanding renewable power [17]. However, EV charging can be managed through a range of policies from time-varying tariffs to bidirectional vehicle-to-grid services allowing direct load control, which can reduce operating costs, GHG emissions, and peak loads, as well as support grid decarbonization [19].

Although EVs have the potential to achieve large climate and health benefits, they may lead to other environmental impacts along their life cycle, and large-scale deployment may impact the global supply chain. The global demand for the critical metals used in EV batteries, including cobalt, lithium, manganese, and nickel, could increase by 8–14 times from 2019 to 2030 [6,20]. The large demand for material-intensive EV batteries may put a strain on the supply chain. Cobalt represents the highest short- and medium-term supply chain risk, although cobalt-free batteries are currently under development [21]. Meanwhile, lithium supply may also be impacted in the future in the absence of mitigation measures such as efficient recycling and improved technology to reduce lithium content [22]. Increased need for materials also leads to environmental impacts [23,24], such as those associated with energy required for material production—a recent life cycle assessment (LCA) of EV batteries estimates about 60 kg equivalent CO_2e per kWh of battery capacity under current technology and supply chains [24] or 20 g CO_2e per km driven assuming an 84-kWh battery and a lifetime mileage of 250,000 km. While these are about an order of magnitude smaller per kilometer driven than use-phase emissions of current internal combustion engine vehicles, battery production is also associated with other impacts (e.g., from emissions of $PM_{2.5}$, NO_x, and SO_2) [24]. While large-scale EV deployment cannot wait long in order to achieve decarbonization targets [4], regional LCA studies can help estimate their life cycle impacts to help inform further emission control policies to mitigate such impacts. Electricity and supply-chain decarbonization would also help reduce life-cycle impacts [24], and material efficiency strategies such as vehicle lightweighting, increasing recycling, reuse and remanufacturing of components, vehicle downsizing, and more intensive use can also be very effective in achieving large cuts in vehicle life cycle GHG emissions [23].

The transition to renewable-powered EVs is crucial to achieving ambitious decarbonization goals and brings along substantial health co-benefits from reduced air pollution. The transition is urgent to meet climate targets, and a focus on rapid EV deployment in urban areas merits strong consideration as it can achieve major public health gains.

Author contributions

Y.J.Z., E.F.C.: investigation, writing. K.X.W.: writing. H.K.W.: conceptualization, supervision.

Declaration of competing interest

The authors declare no conflicts of interest.

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