Environmental protection 85 kWh

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The U.S. transportation sector in the United States accounts for 29% of the total greenhouse gas emissions (GHGs), with almost 60% of transport GHG emissions coming from light-duty vehicles1. A recent report by the National Academy of Sciences underscores the need to expand the adoption of electric vehicles. It highlights that electric vehicles (EVs) must become 50% of new vehicle sales by 2030 to achieve decarbonization goals2. Replacing gasoline vehicles with electric vehicles--which operate on electricity stored in rechargeable batteries--has enormous potential to reduce greenhouse gas emissions.

Here, we develop a new metric, the Critical Emissions Factor (CEF), which we define as the carbon intensity of the regional grid that would be needed for the lifecycle emissions from an electric vehicle to be at parity with the emissions of some of the most efficient gasoline vehicles in the market. We do so while accounting for regional and operational aspects that lead to different emissions levels in different locations, such as climate (ambient temperature) and driving conditions. We also compare CEF to current grid emissions intensity to ascertain which regions have the highest GHG-reduction potential for the near-term widespread roll-out of electric vehicles.

We consider five representative vehicles for hybrid gasoline (HEV) and battery electric technologies (BEV) based on the vehicle class and availability of detailed laboratory test data assessing vehicle efficiency across multiple ambient temperatures and drive cycles. Two gasoline hybrids--Toyota Prius and Honda Accord Hybrid--were chosen to reflect the most efficient gasoline vehicles in the market, and three battery electric vehicles--Tesla Model S, Chevrolet Bolt, and Nissan Leaf--in decreasing battery capacity and, by extension, their range and weight (Table 1).

Figure 1 describes our modeling strategy and data sources, which are as follows:

Temperature data We use hourly on-ground monitoring station temperature measurements from NOAA''s Integrated Surface Database for 3000 stations in the contiguous United States for 201832. Stations with more than 7000 data points (out of 8760 hourly values) were selected, and missing values were imputed using the value from the previous or next day for the same hour. This data allows us to incorporate temperature impacts in vehicle energy consumption.

Modelling strategy and data sources.

However, these tests are known to produce optimistic fuel consumption results relative to on-road driving, resulting in lower than actual emission estimates35. Thus, we have run sensitivity analyses using 5-cycle tests for HEVs, which include drive cycles to reflect aggressive driving (US06) and driving with extreme temperatures (SC03) along with urban and highway driving. For EVs and HEVs, we estimate and use the derived 5-cycle energy consumption using equations from the EPA for HEVs38,39, and for EVs, we use a multiplicative factor of 0.7, as suggested40. We refer the reader to the SI (Sects. 2, 3) for more details and a table with all key assumptions.

Driving data We use the United States Department of Agriculture Rural Urban Codes to classify our counties. Metropolitan counties were assumed to follow urban drive cycles (UDDS), rural counties followed highway drive cycles (HWFET), and the rest of the counties were assumed to follow a combined drive cycle (in the SI Sect. 2.2 for details on counties assignments).

Vehicle and battery manufacturing emissions assumptions are summarized in the SI. We use an attributional framework for these estimates and assume that vehicle manufacturing emissions are constant across vehicle classes and fuel types. We consider NMC111 (LiNi1/3Mn1/3Co1/3O2) battery production in three locations (US, China, and Europe). We also consider LFP (Lithium Iron Phosphate, LiFePO4) produced in the US.

Use-phase emissions For gasoline, we include emissions from gasoline combustion from literature and include the upstream emissions of fuel production (extraction, processing, and transportation of gasoline)24,41,42,43. Our base case electricity emissions assumption for the vehicle charging assumes marginal emission factors for electricity generation (from Ref.44) and convenience charging. We also consider average emissions factors in our sensitivity analyses (from e-GRID) (SI Sect. 4)45 and a scenario where vehicles are charged during the lowest emitting hours (SI Fig. S9).