Environmental and Energy Efficiency of Eco-Friendly Vehicles with Renewable Energy: A Life Cycle Analysis

Topic: Input-Output Analysis: Sustainable Production and Consumption Policies - VI
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Using hydrogen and electricity from renewable energy sources is crucial for achieving a low-carbon and decarbonized society through sustainable mobility systems. However, the immediate decarbonization of energy sources is not feasible, and the introduction of fuel cell vehicles (FCVs) and electric vehicles (EVs) requires the use of hydrogen and electricity generated by fossil fuels. Therefore, a quantitative analysis assessing the improvements in environmental and energy efficiency that can be achieved through the diffusion of FCVs, EVs, and other eco-friendly vehicles is necessary, along with the decarbonization of energy sources. This study aimed to analyze the energy consumption and greenhouse gas (GHG) emissions of eco-friendly vehicles, including FCVs, EVs, hybrid electric vehicles (HEVs), and gasoline vehicles (GVs) throughout their life cycles, and determine their potential contributions to improving environmental and energy efficiency if they become prevalent in society in future.

This study involved four steps, including system boundary setting, information collection of target systems, sector extension of input-output tables, and inputâ€“output analysis:

1. The life cycle of each eco-friendly vehicle system was divided into five stages: system construction (including equipment manufacturing), fuel production, fuel transportation, fuel supply facilities (hydrogen stations or gas stations), vehicle production, and vehicle utilization. The system's functional unit was set at 8,500 cars driving 100,000 km over 10 years.

2. The relevant information was collected and organized based solely on published reports and papers, and the prices, technical levels, and social situations from 2020 to 2025 were assumed. The equipment required for hydrogen energy production was limited to that required for naphtha reforming from existing refinery equipment. Gas stations, which are already used extensively, were assumed to only require renewal of facilities to comply with current regulations. This estimation did not include EV-charging facilities, which are small-scale and decentralized facilities. The vehicle-manufacturing costs for HEVs and GVs were assumed to be in the same weight category as FCVs.

3. Since there is no sector in the existing inputâ€“output table that can accurately simulate vehicle and power generation systems, an input coefficient table was created by extending the 11 sectors related to each system. The Japanese Inputâ€“Output Table, which forms the basis for this compilation, consists of approximately 395 sectors.

4. Lastly, inputâ€“output analysis was performed under these conditions.

This study presents the results of the GHG emissions of the FCV, EV, HEV, and GV systems over their entire life cycles. The estimated GHG emissions per kilometer were 0.34 kg for FCV, 0.24 kg for EV, 0.22 kg for HEV, and 0.48 kg for GV. Regarding the characteristics of each lifecycle stage, the share of emissions from vehicle manufacturing is higher for newer technologies, with FCVs, EVs, HEVs, and GVs accounting for 65%, 50%, 41%, and 34% of emissions, respectively. EVs have the highest GHG emissions from fuel production at approximately 48%, followed by FCVs at approximately 20% and GVs and HEVs at approximately 12%. Additionally, fuel-supply facilities (hydrogen and gas stations) account for approximately 7% of the total FCV, GV, and HEV emissions, with the impacts of hydrogen stations and gas stations being attributed to electricity consumption from pressure boosting and cooling, and electricity consumption from lighting and other equipment, respectively.

Next, the GHG emissions were estimated if all the energy required for driving was derived from renewable electricity. Specifically, we envisioned a system in which FCVs convert electricity generated by wind power into hydrogen through the electrolysis of water, while EVs directly charge the electricity generated by wind power. Consequently, the FCV emission was 0.29 kg-CO2eq. per km, which represents a 15% reduction compared to the emissions of the naphtha reforming system. Emissions from manufacturing and constructing wind power facilities and water electrolyzers were twice as high as those from naphtha reforming; however, the impact was a reduction of approximately 90% in emissions from fuel production. Conversely, the EV emission was 0.13 kg-CO2eq. per km, representing a reduction of more than 40%. In other words, while FCVs powered by renewable hydrogen may compete against EVs powered by grid electricity, the advantage of EVs powered by renewable-energy-derived electricity remains unchanged. However, because FCVs with renewable energy hydrogen exhibit approximately 30% less emission than GVs of similar weight, they should be introduced in areas where they can take advantage of the characteristics of the FCV system, such as short filling time and cruising range.