

KEY INSIGHTS

- Suitable roofs for solar are abundant globally and unlikely to constrain deployment. However, substitution effects between rooftop and non-rooftop solar generation **can lower the mitigation benefits of rooftop solar by 41-98%.**

- Simple grid-factor approaches do not capture how **rooftop solar can change system dispatch, prices, and investments.**

- **Hourly, long-run system modeling is preferred for quantifying emissions impacts** of electric sector interventions, including rooftop solar, electrification, data centers, and energy efficiency.

This brief is based on the report [“Emissions Reductions of Rooftop Solar Are Overstated by Approaches That Inadequately Capture Substitution Effects”](#) published in *Nature Climate Change* (2025)



Emissions Impacts of Rooftop Solar

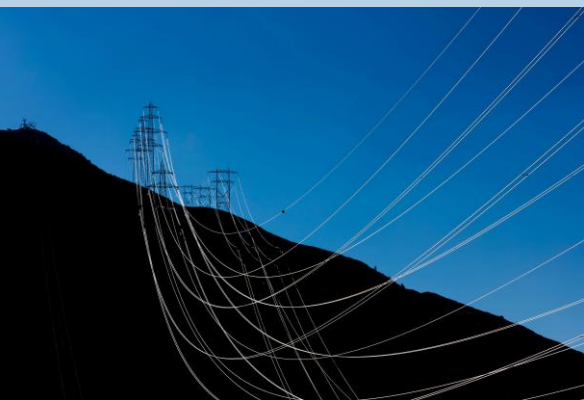
by John Bistline and Asa Watten

Analysis shows that widely used guidance may overstate CO₂ reductions from rooftop solar by inadequately capturing substitution effects.

Many decarbonization options have power sector implications, including rooftop solar, electric vehicles, and heat pumps. However, **common approaches to estimate CO₂ impacts of these interventions can omit key channels** that [materially alter environmental benefits](#), including structural impacts, scale, and policy context. While solar energy is expected to play major roles in energy systems, the extent to which rooftop solar photovoltaic (RPV) reduces emissions remains contested.

U.N. Framework Convention on Climate Change (UNFCCC) guidance is used by many studies to assess CO₂ impacts of technologies such as RPV. The [methods](#) use composite CO₂ factors that blend an “operating margin” (shifts in output from existing assets as demand changes) and “build margin” (changes from installed capacity). But **these approaches likely overstate mitigation** due to:

- Treating emissions factors as fixed regardless of how much RPV is added: Instead, as RPV scales, it changes power system dispatch and investment decisions, so marginal emissions [shift with deployment](#), not just over time.
- Overweighting operating margin effects based on outdated heuristics: Placing 75% weight on the operating margin tends to overstate reductions, since operational margins—driven by existing fossil units—are higher than build margins that reflect [cleaner](#) new resources.



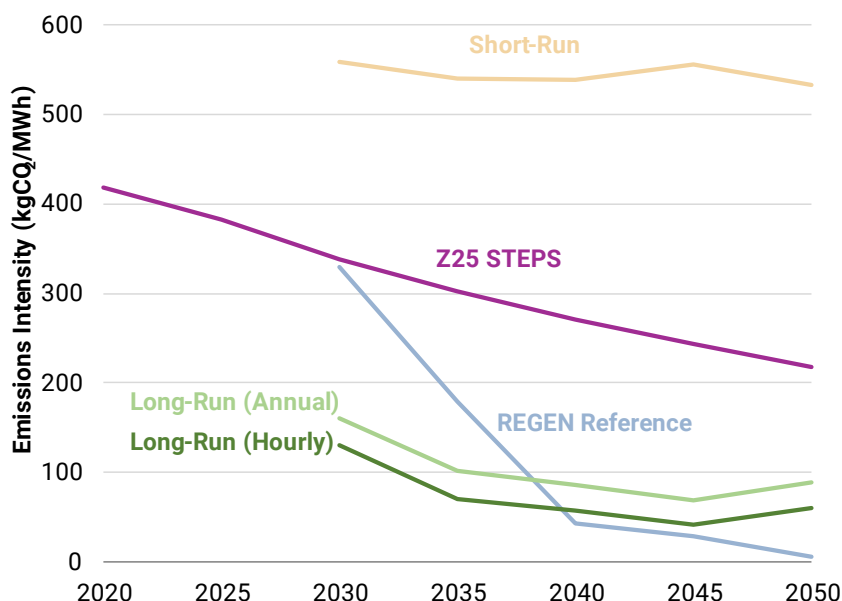


Figure 1. U.S. CO₂ intensity from [Zhang, et al. \(2025\)](#) compared with REGEN outputs. REGEN reference scenario is comparable to the Z25 STEPS scenario. Long- and short-run marginal emissions intensities are based on literature values.

- Ignoring temporal variation in power system impacts: Annual grid emissions intensities ignore solar PV’s unique diurnal and seasonal profiles and dilute substitution with non-RPV.
- Inadequately considering policy context: Under binding policy constraints, RPV displaces other low-emitting generation, which creates limited CO₂ impacts.

A preferable alternative is detailed power-systems [modeling](#), which captures dynamics that marginal-emissions rates miss, including wholesale price changes and substitution between RPV and non-RPV. [Earlier studies](#) show large substitution effects, approaching 1:1 replacement in some scenarios.

Using the open-source U.S. Regional Economy, Greenhouse Gas, and Energy (REGEN) [model](#), we run scenarios with and without RPV deployment to assess

emissions impacts. Emissions intensities are higher using the UNFCCC method in [Zhang, et al. \(2025\)](#) than estimates in REGEN (Figure 1), which implies RPV’s mitigation potential is overstated. REGEN modeling indicates that RPV primarily replaces non-RPV rather than fossil generation, yielding 41% lower benefits in 2035 and 98% in 2050. When systems modeling is infeasible, [long-run marginal emissions factors](#) better capture these substitution effects than UNFCCC-style heuristics or short-run rates.

Despite these lower emissions benefits, expanded RPV can meaningfully complement non-RPV and broader portfolios, contributing to affordable, reliable, and secure decarbonization pathways. In a world constrained by financial and political realities, accurately characterizing mitigation potentials and market dynamics through detailed modeling becomes indispensable.

FOR MORE INFORMATION

Bistline and Watten (2025), “[Emissions Reductions of Rooftop Solar Are Overstated by Approaches That Inadequately Capture Substitution Effects.](#)” *Nature Climate Change*.

CONTACT

John Bistline (lead author)
jbistline@epri.com