

More Renewables, Less Carbon: How Fast, How Far, and at What Cost?

Harvard Electricity Policy Group

June 2019

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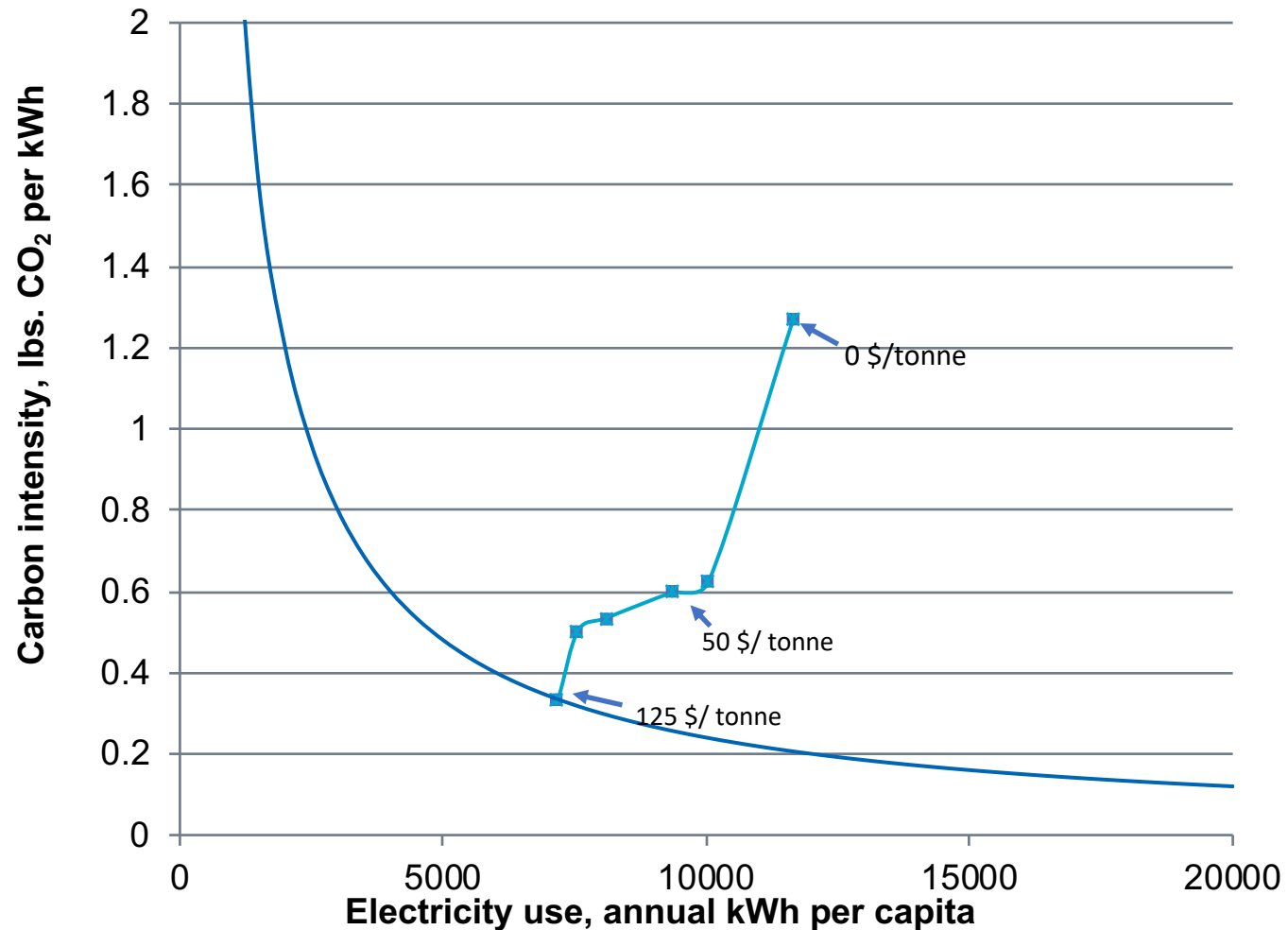
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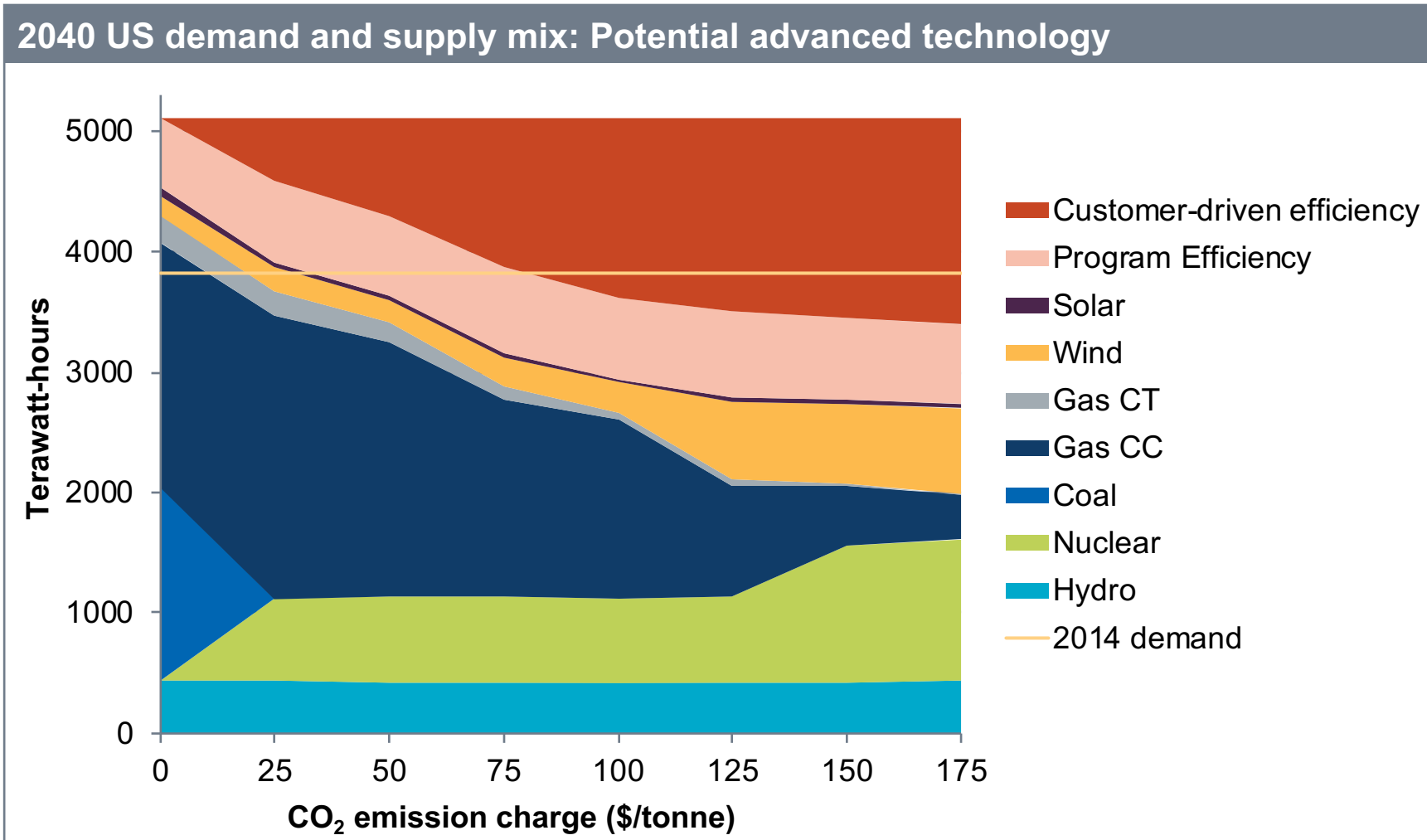
Overview

- Renewables are a means to an end, rather than an end themselves. Therefore, climate policy goals and approaches determine how far, how fast, and what cost more renewable deployment can result in less CO₂ emissions.
- A US electric supply portfolio that cost-effectively internalizes a real 50 dollars per metric tonne charge for CO₂ emissions, or cost-effectively achieves a sustainable per capita CO₂ emission profile, likely involves a US wind and solar generation share of between 6 and 25 percent by the year 2040 based on expected grid-based electricity demand and supply conditions, including the cost and performance characteristics of the current and advanced state of electricity production technologies. Under these conditions, cost-effective wind and solar resource expansions contribute to the overall grid-based electricity system integrated average real cost increases of 23 and 41 percent respectively for the 53 and 80 percent reductions in the annual electricity CO₂ emissions per capita from 2018 levels.
- Accumulating experience in the California electricity system illustrates the impact of key factors determining the cost-effective expansion of wind and solar electricity supply resources, the unintended consequences of renewable policy approaches, and the impact on electricity sector CO₂ emissions.

Potential advanced technology US electricity CO₂ emission per capita, 0 to 125 \$/tonne: 2040

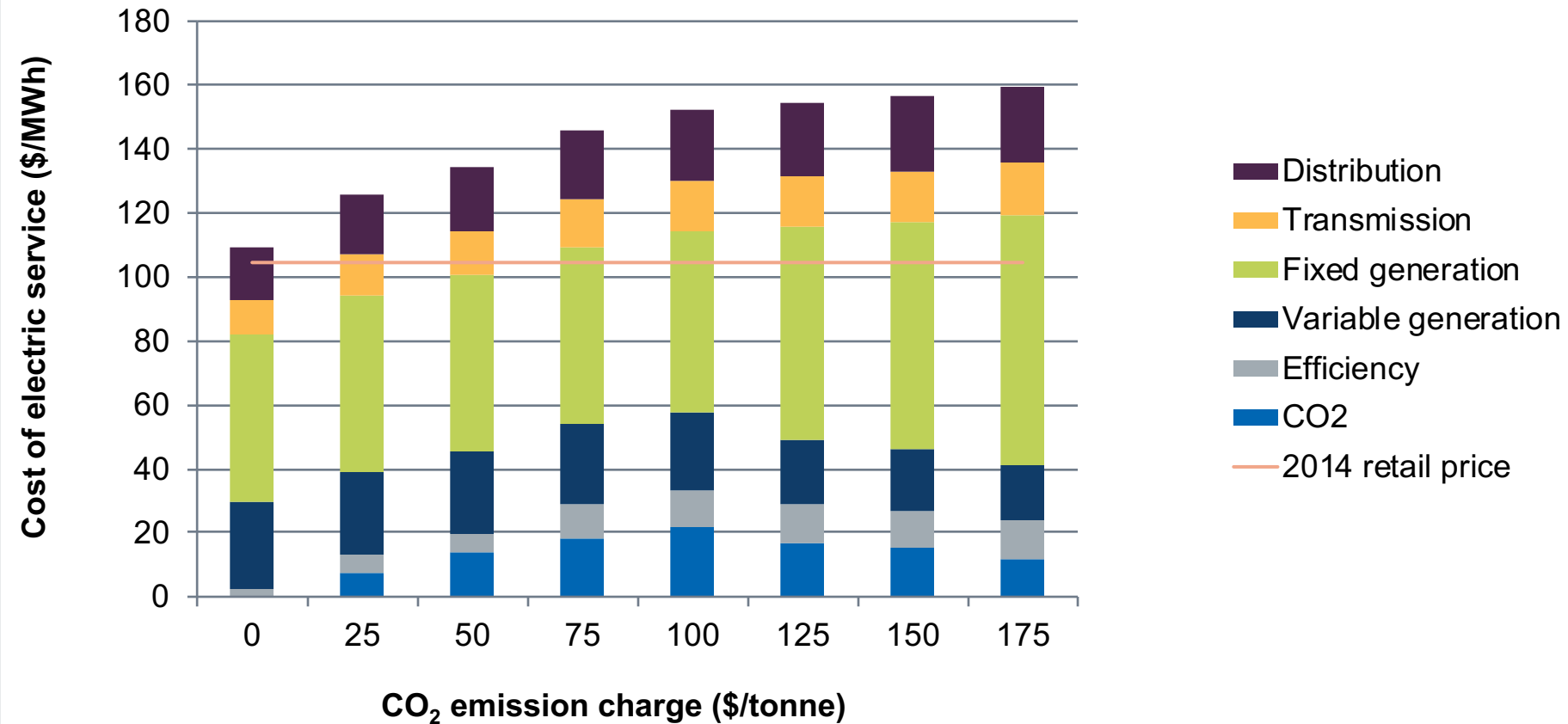


Source: Makovich, Lawrence, *Tilting at Windmills: Making a case for reframing electric sector climate policies*, June 2017, available at https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/files/78_tilting%40windmills.pdf



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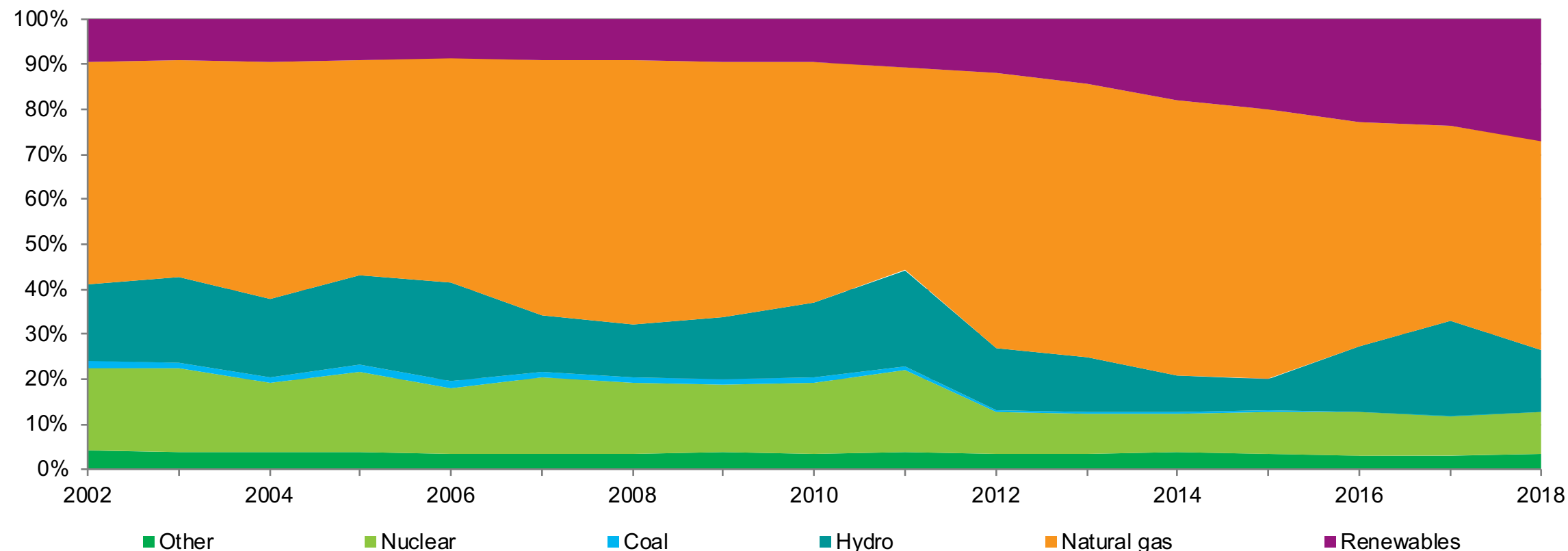
Potential advanced technology real average retail prices



Source: Makovich, Lawrence, *Tilting at Windmills: Making a case for reframing electric sector climate policies*, June 2017, available at https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/files/78_tilting%40windmills.pdf

California in-state power generation by fuel type

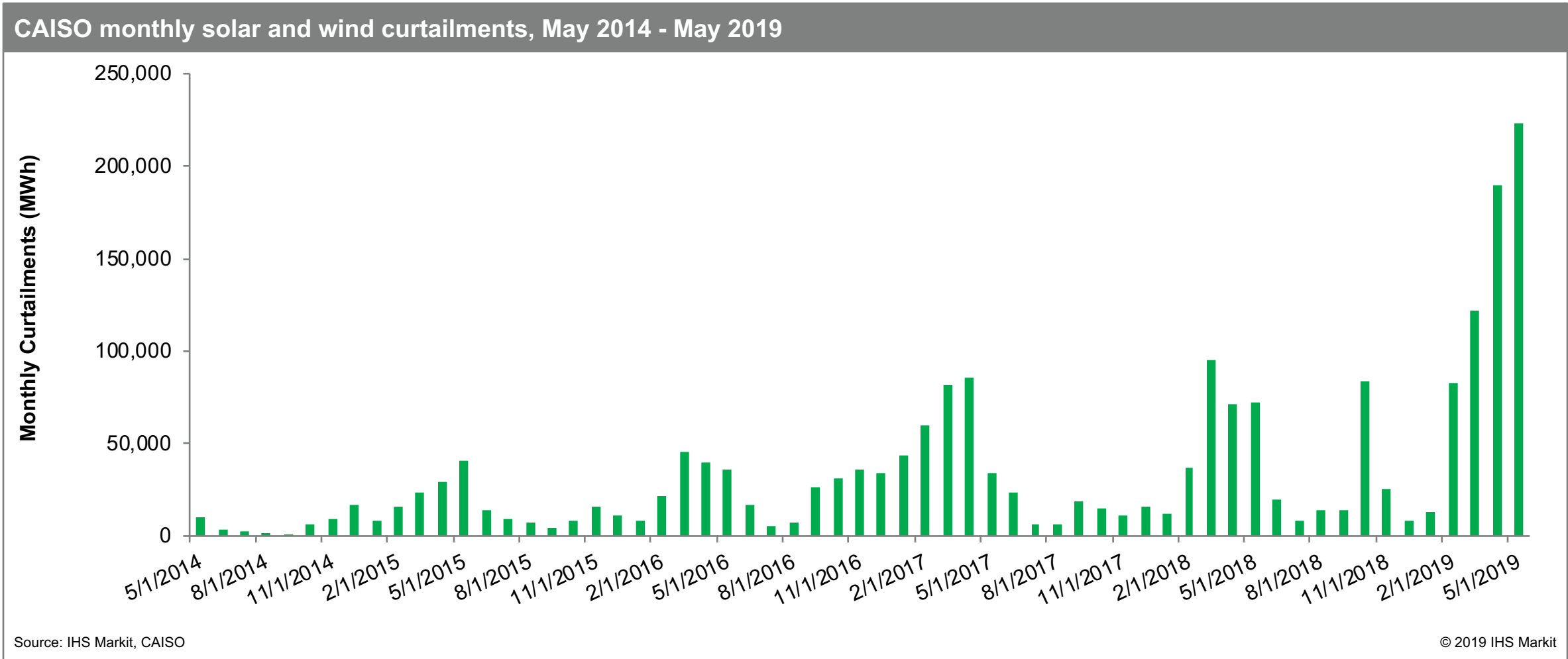
California in-state power generation: Shares by fuel, 2002–2018



Notes: Other includes biomass, waste heat, oil and pet coke
Source: IHS Markit, California Energy Commission

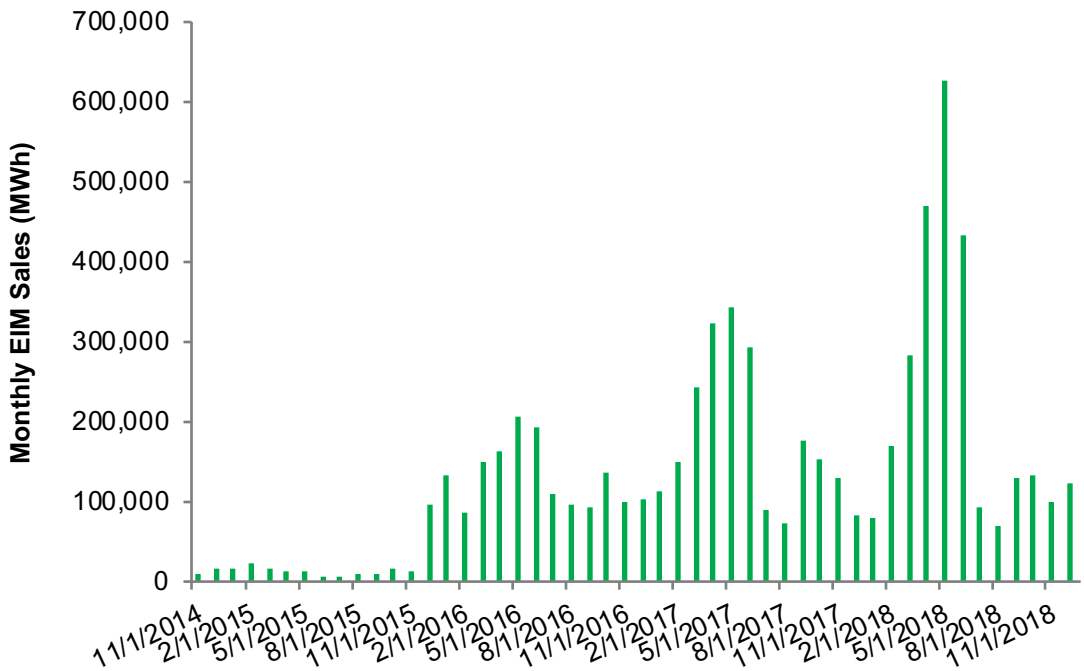
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California ISO monthly wind and solar curtailments



California ISO monthly sales and average price into the Western Energy Imbalance Market

CAISO monthly sales in the Western Energy Imbalance Market, November 2014 - December 2018

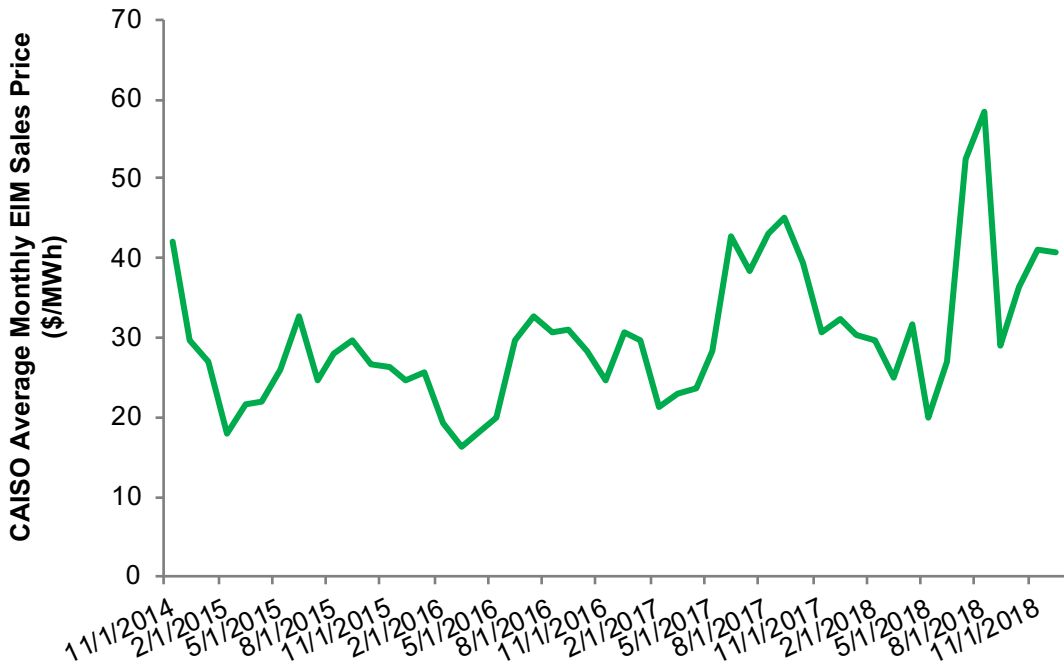


Notes: CAISO monthly EIM sales includes sales to PACW, NEVP, AZPS and PWRX load aggregation points

Source: IHS Markit, Western Energy Imbalance Market

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CAISO average monthly Western Energy Imbalance Market sales price, November 2014 - December 2018

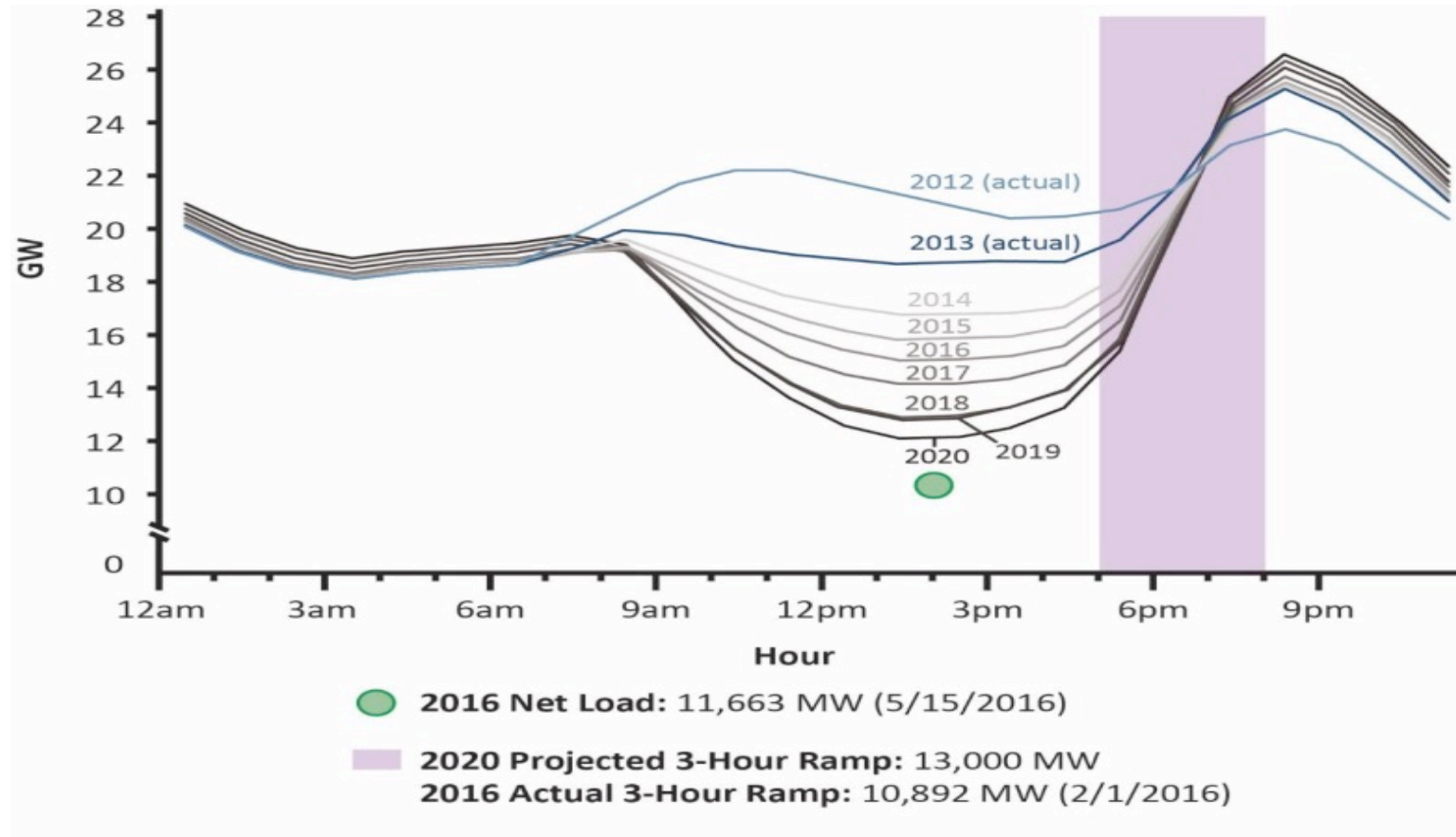


Source: IHS Markit, Western Energy Imbalance Market

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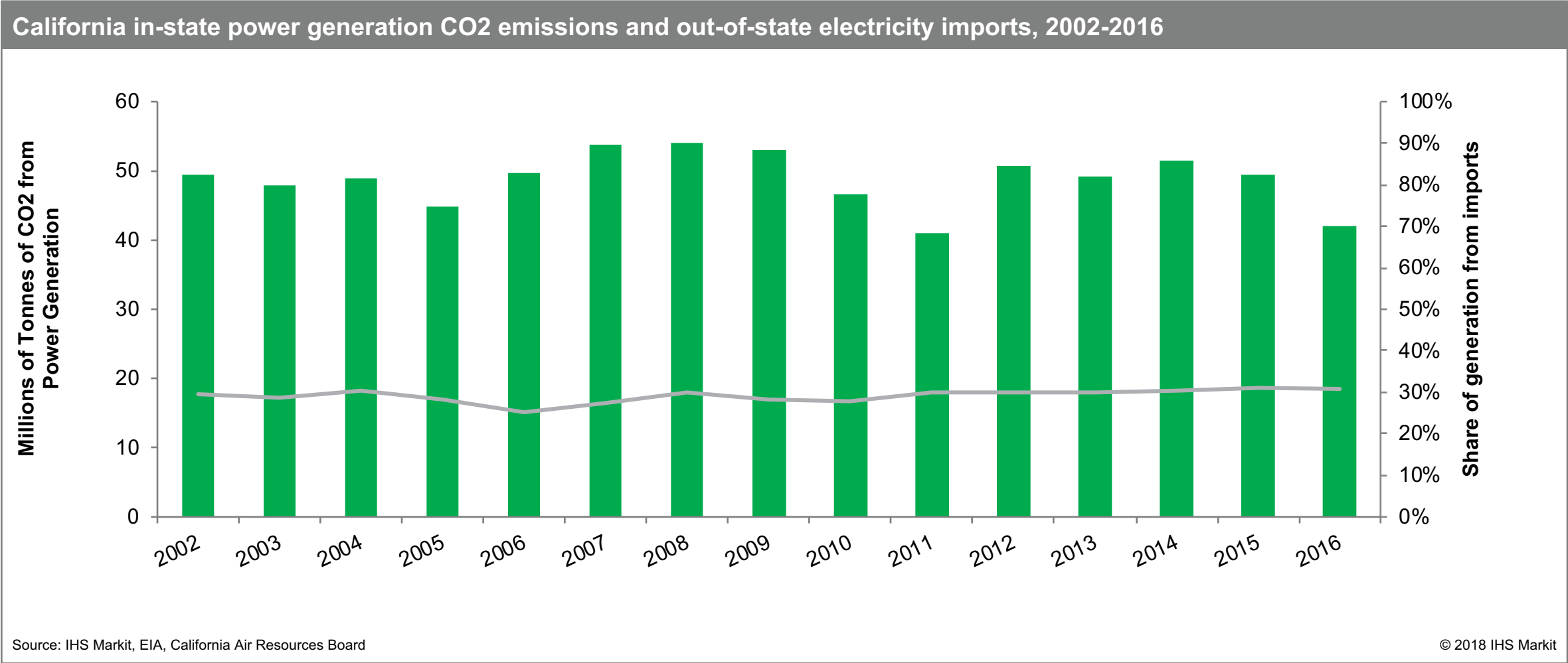
California ISO net load

CAISO representative spring net load curves, 2012 – 2013 (actual) and 2014 – 2020 (projected)

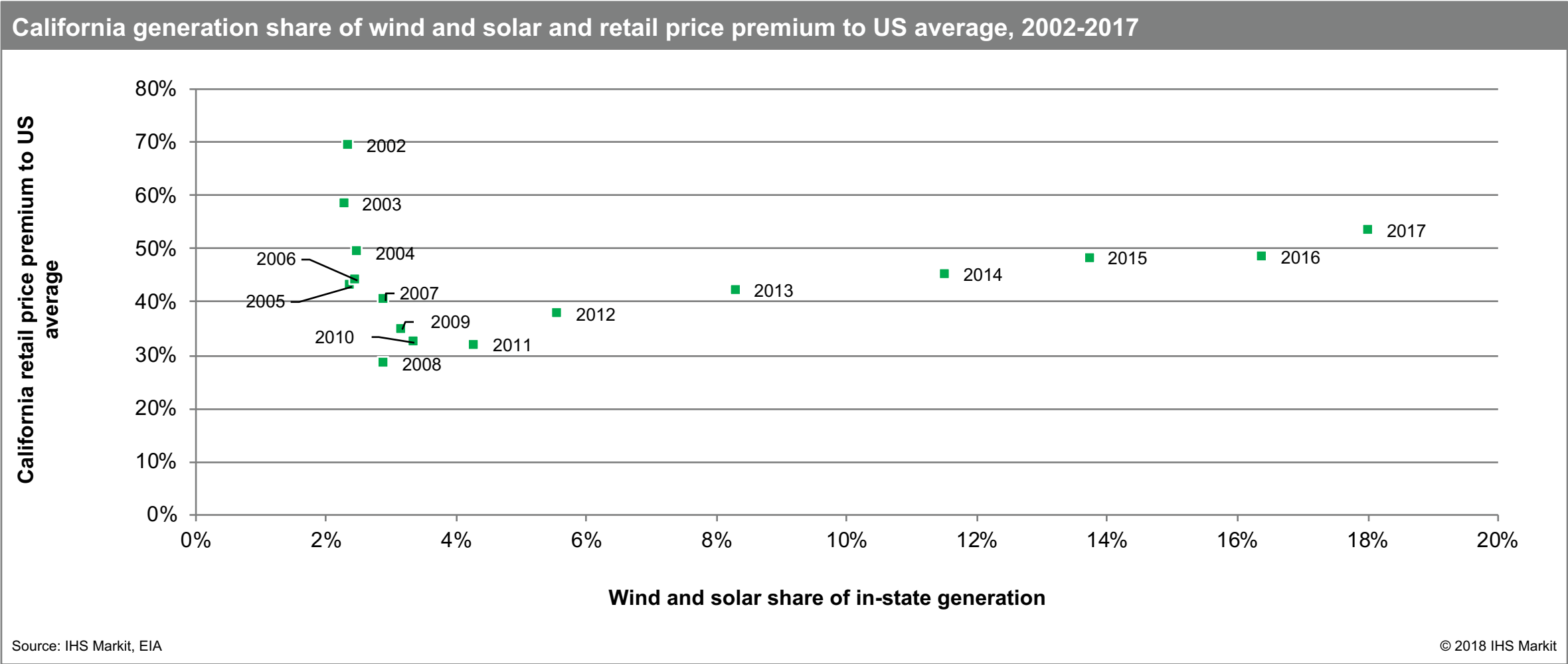


Source: California ISO, http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf accessed October 2, 2017.

California in-state CO₂ emissions from power generation and electricity imports

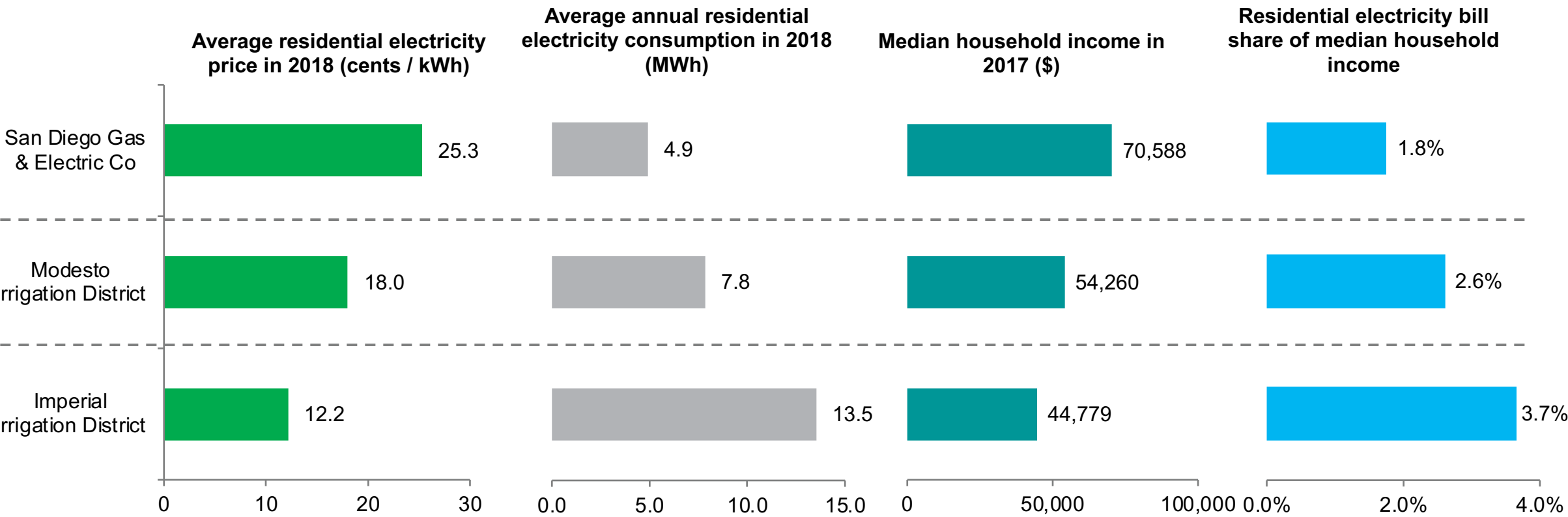


California wind and solar in-state generation shares and retail price premium to US average



Average residential electricity price, annual bill and income data for select counties in California

Average residential electricity price, consumption, and household income data for select counties in California



Source: EIA (Form 861M), US Census Bureau, 2013-2017 American Community Survey, IHS Markit

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