Abstract

This study examines a high-renewable national power system using real operations data rather than models. The objective was to characterise hourly and seasonal solar performance in Denmark during 2024, assess project-scale costs under Danish assumptions, and quantify avoided operational CO_2 within a management and bioeconomy perspective. Hourly records from the Energinet Energi Data Service for both price zones (DK1 and DK2) were converted from MW to MWh and aggregated to daily and monthly panels to derive indicators of solar generation and solar's share of total electricity. Avoided CO_2 was calculated by applying a fixed operational factor of 180 g CO_2 per kWh to observed solar MWh. Project economics were evaluated for a reference 1 MW PV system using Danish inputs.

Results show a mature, data-driven system. Renewables supplied about 72% of annual electricity in 2024, with solar and wind alternating seasonally and day-ahead forecasts exceeding 95% across the year. Using the observed energy sequence and Danish cost assumptions, the reference PV project yielded an LCOE of 370–540 DKK/MWh. Applying the operational emissions factor, a 1 MW PV plant producing 1.3–2.0 GWh per year would avoid approximately 234–360 tonnes CO_2 annually and 5,850–9,000 tonnes over 25 years.

Viewed through Green Innovation Management and bioeconomy lenses, Danish solar functions not only as a clean generator but also as an enabler for sector coupling and circular processes. The two bidding zones show synchronised seasonality with different amplitudes, supporting reliable operation and accurate forecasting. The contribution of this work is a reproducible framework that links hourly operation, cost metrics, and avoided operational emissions using open data, providing a transferable template for European systems moving toward very high renewable shares.