Offshore wind grid

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a provincial peak load and offshore wind levelized costs for mainland China; b wind roses at typical locations for offshore wind development, with each location indicated in a; c offshore wind installation statistics and national planned capacity for all coastal provinces. 2020Q4 plan was incorporated in the analyses.

Provincial supply curves for 2020, 2030 and 2050 are indicated in a, b, and c respectively. Cumulative offshore wind capacity available at each LCOE level, with provinces differentiated by line color. Levelized cost for benchmark coal-fire and nuclear power units equal 0.07 and 0.085 USD/kWh respectively, presented in blue and orange dashed lines.

Curtailment rates for different provinces at all possible wind penetrations are summarized in Fig. 3a (onshore) and Fig. 3b (offshore) respectively. Onshore wind curtailments for inland northern provinces rise rapidly given the limited local power demand, whereas curtailment rates for offshore facilities in major coastal provinces (including Guangdong, Jiangsu, and Shandong) are only apparent when wind investments exceed 100 GW. When applying the policy constraints on curtailment thresholds enforced by the NDRC (15% for Xinjiang and Gansu, 8% for WIM and 5% for other provinces), wind power potential (indicated by black dots in Fig. 3a, b) decreased significantly for essentially all inland provinces. Offshore wind, in contrast, is less affected except for Fujian and Hainan.

The economic potential of wind power, indicated by grid integrated capacity factors (considering both local wind resources and curtailments) is summarized in Fig. 3c (onshore) and in Fig. 3d (offshore). The economics for onshore wind, despite facing higher curtailment rates, is still more favorable in the "three north" region. LOCE for onshore wind in EIM, WIM, JJT and Xinjiang could still reach 0.25 CNY/kWh at 50 GW of wind installation after accounting for the curtailment loss. The economic potential for offshore wind power, when accounting for both resources and grid integration, could also reach 50 GW in major coastal provinces such as Fujian, Jiangsu, Zhejiang and Shandong.

The Chinese government, along with its ambitious commitment to carbon neutrality by 2060, announced a mid-term target to reach 1200 GW of non-hydro renewable investments by 2030, targeted to provide 40% of electricity demand using the contribution from renewables. In response to this national policy, provincial governments released investment agendas for onshore, offshore wind and solar PV for 2025 and 2030 (refer to

Table S23 and figure S33 for details). These investment targets amount to a total of 1228 GW by Feb 2022, in line with the national objective. The provincial plans are aggregated and defined as "provincial government strategies" hereafter.

Two scenarios are considered in our simulation: (1) Business As Usual (BAU) strategy fixes the capacity investment for non-hydro renewables according to the provincial government plan, while allowing for free expansion of thermal units and storage systems; (2) optimal planning strategy (Opt) optimizes the provincial investments for all of the non-hydro renewables, thermal units and storage systems, to fulfill the 40% renewable penetration target proposed by NEA. We note that the government plan in the "BAU" scenario is defined up to Feb 1st 2022 reflecting the status of 14th Five Year Plan, and later changes in government plans are not reflected. The simulation results for the "BAU" and "Opt" scenarios are presented in Fig. 4a.

a Regional distribution of the onshore wind, solar and offshore wind power in the National planning (inner circle) and our optimization planning (outer circle), with each renewable alternative characterized by color types (summarized in left legend). Renewable allocation in each region is calibrated with color depth and regional abbreviation (also summarized in left legend). b The renewable penetration (including hydro power), cost increase and carbon avoided compared with the baseline scenario. The carbon dioxide abatement cost (expenditure to avoid 1ton of CO_2). c Offshore wind provincial allocation in the national planning and our optimization results. Province in the South Grid is calibrated with red color and province in East Grid is calibrated with blue color.

The provincial allocation of offshore wind capacity is improved also from the BAU strategy. Close to half of the offshore capacity in the BAU strategy is allocated to Guangdong, where offshore resources are generally inferior. While Fujian and Zhejiang, with averaged capacity factors 40% higher than Guangdong, contribute only 15% to the national offshore quota. Our optimized results prioritize the deployment in (1) Zhejiang and Jiangsu, taking advantage of their superior offshore wind resources and adequate grid integration capabilities; and (2) in Fujian, the best offshore resources in China. Our optimized allocation elevates the average offshore wind capacity factor from 0.3385 to 0.4010, by over 20%, while significantly lowering the curtailment rate.

Overall, the BAU strategy for 1228 GW of renewable installations contributes only to a penetration of 31.5% by 2030 (including renewables generated from existing hydro power), falling short of the 40% projected target. Our optimized investment plan elevates the renewable penetration level from 31.5% to 40%, with a lower system cost. Also, the improved renewable allocation could contribute to a reduction over the lifespan of these renewable projects of an additional 20 billion tons of CO_2 emissions compared with the current BAU strategy, equivalent to 60% of global CO_2 emissions in 2020.

a Proportion of capacity increment for all the non-hydro renewables, storage systems and thermal units in above four scenarios. b Deployed storage capacity in the proposed scenarios. c System cost breakdown in above four scenarios. The capital expenditure of H_2 electrolyzer and system benefit in hydrogen selling in S4 are illustrated with red and blue bars on the right, respectively.

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