Errata

Clarification to "A low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes, " by Mark Z. Jacobson, Mark A. Delucchi, Mary A. Cameron, and Bethany A. Frew, first published December 8, 2015; 10.1073/pnas.1510028112 (Proc Natl Acad Sci USA 112:15060-15065).

The authors clarify Footnote 4 of Table S2 (Supplementary Information) to state, "As defined in [1], [2], and [3], installed capacity of a hydropower plant differs from its nameplate (or rated or plant) capacity. Nameplate capacity is the maximum electrical power discharge rate of the turbine-generator system in a hydropower facility. Installed capacity is the smaller of the average power produced by available water over a year in the hydropower reservoir (Table 2 of [1]) and the nameplate capacity of a hydropower system [2], [3]. Table S2 defines the hydropower quantity 87.48 GW as "installed" capacity, thus it is the smaller of the nameplate (or rated) capacity of all hydropower turbines in the system and the power output limited by water availability.

"The 87.48 GW of installed hydropower in this table was selected because it is the contemporary nameplate hydropower capacity. However, it is also the maximum *potential* annually averaged discharge rate of hydropower (installed capacity) both today and in 2050 in this study. In other words, it is the practically-determined capacity limited by the maximum amount of water that can pass through turbines in the annual average [1], [2], [3] and set to the contemporary hydropower nameplate capacity (87.48 GW). The *actual* annually averaged discharge rate of hydropower in this study for 2050 is 45.92 GW (Table 2), which is much less than the 87.48 GW maximum *potential* annually averaged discharge rate (installed capacity).

"As indicated in Figures 2b, S4b, and S5b, it is assumed here that 1,282.5 GW nameplate capacity of turbines are added to existing hydropower dams to increase the maximum *instantaneous* discharge rate of hydropower to a total 1,370 GW without changing the reservoir size or maximum *potential* annually averaged discharge rate of hydropower (installed capacity) of 87.48 GW. Thus, while the peak discharge rate may increase significantly for some hours, it decreases significantly for others to ensure the *actual* annually averaged discharge rate of hydropower is not much different from today and much less than its maximum annual value, 87.48 GW. This can be accomplished by modifying powerhouses to increase either the number or nameplate capacity of turbines and the instantaneous flow rate of water to them, by either adding pipes around or above dams or widening penstocks through dams. The "rated capacity per device (MW) column in Table S2" shows values for 2013. An additional "rated capacity" column should be added to 2050 showing 2050 values, which are the same as 2013 values for all devices except hydropower, which should be 20.35 GW due to uprating."

"The cost of uprating is estimated as follows. The cost of electrical equipment (turbines, generators, and transformers) in a hydropower plant ranges from ~$560/kW for 500 MW plants to ~$200-$300/kW for 1000 MW plants (Figs. 4.5 and 4.7 of [4]). We start with the cost for a large 1000-MW plant and add costs for pipes or widening penstocks and for equipment housing and contingencies due to possible supply shortages to arrive at an estimated total cost of the additional hydropower turbines of roughly $385 (325-450) per kW. This amounts to ~$494 billion for all of the additional turbines proposed here, which would increase the total all-sector capital cost in Table 2 by a mean of just over 3%. We believe this cost increase has no impact on the main conclusions of this study. Even if costs were much higher, there are multiple other low-cost solutions with zero added hydropower turbines but more CSP and batteries instead, not only for North America, but also for 20 world regions [5], so the increase in hydropower peak instantaneous discharge is just one of several options.

"Finally, as stated previously in Section 5.4 of [6] but reiterated here, 9.036 GW of the 87.48 GW of already-installed hydropower in this table are Canadian installations providing pre-existing imported hydropower. (The difference between the 87.48 GW here and the 87.86 GW in [6] is that the former is for the 48 contiguous United States and the latter is for all 50 states)."

1. O.P. Rahi, A. Kumar, Economic analysis for refurbishment and uprating of hydropower plants, Renewable Energy, 86 (2016) 1197-1204.
2. Business Dictionary, Installed capacity: definition, http://www.businessdictionary.com/definition/installed-capacity.html, Accessed June 2, 2018.
3. Free Dictionary, Installed capacity: definition, https://encyclopedia2.thefreedictionary.com/Installed+Capacity, Accessed June 2, 2018.
4. IRENA (International Renewable Energy Agency), Renewable Energy Technologies: Cost analysis series. Hydropower, Vol. 1(3), IRENA, Abu Dhabi, 2012.
5. M.Z. Jacobson, M.A. Delucchi, M.A. Cameron, B.V, Mathiesen. Matching demand with supply at low cost among 139 countries within 20 world regions with 100% intermittent wind, water, and sunlight (WWS) for all purposes, Renewable Energy, 123 (2018), 236-248.
6. M.Z. Jacobson, M.A. Delucchi, G. Bazouin, Z.A.F. Bauer, C.C. Heavey, E. Fisher, S.B. Morris, D.J.Y. Piekutowski, T.A. Vencill, T.W. Yeskoo, 100% clean and renewable wind, water, sunlight (WWS) all-sector energy roadmaps for the 50 United States, Energy and Environmental Sciences, 8 (2015) 2093-2117.