Response to Ken Caldeira's (KC's) February 28, 2018 "MZJ Hydro Explainer"

By Mark Z. Jacobson (MZJ) March 4, 2018

1. KC: "Jacobson et al. (PNAS, 2015) filled this gap, in part, by assuming that huge amounts of hydropower would be available."

MZJ: Misleading. We increased the peak discharge rate of hydropower, not the size of any dam or the number dams or, beyond a tiny amount, the annual average flow rate from dams.

2. KC: "Jacobson et al. (E&ES, 2015) serves as the primary basis for the capacity numbers in Jacobson et al. (PNAS, 2015).

A) MZJ. True with respect to existing and new energy generation but false with respect to storage. Added hydropower turbines are a component of storage, not new generation.

B) First, the Introduction to E&ES (2015) states, "*A separate study (PNAS, 2015) provides a grid integration analysis to examine the ability of the intermittent energy produced from the state plans here, in combination, to match time-varying electric and thermal loads when combined with storage and demand response.*"

C) The sentence above clearly indicates that the data from the E&ES article are "*energy produc(tion)*" data, but data from the PNAS article are "*storage and demand response*" data. All E&ES energy production data are annual average data (e.g., Table 1, Table 3) or characteristics of generators for annual average power (Table 2).

D) As an example, for hydropower, the annual average energy added to reservoirs in the PNAS paper is taken exactly from the annual average energy produced by hydro given in Section 5.4, and Tables 1 and 3 of the E&ES paper.

E) In the PNAS article, turbines were added to existing dams, increasing the nameplate capacity of hydro (from 87.48 GW to 1348 GW, or by a factor of 14.4), as clearly indicated in Figures 2B, 4B, S4B, and S5B but not stated in the text. However, the installed capacity was held constant at 87.48 GW as clearly indicated in Table S2, and the annual energy output was virtually the same (within 0.5%) of the 2013 CONUS energy output, as proven by Table 2 and Figures 2B of the PNAS main text.

F) Turbines were added to existing dams solely to help match supply with demand by increasing the discharge rate of hydroelectric storage, NOT to provide a new source of or additional hydropower energy. As such, the E&ES article was absolutely accurate in reporting that it provided energy production values, whereas the PNAS article provided storage and other information necessary for keeping the grid stable.

G) Some might ask, *how can we add turbines to existing dams (increasing nameplate capacity) without increasing the installed capacity*?

H) The reason is simple. In the PNAS study, we defined the installed capacity as the maximum potential annual average energy output of any energy device (which is its physically exact definition). For hydropower, we assumed dams could be no larger in 2050 than in 2013, so the maximum potential annual average energy output among all dams in 2050 was required to equal that in 2013. The 2013 maximum potential annual average energy output (installed capacity) was further assumed to equal the 2013 nameplate capacity among all dams. To summarize, the 2050 installed capacity in the PNAS study for hydropower was set to the 2013 installed capacity (as proven in Table S2), which was assumed to equal the 2013 hydropower nameplate capacity from the E&ES article (as proven from E&ES article). The installed capacities of all other devices were allowed to grow from 2013 to 2050 (as proven in PNAS Table S2).

I) By using 2013 nameplate capacity as 2050 installed capacity for hydropower, we assumed that **the maximum potential annual-average output of a hydropower dam is limited not only by nameplate capacity, but also by the maximum amount of water a dam could hold for energy in the annual average**. The fact that we prevented hydropower from exceeding the maximum potential annual average output is proven by the numbers in Table 2, Figure 2, and Footnote 4 of Table S2, which states, "*Hydropower use varies during the year but is limited by its annual power supply*."

J) Because we prohibited an increase in the maximum potential annual average energy output or water flow, when we added turbines to existing dams, we increased the nameplate capacity but not the installed capacity of turbines.

K) This assumption and definition of installed capacity are supported by the Business Dictionary, which defines "*Installed Capacity" as "Production capacity of plant based **either** on its rated (nameplate) capacity or actual (practically determined) capacity.*" Thus, Installed Capacity clearly has more than one meaning.

L) It is also supported by the Free Dictionary, which defines installed capacity as *"(electricity) The maximum runoff of a hydroelectric facility that can be constantly maintained and utilized by equipment*."

M) Both suggest that installed capacity can be limited by water available in the dam and/or can differ from nameplate capacity. Whereas, we were not clear in writing what we did nor of the definition of all our terms, this is exactly how we modeled the system as proven by all figures and data, namely by increasing the number of turbines (nameplate capacity) while keeping the maximum potential annually-averaged energy output (installed capacity) constant and keeping the actual annually-averaged energy output almost constant.

3. KC: "Jacobson et al. (E&ES, 2015) makes it clear that 'capacity' refers to name-plate capacity."

MZJ: Yes, the 2013 capacities in the E&ES (2015) article are both nameplate capacities and installed capacities, because the two are equal to each other before adding turbines to existing dams while holding the maximum potential annual average energy output constant, which was done in the PNAS paper. Please see the detailed explanation in Response 2H.

4. KC: "Most of the capacity numbers in the Jacobson et al. (E&ES, 2015) come from the U.S. EIA."

MZJ: Correct. As stated, all capacity numbers in E&ES (2015) are both installed and nameplate capacities in 2013, because those equal each other in 2013, as described clearly in Response 2H here.

5. KC: "Crucially, nowhere in this lengthy discussion of the total hydroelectric capacity assumed in the WWS and additional possible sources of hydroelectric capacity does Jacobson et al. (E&ES, 2015) mention the possibility of adding over 1,000 GW of additional generating capacity to existing dams by adding new turbines."

MZJ: Absolutely correct. The "lengthy discussion" KC refers to is on methods of increasing annual average energy output from hydropower, NOT increasing the peak discharge rate of hydropower. As clearly stated in the Introduction of the E&ES paper (Response 1), the E&ES paper provides data regarding energy PRODUCTION and the PNAS paper provides information about STORAGE. Increasing hydropower turbines without increasing the hydropower maximum potential annual energy output affects the discharge rate of hydropower STORAGE, not PRODUCTION of additional hydropower energy. Thus, it is wrong to claim or believe there should have been a discussion of increasing the hydropower discharge rate in the E&ES article

6. KC: "The May 2015 E&ES article by MZJ et al. explicitly states that the maximum potential instantaneous discharge power production capacity of hydroelectric generators in the 100% WWS roadmap for the 50 U.S. states is 91.65 GW."

MZJ: That is absolutely correct for the 2015 E&ES article, which considered meeting only annually averaged power demand, not time-dependent power demand. There is nothing inconsistent about this fact (See Response 2H).

6. KC: "Jacobson et al. (E&ES) also explicitly distinguishes maximum power capacity from average delivered power in several instances."

MZJ: Yes, absolutely correct. The 2015 E&ES article considered annually averaged power delivered as well as maximum annual average power before hydropower turbines were added in the subsequent PNAS article.

7. KC: "The E&ES companion paper to the Jacobson et al. (PNAS, 2015) therefore explicitly establishes that the maximum potential power capacity that could be included in the PNAS paper in the contiguous 48 U.S. states is 87.412 GW.

MZJ. That is the maximum potential installed capacity in the PNAS paper, but not the maximum potential nameplate capacity (Responses 2G-2M).

The E&ES article explicitly states that the PNAS paper treats the storage necessary to match time-varying demand, whereas the E&ES paper does not (Response 2), so there is no basis to believe that the added hydropower turbines should be discussed in the E&ES paper. Hydropower turbines are a component of storage, not a component of additional power generation (Response 2).

8. KC: "The text (of the PNAS article) further establishes that the installed capacities for each generator type for the continental United States are based on ref. 22, which is Jacobson et al. (E&ES).

MZJ. Yes, absolutely. This is clearly stated in Response 2H.

9. KC: "In contrast, the table establishes that the authors assume that total installed hydroelectric capacity in the Continental U.S. is assumed to increase from 87.42 GW in 2013 to 87.48 GW in 2050."

MZJ. Correct, Table S2 contains installed capacities (maximum potential annual average discharge rates) (see Response 2H), and the numbers of devices were calculated simply by dividing the installed capacity by an example rated capacity. As seen in this Clarification,

http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/Clarification-PNAS15.pdf

it has already been acknowledged that Table S2 was not clear that turbines were added.

10. KC: "The hydro capacity represented in the Jacobson et al. (PNAS, 2015) tables is inconsistent with the amount of hydro capacity used in their simulations.

MZJ. Not true. Figures 2B, 4B, S4B, and S5B, which all show hydropower discharge rates exceeding the installed capacity of hydropower in Table S2, are consistent with Table S2, because the installed capacity in Table S2 is the maximum potential annual average discharge rate (see online Clarification and Response 2H), NOT the nameplate capacity, which gives the maximum instantaneous discharge rate (Response 2H). While we were not clear what we did (see online Clarification), there is no discrepancy. Further, Figures 2B, 4B, S4B, and S5B show we increased the peak discharge rate thus nameplate capacity, and Figure 2B and Table 2 show we kept annual average power demand far below the maximum potential annual average demand and close to 2013 values. Thus, results were consistent with our intention.

11. KC: "The total installed hydroelectric capacity or maximum potential power generation reported in Table S2…"

MZJ. No, in the PNAS paper, the installed capacity (maximum potential annual average discharge rate) is not the maximum potential (instantaneous) power generation (nameplate capacity) (Response 2H).

11. KC: "…a reasonable reader should interpret the 'installed capacity…"

MZJ. Whereas, we were certainly not clear, it is not appropriate for KC to tell readers how they should interpret "installed capacity" to suit his purpose when "installed capacity" has more than one definition (Responses 2K and 2L) and was absolutely intended to mean by us the maximum potential annual average discharge rate, which it physically is for any generator.

12. KC: "…maximum power capacity for hydroelectric facilities in the PNAS WWS study for the 48 continental United States is 87.48 GW, not the 1,348 GW actually dispatched by the LOADMATCH model."

MZJ: False. The PNAS paper itself (Figures 2B, 4B, S4B, and S5B; Table 2; Table S2) and the associated hydropower data itself

https://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/HydroTimeSeriesPNAS2015.xlsx

prove beyond any doubt that the model was intended to dispatched far beyond the installed capacity while keeping the annual average power production under the maximum potential value (installed capacity) of 87.48 GW.

12. KC: Thus, information in the E&ES and PNAS papers do not appear to be

consistent with MZJ's assertions that he and his coauthors had intentionally meant to add more than 1,000 GW of generating capacity to existing hydropower facilities in their model…Nor does the available evidence indicate that they intentionally assumed more than 1,000 GW of additional hydro capacity and then simply failed to disclose this assumption at any point in either of the two papers. Such failure to explicitly describe such a large and substantively important assumption to readers and peer reviewers might itself constitute a breach of academic standards.

MZJ: This is a defamatory claim disproven by the model data and information in the PNAS paper (Response 11) and the fact that a clarification was issued immediately to the first person, Dr. Clack, who found the results unclear, on February 29, 2016.

What is clear is that Dr. Clack and Dr. Caldeira were absolutely aware of the assumption (because Dr. Clack was informed on February 29, 2016 and replied, "I am not disagreeing with the possibility it can be done with CSP and hydro, etc.," and Dr. Caldeira was informed in writing of the assumption prior to publication), yet both pretended they were unaware of the assumption, publishing, "This error is so substantial, we hope there is another explanation for the large amounts of hydropower output depicted in these figures." Even if Dr. Caldeira disagreed with the assumption, the fact that he pretended not to know exactly what the assumption was may constitute a breach of research standards.

In addition to this, Dr. Caldeira published that our Table 1 contained maximum values whereas it contained average values and published a comparison of U.S. data versus our U.S plus Canadian estimates, pretending he was comparing apples with apples. The publication of the first false claim when he had been informed ahead of time of it, and his refusal to correct the second claim may constitute a breach of research standards.

The facts around these issues described here:

http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/18-02-Correction.pdf