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October 17, 2018

RE: Taiwan's Transition to 100% Clean, Renewable Energy for All Purposes

To whom it may concern,

I am writing this letter to quantify the feasibility of transitioning the energy infrastructure of Taiwan for all purposes (electricity, transportation, heating/cooling, industry, agriculture/forestry/fishing) to 100% clean, renewable energy and storage while keeping the electric power grid stable.

Clean, renewable energy as defined here includes only wind (onshore and offshore), solar (photovoltaics, or PV, on rooftops and in power plants), geothermal, hydroelectric, tidal, and wave power). These technologies are collectively referred to as wind, water, and solar (WWS) technologies. The idea is to electrify everything and provide that electricity with clean, renewable energy combined with electricity, heat, cold, and hydrogen storage and transmission.

Under the WWS system, heating of air and water and cooling of air and refrigerators in buildings would be provided by electric heat pumps; stoves would be electric induction; light bulbs would be LED; vehicles would be battery-electric (or in some cases, hydrogen fuel cell, where the hydrogen is produced from electricity); high-temperature heat would be obtained from electric arc furnaces, induction furnaces, and dielectric heaters; etc. There would be no energy need for coal, oil, natural gas, biofuels, or even nuclear power.

Our results for Taiwan are published in two separate papers referenced at the end of this letter (Jacobson et al., 2017 and 2018). The main estimated benefits of such a transition are summarized as follows:

1) Creation of 240,000 more full-time, long-term jobs than lost
2) 2050 cost electricity replacing current electricity: 10.1 (8-13) ¢/kWh-2013 USD
3) 2050 cost electricity replacing all energy: 11.3 (8.1-15.8) ¢/kWh-2013 USD
4) 2050 climate cost savings: 24 (14-51) ¢/kWh-2013 USD
5) 2050 air pollution health cost savings: 6.6 (0.8-25.4) ¢/kWh-2013 USD
6) 2050 air pollution deaths avoided: 6,200 (1,500-14,000) per year
7) 2050 reduction in kWh needed due to efficiency of a WWS system: 40.3%-55%
8) Capital cost for generation + storage + transmission: $1.27 (0.93-1.61) trillion

9) WWS social cost is 73% less than that of a fossil system per kWh and 87% less in terms of absolute USD.

In short, if the corresponding power generation and energy storage systems are actively developed, with the existing technology, it is feasible for Taiwan to supply 100% of its electricity and energy needs with renewable energy by 2050.

Table 1, below, gives the nameplate capacities needed for WWS generators to power 100% of Taiwan and the maximum charge rates, discharge rates, and storage capacities needed for all electricity, cold, and heat storage needed to match supply with demand in Taiwan.

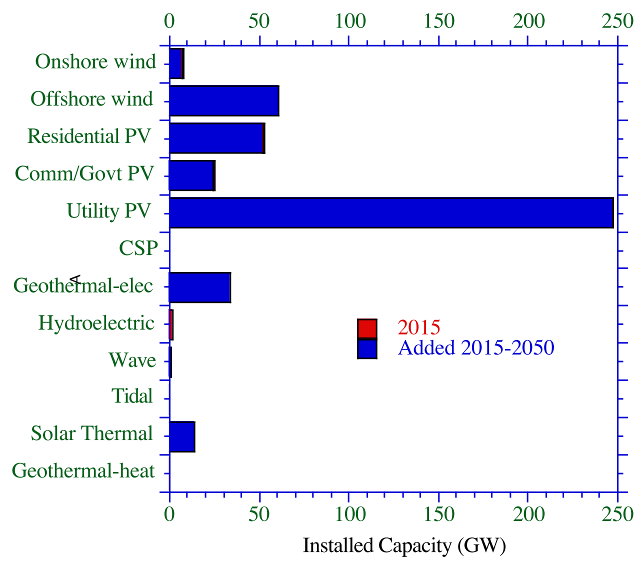
Table 1. (a) 2015 and proposed 2050 installed capacity for WWS generators to power 100% of all energy sectors in Taiwan while matching demand with supply on the grid. Figure 1 graphs these results. (b) Maximum charge rates, discharge rate, and storage capacity of all electricity, cold and heat storage needed for supply + storage to match demand in Taiwan.

(a) WWS Generator	2015 (GW)	2050 (GW)
Onshore wind	0.647	7.47
Offshore wind	0	61.0
Residential PV	0.274	52.6
Comm./govt. PV	0.341	25.1
Utility PV	0.395	247.4
CSP	0	0
Geothermal-elec.	0	33.6
Hydropower	2.08	2.08
Wave	0	1.05
Tidal	0	0.0267
Solar thermal	0	14.0
Geothermal-heat	0.0001	0.0001

(b) Storage type	Max charge rate (GW)	Max discharge rate (GW)	Storage (TWh)
CSP	0	0	0
PHS	49.1	49.1	0.687
Batteries	350	350	0.679
Hydropower	0.982	2.08	8.60
CW+ice	6.22	6.22	0.0871
HW	227.3	227.3	3.18
UTES-heat	14.0	227	131
UTES-elec	455	--	--

CSP = concentrated solar power; PHS=pumped hydropower storage; CW+ice= chilled water storage plus ice storage; HW=hot water storage; UTES-heat=underground thermal energy storage in rocks, where heat is obtained from solar thermal collectors; UTES-elec=UTES storage in rocks, where heat is obtained from excess WWS electricity. In addition, hydrogen was produced (1.29 Tg-H_2/yr) and stored (0.0354 Tg-H_2 tanks) for use only in transportation. Battery electric vehicles were also used in transportation.

Figure 1. 2015 and proposed 2015-2050 additions of installed capacity of WWS generators for Taiwan.



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Figures 2 and 3 show 5-year results from Jacobson et al. (2018) indicating that 100% WWS supply and storage can match demand every 30 seconds for 5 years in Taiwan.

Figure 2. Five-year (60-month, 2050-2054, with a 30-s time step) time-series comparison for Taiwan of computer modeled (a) monthly-averaged total wind-water-solar (WWS) power generation versus the sum of load met across all energy sectors (electricity, transportation, heating/cooling, industry, agriculture/forestry fishing) plus losses plus changes in storage plus shedding, (b) breakdown of load plus losses plus changes in storage plus shedding into individual components, and (c) breakdown of WWS power generation by generation technology.

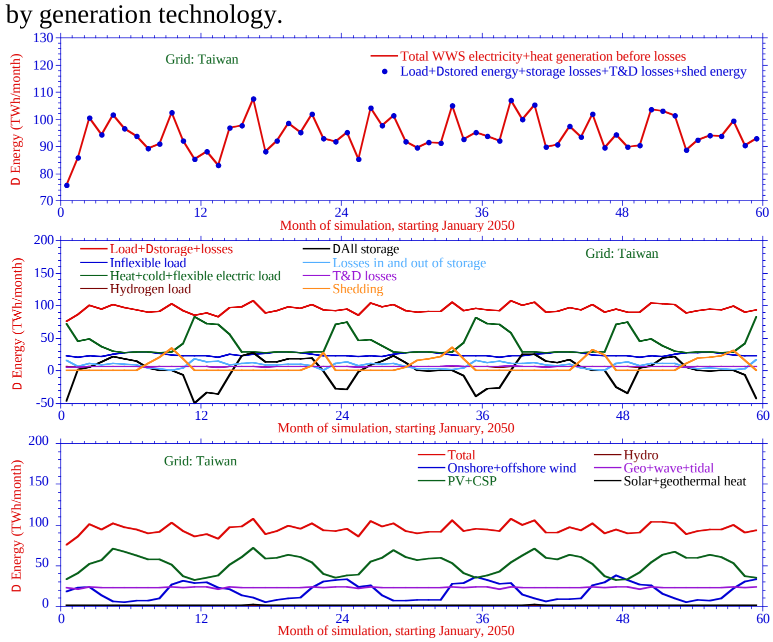
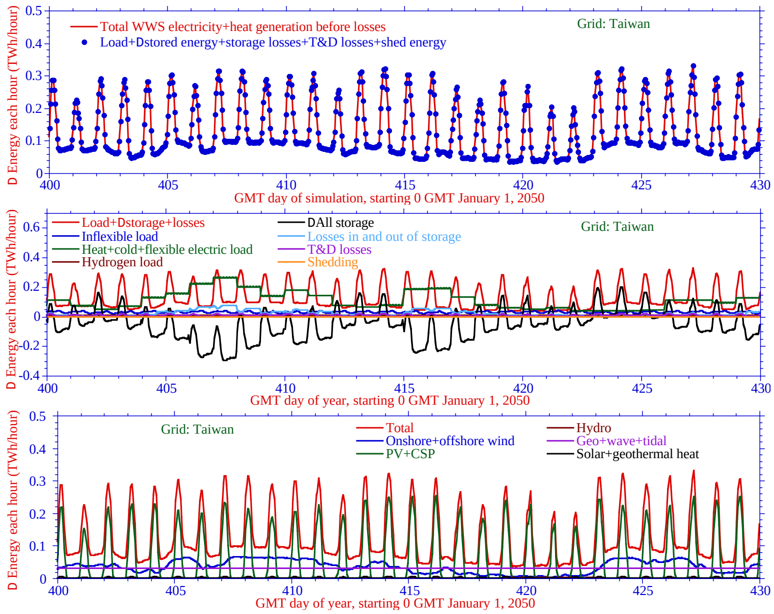


Figure 3. Same as Fig. 2, but with hourly results for a 30-day period during the 5-year simulation.



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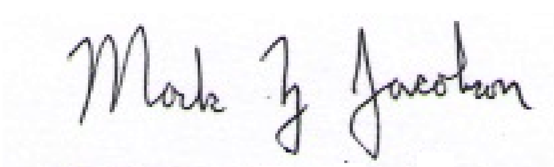
Jacobson, M.Z., M.A. Delucchi, M.A. Cameron, and B.V, Mathiesen, Matching demand with supply at low cost among 139 countries within 20 world regions with 100% intermittent wind, water, and sunlight (WWS) for all purposes, Renewable Energy, 123, 236-248, 2018, https://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/WorldGridIntegration.pdf

Thank you for considering this information. Please let me know if you have questions.

Sincerely,



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