Timeline and Land Area Required to Transition the All-Purpose End-Use Power of 143 Countries to 100 Percent Wind-Water-Solar and Five Reasons End-Use Demand Decreases 57.1 Percent Along the Way

In

100% Clean, Renewable Energy and Storage for Everything

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https://web.stanford.edu/group/efmh/jacobson/WWSBook/WWSBook.html

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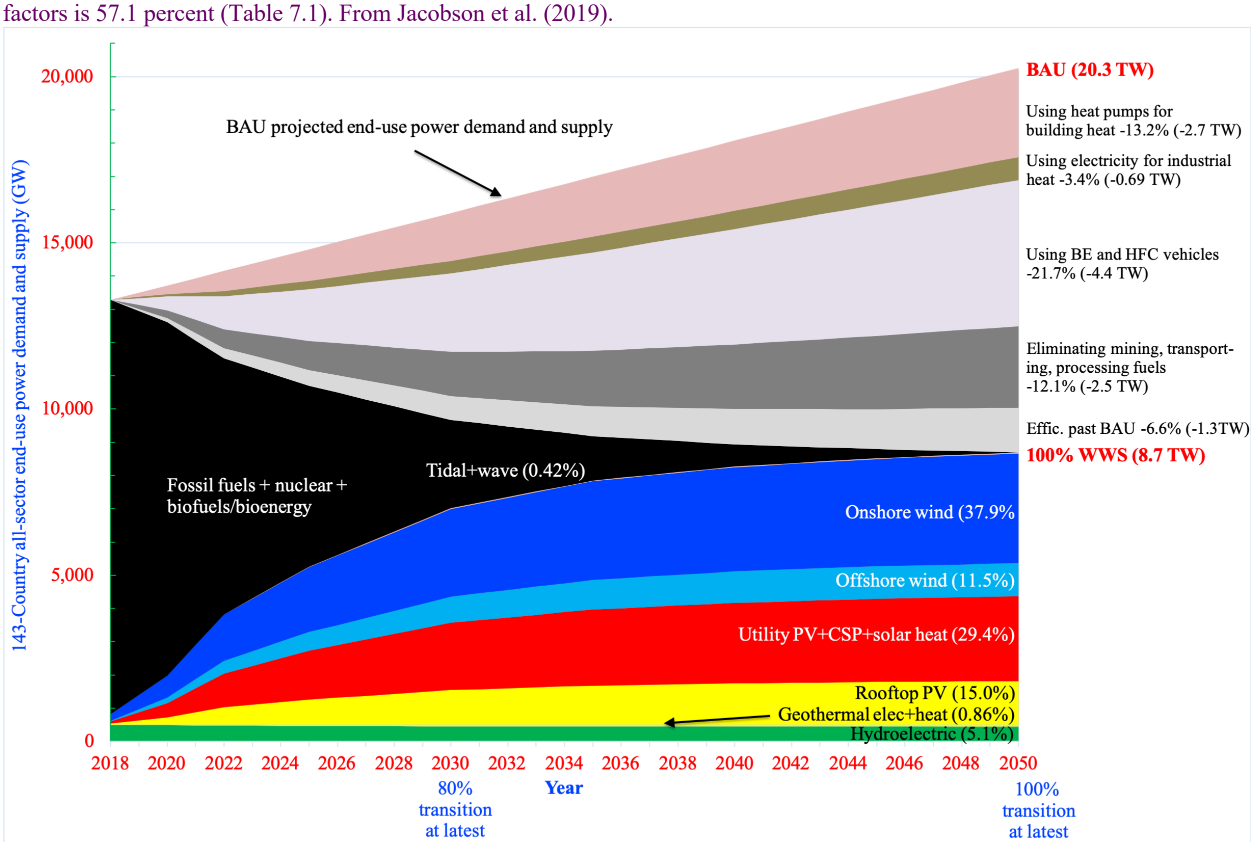
Figure 9.5. Timeline for 143 countries, representing more than 99 percent of world emissions, to transition from conventional fuels (BAU) to 100 percent wind-water-solar (WWS) in all energy sectors. Also shown are the annually averaged end-use power demand reductions that occur along the way. The energy sectors transitioned include the electricity, transportation, building heating/cooling, industrial, agriculture/forestry/fishing, and military sectors. The percentages next to each WWS energy source are the 2050 estimated percent supply of end-use power by the source. The 100 percent demarcation in 2050 indicates that 100 percent of end-use power in the annual average will be provided by WWS among all energy sectors by no later than 2050, but ideally sooner. An 80 percent transition is proposed to occur by no later than 2030. End-use power demand reductions occur for five reasons: (1) the efficiency of moving low-temperature building heat with heat pumps instead of creating heat with combustion; (2) the efficiency of electricity over combustion for high-temperature industrial heat; (3) the efficiency of electricity in battery-electric (BE) vehicles and in electrolytic hydrogen fuel cell (HFC) vehicles over combustion vehicles for transportation; (4) eliminating the energy to mine, transport, and process fossil fuels, biofuels, bioenergy, and uranium; and (5) improving end-use energy efficiency and reducing energy use beyond in the BAU case. The total demand reduction due to these factors is 57.1 percent (Table 7.1). From Jacobson et al. (2019).



Updated from

http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/WorldGridIntegration.pdf

http://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf

8.3. Estimating Footprint and Spacing Areas of WWS Generators

Footprint is the physical area on the top surface of soil or water needed for each energy device. It does not include areas of underground structures (Section 6.7). Spacing is the area between some devices, such as wind turbines, wave devices, and tidal turbines, needed to minimize interference of the wake of one turbine with downwind turbines. Spacing area can be used for multiple purposes, including rangeland, ranching land, forest land, installing solar panels, open space, and open water.

New land footprint arises only for solar PV plants, CSP plants, onshore wind turbines, geothermal plants, and solar thermal plants. Offshore wind, wave, and tidal generators are in water, so they do not take up new land, and rooftop PV does not take up new land. The footprint area of a wind turbine is relatively trivial. It is primarily the area of the cement around the base of the turbine tower that is visible above the ground. Paved roads associated with wind farms are also considered footprint, but unpaved roads are not.

The total new land area for footprint required with 100 percent WWS is about 0.17 percent of the 143-country land area (Figure 8.11). Almost all of that is for utility PV and CSP. WWS has no footprint associated with mining fuels to run equipment, but both WWS and BAU energy infrastructures require one-time mining for raw materials for new equipment.

The only spacing area over land needed in a 100 percent WWS world is the land area between onshore wind turbines. Figure 8.11 indicates that the spacing area for onshore wind to power 143 countries is about 0.48 percent of the 143-country land area..

Together, the new land footprint and spacing areas for 100 percent WWS across all energy sectors are 0.65 percent of the 143-country land area (Figure 8.11), and most of this land area is multi-purpose spacing land. In comparison, Table 3.3 indicates that the land area required for the fossil fuel infrastructure in the United States is about 1.3 percent of the United States land area. Thus, replacing fossil fuels with 100 percent WWS should reduce land area substantially.

However, solar PV panels can be installed on some of the space between wind turbines. As such, some footprint and spacing areas overlap, and the land plus footprint area in Figure 8.11 of 0.65 percent is an upper limit. The lower limit is the spacing area alone, which is 0.48 percent.

Figure 8.11. Footprint plus spacing areas (km^2) required beyond existing 2018 installations, to power all energy sectors (electricity, transportation, heating/cooling, industry, agriculture/forestry/fishing, the military) in 143 countries in 2050 with 100 percent WWS. For hydropower, the new footprint plus spacing area is zero since no new installations are proposed. For rooftop PV, the circle represents the additional area of 2050 rooftops that needs to be covered (thus does not represent new land). From Jacobson et al. (2019).