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Projections of when each of 150 countries may eliminate air pollution and carbon emissions from all energy

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Whether the world addresses global warming, air pollution, and energy insecurity in a timely manner depends largely on country transition rates to clean, renewable energy. Yet, no study has examined transition rates by country, especially using recent data. This study estimates when 150 countries can potentially transition to 100% clean, renewable energy across all energy sectors, upon near-electrification of each sector, if the countries add such energy at their most recent rates. Such a transition eliminates air pollution and carbon emissions from energy. Results suggest the world's largest energy consumer and emitter, China, is currently on track to transition fully, thus eliminate 100% of its energy-related health- and climate-damaging pollution, by 2051. China's projected 2025 renewable output increase is 20 times France's fastest (in 1981) nuclear output increase. Further, in 2025, China may already produce ~54% of the clean, renewable energy that the United States will need for supplying 100% of its all-sector demand with clean, renewable energy in 2050. Seven countries could potentially reach 100% renewables faster than China. India and the United States may reach 100% only beyond 2130. Thus, policies focusing on clean, renewable energy alone can effectively speed a transition.

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Sustainability spotlight

This paper projects when each of 150 countries can eliminate all energy-related health- and climate-damaging emissions by transitioning to 100% clean, renewable electricity and heat across all energy sectors after near electrification of each sector. It addresses United Nations Sustainable Development Goals 3 (good health and well-being), 7 (affordable and clean energy), 11 (sustainable cities and communities), 12 (responsible consumption and production), and 13 (climate action). The study finds that eight countries, including China, the world's largest energy consumer and CO_2 emitter, can reach 100% by 2051. The U.S. and India may reach 100% only after 2130. China' transition rate is faster than any clean-energy conversion in history. Thus, a focus on clean, renewable energy can speed a transition.

1 Introduction

The world needs to eliminate rapidly atmospheric gases and particles that affect human health and climate. Gas and particle emissions and their atmospheric transformations cause ~7.4 million deaths and billions more illnesses per year[1,2] in addition to an average global warming of ~1.5 °C in 2024 relative to the 1850–1900 period.[3,4] About 90% of anthropogenic air pollutant emissions and 75–80% of anthropogenic climate-damaging emissions originate from energy.[5]

Whereas several studies have discussed country-specific emission-phaseout policies[6,7] and other studies have projected what is needed to transition countries to 100% clean, renewable energy across all energy sectors to eliminate gas and particle emissions from energy,[5,8–14] no study has projected when each country might reach this goal based on existing clean, renewable generation and the growth rate of such generation. Such a study is important for four reasons. First, if some countries can transition quickly, they can serve as good examples for other countries to learn from. Second, comparing the transition speeds among countries can spur competition to encourage countries on a slow timeline to speed up. Third, many countries on a slow timeline may have a false optimistic sense of their progress, so quantifying their real progress may encourage them to speed their transition. Fourth, understanding the timeline of a world transition may help countries better project and prepare for more air pollution and climate damage.

In this study, dates are projected by which each of 150 countries can eliminate all air-quality- and climate-relevant-gas-and-particle emissions from all energy sectors by electrifying or using direct heat for all sectors and providing the electricity and heat from clean, renewable sources. All energy sectors include the residential, commercial, transportation, industrial, agriculture-forestry-fishing, and military-other sectors.

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Electrifying all sectors means converting technologies (*e.g.*, combustion vehicles; combustion heaters), currently powered by fossil fuels or bioenergy fuels, to those powered by electricity (*e.g.*, electric vehicles; electric heat pumps or electric resistance furnaces). Clean, renewable electricity and heat sources also referred to as wind-water-solar, or WWS, sources, include onshore and offshore wind electricity, solar photovoltaic electricity, concentrated solar electricity, direct solar heat, geothermal electricity and heat, hydroelectricity, and tidal and wave electricity sources.[5,14]

Nuclear is not included as a WWS source because it carries seven major risks: long time-lag between planning and operation (12–23 years worldwide today); carbon and pollution emissions from the background grid due to the long time-lag, reactor construction, and continuous uranium mining and processing; nuclear weapons proliferation risk; reactor core meltdown risk; radioactive waste storage risk; underground uranium mining lung cancer risk from radon; and high cost.[10] Bioenergy is not included because of the air pollution that results from its combustion; the greenhouse gases and pollutants that are emitted during the production of a bioenergy fuel; and the substantial land and water needed to grow many types of bioenergy crops.[10]

Electrifying almost all processes across all energy sectors, using direct heat for the remaining processes, and using WWS to provide all electricity and direct heat eliminates ~100% of fossil-fuel and bioenergy-fuel combustion emissions from energy, but only about 90% of total anthropogenic air pollutant emissions and 75–80% of total anthropogenic climate-damaging emissions.[5] Remaining anthropogenic air pollutant emissions are primarily from open biomass burning, road dust, and construction dust.[5] Remaining anthropogenic climate-damaging emissions are from those sources plus from fertilizers and industry producing nitrous oxide; halogens; agriculture and landfills producing methane; and cement and steel manufacturing chemically producing carbon dioxide. This paper focuses only on the time to eliminate 100% of fossil-fuel plus bioenergy-fuel emissions from all energy by electrifying or using direct heat for such energy and providing all electricity and heat with 100% WWS.

The projected transition-to-100%-WWS dates are determined by combining 2050 estimates for each country of what is needed to achieve 100% WWS across all energy sectors[14] with data quantifying the clean, renewable generators already installed in 2023, 2024, and, in some cases, 2025, along with the rates of change of such installations.[15–20] Data from further back than 2023 were not used given that they are based on older technologies, policies, and costs than from more recent years. Whereas projections based on current installation rates may provide reasonable estimates of transition times that are short (*e.g.*, less than 30 years), they result in more uncertain estimates of longer transition times. The longer the transition time, the more uncertain the estimate because countries may change priorities and technology costs may decrease substantially over time, causing a country to adjust its transition rate over time. However, transition times of up to 325 years are shown here just to compare the relative progress of different countries rather than to give a firm idea of when countries with long transition times will reach 100% WWS.

Whereas this study considers the rates at which generators are being installed, it does not consider rates at which storage and electric machines and appliances (*e.g.*, electric vehicles, electric heat pumps, and electric resistance furnaces) are being adopted. Nevertheless, the Discussion analyzes how fast China is adopting some of these technologies. The study assumes that the adoption of these technologies will accompany the installation of WWS electricity- and heat-generating technologies because such electric appliances and machines reduce end-use energy demand (total final consumption, or TFC) substantially relative to their conventional counterparts (*e.g.*, internal-combustion-engine vehicles, gas heaters, and fossil-fuel furnaces, respectively).[5] Thus, the estimates here are based on how fast WWS electricity and heat generators are being installed relative to how much WWS generation is needed to provide 100% of all-sector electricity and heat across all energy sectors, after electrifying most all non-electric processes, for a country.

2 Experimental section

2.1 Methods

End-use energy demand (TFC) data (GWh per y, or annual GW-demand) from 2022, published by the International Energy Agency,[21] were first projected in a separate study[14] to 2050 in a business-as-usual (BAU) scenario for each of seven fuel types within each of six end-use energy sectors within each of 150 countries. The seven fuel types include oil, fossil gas, coal, electricity, heat for sale, solar and geothermal heat, and wood and waste heat. The end-use energy sectors include the residential, commercial, transportation, industrial, agriculture-forestry-fishing, and military-other sectors. Table S1 lists the 150 countries. Energy use for transportation includes energy for ground, air, and marine transport, including international aviation and shipping. The projections to 2050 assume moderate economic growth, population growth, energy consumption growth, modest energy policy changes that vary by world region, use of some renewable energy, modest energy-efficiency measures, and reductions in energy use.

The 2050 BAU projections of end-use demand (TFC) were then used as a starting point to estimate how much electrical and direct heat energy (GWh per y) might be needed if each BAU fuel type in each end-use sector in each country were switched to electricity, electrolytic hydrogen, low-temperature heat, or high-temperature heat, and if such electricity, hydrogen, and heat were provided by WWS. For example, air and water heating for buildings, originally provided by combustion heaters, was assumed to instead be provided by electric heat pumps. Vehicle transport, originally provided by internal-combustion-engine vehicles, was instead provided by battery-electric vehicles for all but very-long-distance aircraft, ships, trucks, and trains, which were propelled instead with hydrogen-fuel-cell electricity.[22] Industrial heat, originally provided by combustion furnaces and boilers, was instead provided by electric furnaces and firebrick storage. The resulting reductions in end-use energy demand (TFC) were calculated with conversion factors that vary by fuel

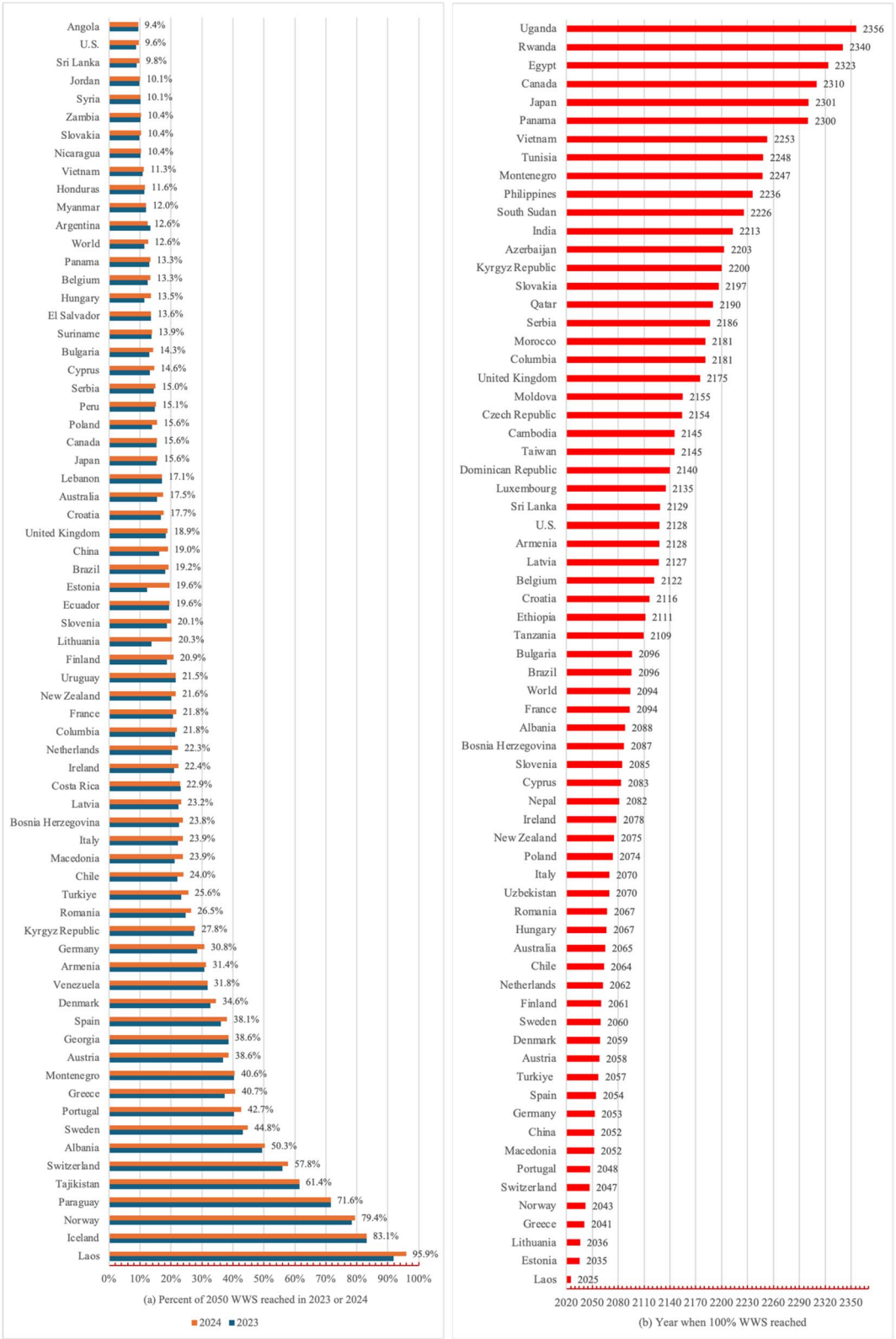

Fig. 1 (a) Percentages of end-use power needed from WWS generators across all energy sectors in 2050 to keep the grid stable actually met by WWS installations in 2023 and 2024. The numbers shown are for 2024. (b) Estimated year that a country is expected to meet 100% of their 2050 end-use demand across all energy sectors after near electrification of all sectors based on the WWS growth rate between 2023 and 2024. Table S1 provides values from both charts for 150 countries.

type within each energy sector.[5,14] For example, transitioning from a gasoline passenger car to a battery-electric passenger car reduces end-use demand (TFC) in 2050 by ~79%.[5,14] A resource analysis was performed for each country to determine which WWS technologies could be developed feasibly, and a mix of WWS technologies was chosen for each country based on this and other factors.[14] The assumption that each country could be converted was not based on policies set in the country but was motivated by the goal that such a transition could address air pollution, climate, and energy security in each country.[14]

Results indicate that such a transition may reduce 2050 annual average end-use power demand (TFC) among the 150 countries by an average of 54.2% (from 19.56 TW-demand to 8.96 TW-demand): 19.75 percentage points due to the efficiency of WWS electricity for transportation, 4.11 percentage points due to the efficiency of WWS electricity for industrial heat, 13.14 percentage points due to the efficiency of WWS for heat pumps instead of combustion heaters, 10.6 percentage points due to eliminating energy for mining, transporting, and refining of fossil fuels and uranium; and 6.57 percentage points due to end-use energy-efficiency improvements and reduced energy use beyond those with BAU.[14]

The end-use demands just calculated are 2050 annual-average electricity and heat targets for each of 150 countries to be met by WWS. However, such targets do not account for the additional generation and storage needed to keep the grid stable or for transmission and distribution losses. The 150 countries were then combined into 29 world regions, and grid stability analyses were performed with the LOADMATCH grid model in each region at a time step of 30 seconds to estimate the nameplate capacities of WWS generators and storage devices needed to meet the demand for three consecutive years (2050–2052) (Table S1). The grid analyses used 30-s wind and solar generation and building heating and cooling-demand data for each country produced by a global weather-prediction model.[14] The grid studies resulted in a 150-country average of ~25% oversizing of generators needed to match continuous demand compared with those needed to match annual-average demand.[14] Some end results of that study were a quantification of the nameplate capacities needed (GW-nameplate) for different WWS generation and storage technologies as well as the WWS generator and storage outputs produced (GWh per y, or annual GW-supplied) before transmission and distribution losses to meet total end-use demand (TFC) after such losses, in each country.[14]

Nameplate capacities of WWS technologies already installed in each of the 150 countries for 2023 and 2024 were then obtained here from IRENA[15] and SEIA.[16] Nameplate capacities were also obtained for China for the first 10 months of 2025,[17] India for the first 9 months of 2025,[18] and the U.S. for the first 7 months of 2025.[19,20] Such partial-year values were extrapolated linearly to all of 2025. The 2023, 2024, and 2025 nameplate capacities (Table S1) were then multiplied by capacity factors (Table S3) and transmission and distribution efficiencies (Table S1, Footnote) to provide annually-averaged power supplied by each generator and by the sum of all generators in a country (Table S1). The difference between the WWS annual-average power needed in 2050 and that already supplied in 2024 or 2025 (in the case of China, India, and the U.S.) was then divided by the rate of WWS power output growth between 2023 and 2024 or between 2024 and 2025 to estimate the number of years beyond 2024 or 2025 needed for the country to reach 100% WWS across all energy sectors assuming WWS growth continued to occur at its 2023-to-2024 or 2024-to-2025 rate.

3 Results

Based on WWS generator installations and corresponding WWS output increases between 2023 and 2024, three countries (Laos, Estonia, and Lithuania) could reach 100% WWS generation (thus eliminate all air pollution and carbon-equivalent emissions from energy) across all energy sectors by 2036 or earlier (Table S1 and Fig. 1b). Four more countries (Greece, Norway, Switzerland, and Portugal) could reach 100% by 2048 or earlier (Table S1 and Fig. 1b). China, which consumes more of the world's end-use energy (23.2% of all end-use energy in 2022) and emits more of the world's anthropogenic carbon dioxide (35.0% in 2023) than any other country,[14] is estimated to achieve a full transition, based on 2023-to-2024 installations, by 2052 (Fig. 2). The U.S., the world's largest economy, and India, the world's most populated country, are estimated to reach 100% WWS only by 2128 and 2212, respectively (Fig. 2 and 4), based on 2023-to-2024 installations. The world, on average, is on track to reach 100% WWS only by 2094 (Fig. 1b).

Whereas by the end of 2024, China, U.S., and India WWS outputs were only 19.03%, 9.60%, and 4.65%, respectively, of the outputs they need for a 100% all-sector WWS energy transition by 2050 (Fig. 1a and Table S1), the estimated growth rates of WWS outputs in these countries between 2024 and 2025 were 2.99% per y, 0.724% per y, and 0.829% per y, respectively (Fig. 3). As such, based on 2024 to 2025 WWS output growth data, China, the U.S., and India may reach the 100% transition

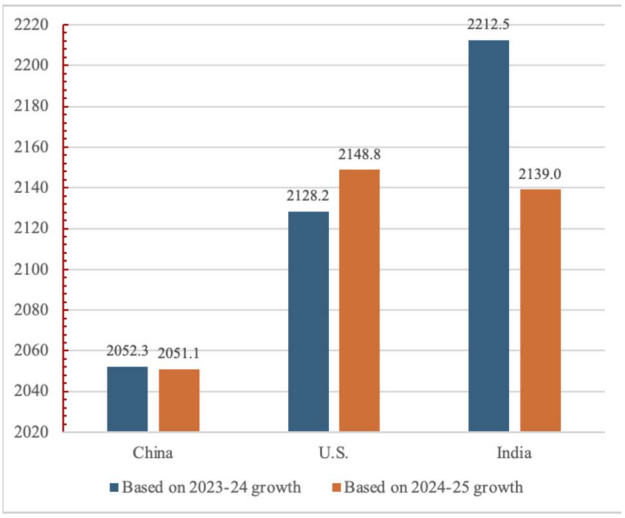

Fig. 2 Estimated year that China, the U.S., and India will meet 100% of their 2050 end-used demand across all energy sectors after electrification of all sectors, based on the WWS growth rate in the country between 2023 and 2024 and between 2024 and 2025. Derived from data in Table S1.

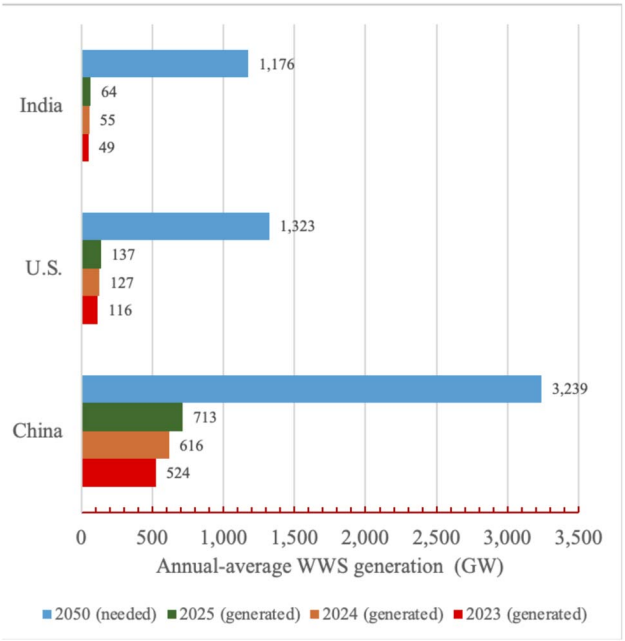

Fig. 3 Comparison of estimated 2050 annual-average WWS power generation (not nameplate capacity) needed to meet 100% of all-sector end-use demand while keeping the grid stable (blue) with estimated WWS generation already provided in 2023, 2024, and 2025, for China, the U.S., and India. In 2025, China is projected to produce 54% of the WWS output the U.S. needs in 2050. Derived from data in Table S1.

goal by 2051, 2148, and 2139, respectively, (Fig. 2 and 4). Thus, China is well on its way to a full transition, thereby eliminating 100% of its air-pollution- and climate-damaging emissions by 2051. Further, India has slightly surpassed the U.S. in terms of when it may reach 100% WWS. However, the U.S. still produced far more WWS output than India in 2025 (Fig. 3).

Several countries (Laos-95.9%, Iceland-83.1%, Norway-79.4%, Paraguay-71.6%, Tajikistan-61.4%, Switzerland-57.8%, and Albania-50.3%), were already very close to 100% WWS across all energy sectors in 2024 (Fig. 1b and 4). These countries all have substantial hydropower installed. Iceland also has geothermal electricity and heat and some wind (Fig. S1). Norway also has a lot of wind turbines installed (Fig. 5). Switzerland also has a lot of solar photovoltaics installed (Fig. S1). Most of these high-WWS countries are still far from achieving 100% WWS across all energy sectors because the growth rate of WWS between 2023 and 2024 in those countries was low. Exceptions are Laos, Norway, and Switzerland, discussed shortly.

4 Discussion

The most substantial and encouraging finding of this study is the rate by which China is transitioning its energy economy. China installed an astounding 70.01 GW-nameplate of wind, ~7.8 GW-nameplate of hydro, and 252.87 GW-nameplate of solar PV during the first 10 months of 2025[17] on top of installing 79.85 GW-nameplate of wind, 14.4 GW-nameplate of hydro, and 278.01 GW-nameplate of solar PV during all of 2024.[15] The 372.3 GW-nameplate of WWS China installed in 2024 is 95.5 times the 3.9 GW-nameplate of new nuclear connected to China's grid in 2024.[23] The 330.7 GW-nameplate of WWS installed by China during the first 10 months of 2025 puts the country on pace (assuming a linear extrapolation) to install ~397 GW-nameplate during all of 2025, ~7% more than in 2024. Accounting for capacity factors and transmission and distribution losses,

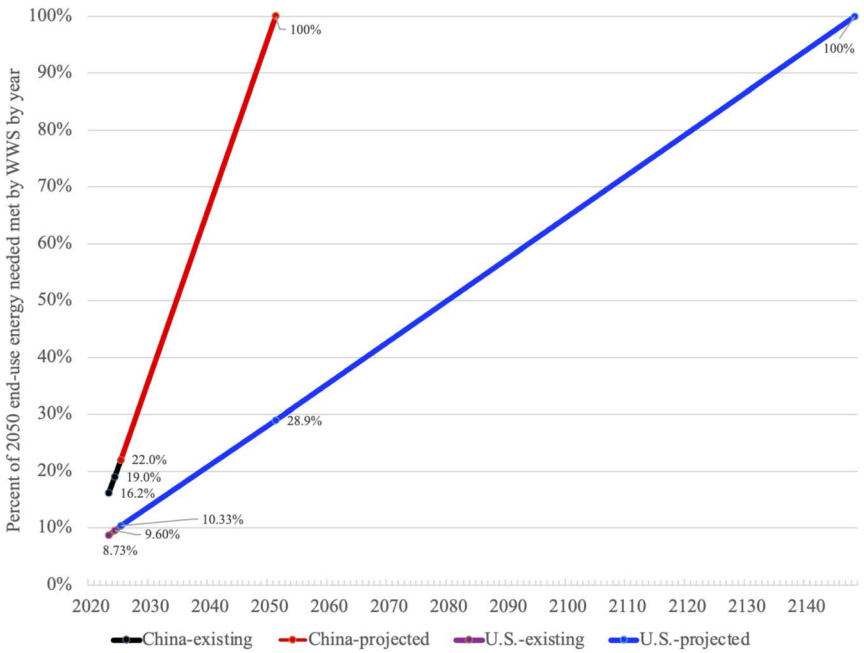

Fig. 4 Percent of 2050 end-use energy needed upon electrification of all energy sectors estimated to be met already by WWS in 2023, 2024, and 2025, and the year that 100% of end-use energy is projected to be met by WWS, in China (by 2051) and the U.S. (by 2148).

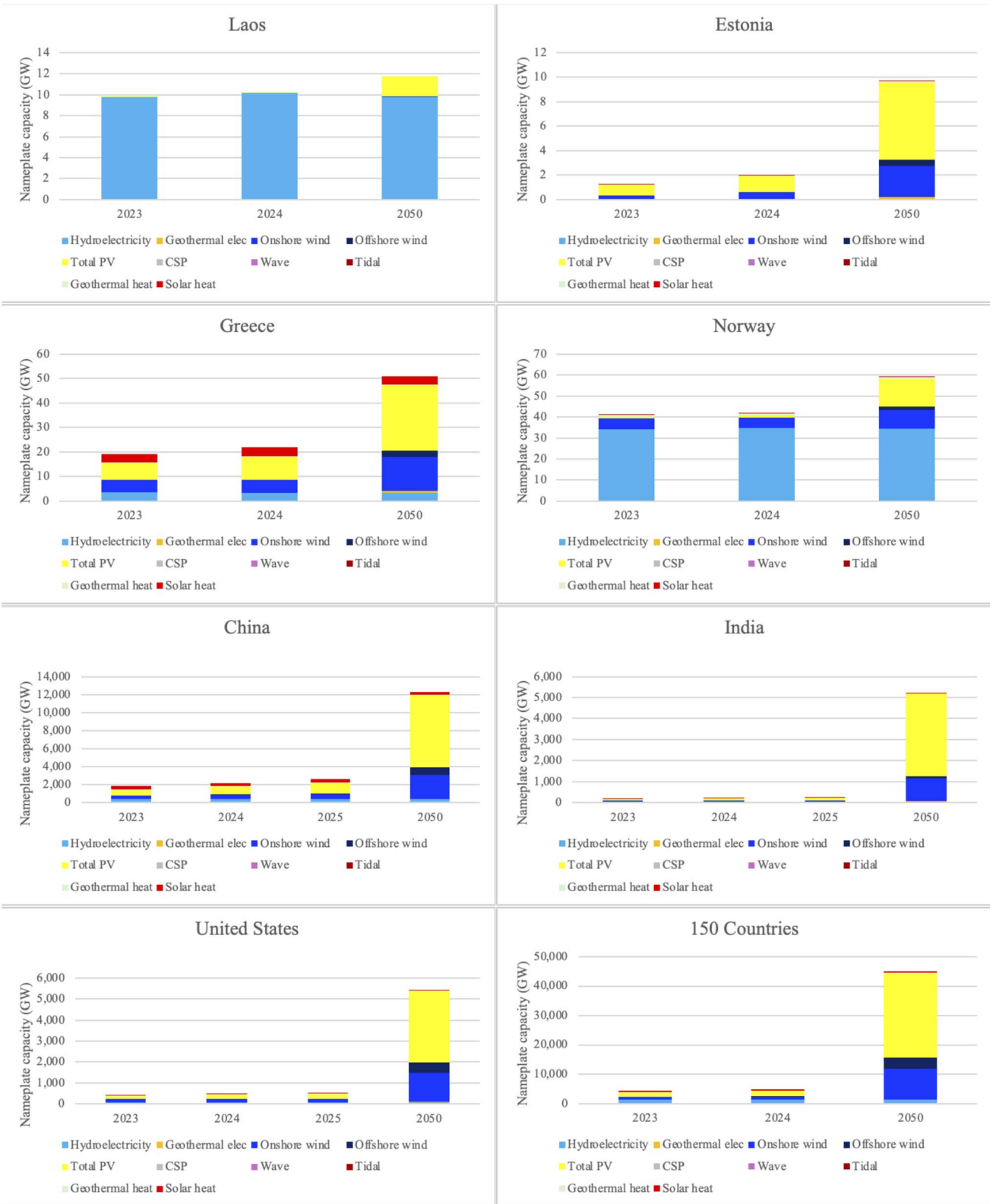

Fig. 5 Comparison, for selected countries, of estimated 2050 WWS nameplate capacities needed to power 100% of all-sector energy demand with WWS after electrification of all energy sectors, and accounting for grid stability, with actual WWS nameplate capacities installed in 2023, 2024, and (for China, the U.S., and India) 2025. Derived from data in Table S1. Figure S1 shows results for additional countries.

China's may produce 96.9 GW more annual-average WWS power output in 2025 than in 2024 (Fig. 3 and Table S1).

In comparison, the U.S. added 3.288 GW-nameplate of wind,[19] 4 MW-nameplate of hydro,[19] ~3.91 GW-nameplate of behind-the-meter PV,[20] and 16.05 GW-nameplate of utility PV[19] during the first 7 months of 2025, which linearly extrapolates to 42.7 GW-nameplate more WWS and 9.59 GW more annual-average WWS output after transmission and distribution losses, for all of 2025 (Table S1). During the first 9 months of 2025, India added 4.96 GW-nameplate of wind, ~1.95 GW-nameplate of hydro, and 29.47 GW-nameplate of solar,[18] which linearly extrapolates to 45.9 GW-nameplate more WWS and 9.75 GW more annual-average WWS output for all of 2025 (Table S1). Thus, the projected new 2025 WWS output in China is ~10.1 times that in the U.S. and ~9.9 times that in India.

China's 2025 rate of WWS output growth may be the fastest rate of growth in low-emitting energy in world history. For example, the 2024 annual-average power output of France's 61.37 GW-nameplate of active nuclear reactors was 41.2 GW.[24] These plants became operational between 1977 and 1999, with a peak addition of 7.2 GW-nameplate in 1981. Ignoring the long planning and construction times for these reactors and considering only the year they became operational, in 1981, France added ~4.8 GW-output from nuclear. This is only ~5% the WWS output China may add in 2025 (96.9 GW). If China's 2025 growth rate of WWS power output persists into the future, and if China electrifies all energy sectors to the greatest extent possible, China could become 100% WWS across all energy sectors, with a stable grid, by 2051 (Table S1, Fig. 2 and 4). Thus, China will accomplish far more than providing all its electricity demand growth with WWS: it will provide all energy for all electricity, all transportation, all building energy, and all industrial processes with WWS, eliminating energy-related air pollutants and climate-relevant pollutants as well as eliminating energy insecurity associated with fossil fuels.

The scale of China's installation of clean, renewable electricity has been so large that, in 2025, China may produce ~54% of the clean, renewable energy the U.S. needs by 2050 to power itself with 100% clean, renewable energy across all energy sectors (Fig. 3 and Table S1). Given the larger economy of the U.S. than China and the comparable land sizes of the two countries, this result suggests that the main barriers to the U.S. obtaining a WWS buildout as large as China's are social and political, not technical or economic.

The conclusion that China is on pace to reach 100% WWS across all energy sectors by 2051 is dependent on the assumption that it will keep building WWS at its 2025 pace (~397 GW year^{-1}) (Table S1). If China instead builds, after 2025, at its 2024 pace (~372 GW year^{-1}) (Table S1), which is 6.3% slower, it will reach 100% WWS by only 2052. If China builds at 300 GW year^{-1} (24.4% lower than 2025), it will reach 100% WWS by only 2058. As such, China's pace of adding WWS would need to decrease substantially relative to its pace in 2024 and 2025 for the country not to be able to transition completely before 2060.

A concern is that China's rapid transition to intermittent wind and solar will not be accompanied by sufficient additions of storage. However, in June 2025, China broke ground on the world's largest (60 GW) hydropower station, almost three-times the output of Three Gorges Dam.[25] Hydropower can be used for both baseload and peaking power and can back up an enormous amount of wind and solar. In addition, during July 2025, four-hour battery system prices decreased to USD $51.59/kWh in China, a price 30% lower than in 2024.[26] Such a low battery price almost eliminates a barrier to the large-scale implementation of battery storage for WWS generation.[10]

An uncertainty is whether China will electrify transportation, buildings, and industry by 2051, the year it can theoretically achieve 100% WWS across all energy sectors. Technically and economically, such a transition should be feasible, but for social and political reasons (*e.g.*, subsidy phaseouts, changes in priorities), such a transition may or may not occur on time. However, some recent data appear encouraging. In 2024, China sold 11 million battery-electric vehicles, which represent more than 50% of the vehicles sold in the country.[27] If China increases this number to 100% by 2030, they will replace almost their entire vehicle fleet to electric by 2051, given the typical-vehicle lifetime of 10–15 years.

The industrial sector is more challenging, not only because most energy in China is consumed in that sector, but also because the industrial sector is the least-transitioned sector worldwide. However, electric arc furnaces, induction furnaces, resistance furnaces, dielectric heaters, electron beam heaters, and heat pumps are already commercially available to replace combustion fuels for industrial heat. In addition, firebricks are already available commercially to store high-temperature heat.[13] Methods also exist to transition cement and steel specifically.[5]

Buildings can be transitioned with a combination of electric heat pumps for air and water heating and air conditioning; electric induction cooktops for cooking, LED lights, more insulation, and energy-efficient appliances and machines. China is already the world's largest market for electric heat pumps and has the manufacturing base to ramp that up.[28] Given the availability of the electric-appliance and machine technologies needed to transition buildings, what is needed to convert China's buildings is primarily strong incentives. In sum, China appears poised to electrify its non-electric energy to meet 100% of its demand with WWS by 2051.

One other concern with China's transition is their continued building of coal plants. In 2024, China began operating 31 GW-nameplate of new coal plants.[29] This represents only 8.3% of the 372.3 GW-nameplate of WWS that China added in 2024, but these new additions are still of concern. However, during the first 8 months of 2025, China reduced its coal use for electric power by 1.5% *versus* the first 8 months of 2024. Thus, although China continues to increase its nameplate capacity of coal power plants, it is reducing its coal electricity output by replacing coal with WWS for electricity generation. In order for China to reach 100% WWS by 2051, it will need to reduce its coal-electricity output all the way to zero. This may or may not result in China decommissioning its coal plants. It is far less important for China to decommission its coal-electricity plants than to eliminate its coal use for electricity. Reducing coal-electricity output is cost-effective given that the energy costs and social costs of coal are much larger than are those of a WWS

system.[5] Eliminating coal-electricity output will also help allow China's manufacturing to be produced with 100% WWS, ensuring that China's exports and the WWS equipment it is installing are also produced from clean, renewable sources.

Another concern is the potential for bottlenecks to slow down the transition to 100% WWS. Bottlenecks may arise due to limited availability of critical minerals, supply-chain constraints, or lack of financing.[14] This study does not assume such bottlenecks will not occur. Instead, it estimates the year that countries might reach 100% WWS across all energy sectors if they continue transitioning at their current rate because bottlenecks have been overcome. A benefit of a transition is the substantial reduction in the mass of mined material needed with 100% WWS *versus* with the current energy infrastructure.[14]

A final concern is that solar PV panels, wind turbines, and batteries have limited lifetimes, so must ultimately be replaced, slowing a transition. Whereas replacements of aged WWS technologies may extend the transition dates projected here, lifetimes of critical WWS technology have increased, mitigating this problem. For example, solar PV panels are now typically warrantied for 25–30 years and are expected to last up to 35 years.[30] The expected lifetime of a wind turbine is now 25–40 years, with an average of 30 years.[31] Some batteries today are warrantied for the lesser of 15 000 cycles (41 years if cycled once per day) or 15 years[32] thus can potentially last at least 25 years. As such, PV panels, wind turbines, and batteries installed today may all likely still be operating in 2050.

Another substantial finding of this study is that several smaller countries appear to be closer in time than China to reaching 100% WWS across all energy sectors. These countries have either (1) substantial 2024 WWS output and installations so are already close to 100% WWS supply across all sectors (*e.g.*, 95.9% of Laos' 2050 WWS needed output was already supplied in 2024 and Laos experienced a 4.07%/y WWS-output growth rate between 2023 and 2024; Norway 79.4%; 1.11% per y), (2) a moderate 2024 WWS output and a moderately-fast 2023–24 WWS-output growth rate (Greece 40.8%, 3.46% per y; Switzerland 57.8%, 1.86% per y), or (3) a low 2024 WWS output but a fast WWS-output growth rate (Estonia 19.6%, 7.22%/ per ; Lithuania 20.3%, 6.67% per y) (Table S1 and Fig. 5).

A relevant question is, why Laos so close to 100% WWS across all energy sectors? In 2024, Laos could reach 100% WWS, if it electrified all energy, by 2025 (Fig. 1b). The first reason is that it has an enormous amount of hydropower relative to its demand. In 2023, in fact, Laos met 263% of its electricity demand with hydropower alone.[33] Second, electrification and providing the electricity with WWS is projected to reduce Laos' 2050 end-use demand (TFC) across all energy sectors by 52%,[14] for the reasons described in Methods. Thus, despite a projected increase in energy demand due to population increase and economic growth, that increase will be offset largely by the conversion to electricity powered by WWS. The combination of these two factors means Laos is the country in the world closest to 100% WWS across all energy sectors if it electrifies all its energy sectors.

At the other end of the spectrum, several countries that have strong targets for decarbonization and already have substantial or some WWS installed, are moving much more slowly than expected. These countries may have a false sense of their progress and of what is needed. For example, in 2024, Iceland already produced 100% of its electricity from WWS[33] and 83.1% of the WWS electricity and heat it needs in 2050 to reach 100% WWS across all energy sectors upon electrifying all sectors (Table S1 and Fig. S1). It also has a target of becoming carbon neutral by 2040. However, because Iceland's WWS growth rate between 2023 and 2024 was so small, it cannot reach 100% WWS across all energy sectors until after the year 2350 if it continues building WWS at this slow pace. Similarly, the United Kingdom, and Canada, which both have 2050 decarbonization targets, were already producing, in 2024, 18.9% and 15.6%, respectively, of the WWS electricity and heat they need to reach 100% WWS across all energy sectors. Yet, at the slow rate they are increasing WWS, they will reach 100% WWS only by 2175 and beyond the year 2350, respectively. These examples illustrate a potential benefit of this study: to provide countries with a realistic sense of their progress toward moving to clean, renewable energy across all energy sectors so that they can then determine if faster progress is necessary.

5 Conclusions

The fact that the world's largest energy consumer and emitter, China, could eliminate its energy-related air pollution- and climate-relevant emissions by 2051 due to its rapid pace of WWS deployment should give hope to the world. The fact that China is already producing so much WWS electricity that it may supply, in 2025 ~54% of what the U.S. needs in 2050 to go 100% WWS across all energy sectors, indicates there is no technical or economic barrier stopping the U.S. from reaching 100% WWS either. Because seven countries are further ahead than China in the transition, there is hope for other countries as well. These results suggest that the main barriers to a transition in any country are generally not technical or economic, but social and political.

China's energy transition is being carried out with enormous amounts of solar, wind, and hydro as well as electric vehicles and electric heat pumps. China is installing WWS electricity at a rate almost two orders of magnitude the rate it is installing new nuclear. The country is also not distracted much by carbon capture, direct air capture, blue hydrogen, biofuels, or biomass. The examples set by China and several other countries suggest that the world as a whole can succeed in a rapid transition if all countries make a strong social and political commitment to a transition and focus, like a laser, on clean, renewable energy.

Author contributions

Mark Z. Jacobson: conceptualization, methodology, investigation, software, visualization, writing – original draft, writing – review & editing.

Conflicts of interest

There are no competing interests to declare.

Note added after first publication

This article replaces the version published on 19 December 2025 in which ref. 17 was incorrect.

Nomenclature

BAU	Business-as-usual
GW	Gigawatts
LED	Light-emitting diode
PV	Photovoltaics
TFC	Total final consumption
USD	United States Dollars
WWS	Wind-water-solar

Data availability

All the data supporting the findings of this study are presented in the article, its supplementary information (SI) File, and its references. Supplementary information: additional tables and figures supporting this study. See DOI: https://doi.org/10.1039/d5su00912j.

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Supplementary Information

Projections of When Each of 150 Countries May Eliminate Air Pollution and Carbon Emissions From All Energy

Mark Z. Jacobson

This Supplementary Information file (pages S1-S16) contains three additional tables (Tables S1-S3) and one additional figure (Figure S1).

Supplementary Tables

Table S1. Columns (a)-(l): nameplate capacities of wind-water-solar (WWS) generators installed in each of 150 countries by the end of 2023, 2024, and (for China, India, and the U.S.) 2025, as well as WWS nameplate capacities needed in 2050 upon near-electrification of all energy sectors while keeping the grid stable with only WWS. Column (m): estimated output from all WWS nameplate capacities in 2023, 2024, 2025, and 2050. Column (n): estimated percentages of WWS output needed in 2050 that were already met at the end of 2024 or 2025. Column (o): year by which each country can reach 100% WWS if either the 2023-to-2024 (for 2024 numbers) or 2024-to-2025 (for 2025 numbers) growth rate of WWS output persists.

Country	Year	(a) On-shore wind (GW)	(b) Off-shore wind (GW)	(c) Roof PV (GW)	(d) Utility PV (GW)	(e) CSP (GW)	(f) Geo-elec (GW)	(g) Hydro (GW)	(h) Wave (GW)	(i) Tidal (GW)	(j) Geo-heat (GW)	(k) Solar heat (GW)	(l) Total WWS name-plate (GW)	(m) Total WWS output (GW)	(n) Pct of 2050 met (%)	(o) Year to 100% WWS
Albania	2023	0.000	0.000	0.087	0.120	0.000	0.000	2.519	0.000	0.000	0.016	0.206	2.948	1.050	49.5	
	2024	0.000	0.000	0.129	0.178	0.000	0.000	2.519	0.000	0.000	0.016	0.206	3.048	1.067	50.3	**2088**
	2050	1.357	0.223	1.413	1.296	0.000	0.000	2.493	0.000	0.002	0.016	0.206	7.008	2.122		
Algeria	2023	0.010	0.000	0.183	0.254	0.025	0.000	0.129	0.000	0.000	0.078	0.000	0.679	0.183	0.3	
	2024	0.010	0.000	0.183	0.254	0.025	0.000	0.129	0.000	0.000	0.078	0.000	0.679	0.183	0.3	**2350+**
	2050	54.123	5.260	75.088	59.569	0.000	0.001	0.129	0.185	0.020	0.078	0.000	194.453	57.925		
Angola	2023	0.000	0.000	0.152	0.210	0.000	0.000	3.729	0.000	0.000	0.000	0.000	4.091	1.290	9.4	
	2024	0.000	0.000	0.152	0.210	0.000	0.000	3.729	0.000	0.000	0.000	0.000	4.091	1.290	9.4	**2350+**
	2050	18.023	3.874	13.644	10.093	0.000	0.000	3.729	0.015	0.016	0.000	0.000	49.394	13.687		
Argentina	2023	3.706	0.000	0.589	0.816	0.000	0.000	10.39	0.000	0.000	0.205	0.199	15.905	5.459	13.4	
	2024	4.320	0.000	0.729	1.012	0.000	0.000	9.195	0.000	0.000	0.205	0.199	15.660	5.128	12.6	**2350+**
	2050	52.217	7.229	68.753	45.948	0.005	1.010	10.39	0.000	0.057	0.205	0.199	186.013	40.810		
Armenia	2023	0.003	0.000	0.168	0.234	0.000	0.000	1.358	0.000	0.000	0.002	0.000	1.765	0.654	30.7	
	2024	0.003	0.000	0.203	0.282	0.000	0.000	1.351	0.000	0.000	0.002	0.000	1.841	0.668	31.4	**2128**
	2050	1.939	0.000	1.528	1.861	0.000	0.025	1.358	0.000	0.000	0.002	0.000	6.712	2.127		
Australia	2023	12.908	0.000	13.944	19.335	0.003	0.000	8.440	0.000	0.000	0.094	6.776	61.500	15.892	15.5	
	2024	15.288	0.000	16.119	22.350	0.003	0.000	8.792	0.000	0.000	0.094	6.776	69.422	17.967	17.5	**2065**
	2050	112.492	12.493	106.040	145.560	0.000	0.400	8.440	0.131	0.176	0.094	6.776	392.603	102.731		
Azerbaijan	2023	0.067	0.000	0.118	0.164	0.000	0.000	1.302	0.000	0.000	0.000	0.000	1.651	0.633	7.3	
	2024	0.064	0.000	0.123	0.170	0.000	0.000	1.407	0.000	0.000	0.000	0.000	1.764	0.678	7.8	**2203**
	2050	8.171	0.000	10.288	12.251	0.000	0.000	1.302	0.000	0.000	0.000	0.000	32.013	8.724		
Bahrain	2023	0.003	0.000	0.024	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060	0.013	0.1	
	2024	0.003	0.000	0.028	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.015	0.2	**2350+**
	2050	0.187	2.904	1.610	36.884	0.007	0.000	0.000	0.000	0.006	0.000	0.000	41.598	9.241		
Bangladesh	2023	0.003	0.000	0.313	0.433	0.000	0.000	0.230	0.000	0.000	0.000	0.000	0.979	0.243	0.5	
	2024	0.003	0.000	0.354	0.492	0.000	0.000	0.230	0.000	0.000	0.000	0.000	1.079	0.263	0.6	**2350+**
	2050	7.133	7.846	39.745	158.915	0.000	0.000	0.230	0.156	0.089	0.000	0.000	214.113	45.505		
Belarus	2023	0.122	0.000	0.114	0.159	0.000	0.000	0.097	0.000	0.000	0.010	0.000	0.502	0.138	1.0	
	2024	0.122	0.000	0.111	0.154	0.000	0.000	0.086	0.000	0.000	0.010	0.000	0.483	0.132	1.0	**2350+**
	2050	15.031	0.000	13.547	32.887	0.000	0.010	0.097	0.000	0.000	0.010	0.000	61.582	13.923		
Belgium	2023	3.192	2.262	3.499	4.853	0.000	0.000	0.124	0.000	0.000	0.306	0.515	14.751	4.106	12.5	
	2024	3.337	2.262	4.086	5.666	0.000	0.000	0.128	0.000	0.000	0.306	0.515	16.300	4.397	13.3	**2122**
	2050	14.589	12.970	4.928	105.533	0.000	2.511	0.123	0.000	0.003	0.306	0.515	141.478	32.959		
Benin	2023	0.000	0.000	0.015	0.020	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.036	0.006	0.2	
	2024	0.000	0.000	0.015	0.020	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.036	0.006	0.2	**2350+**
	2050	11.242	0.663	5.667	3.975	0.005	0.000	0.001	0.012	0.005	0.000	0.000	21.570	3.666		
Bolivia	2023	0.135	0.000	0.072	0.101	0.000	0.000	0.736	0.000	0.000	0.001	0.000	1.045	0.373	7.0	
	2024	0.135	0.000	0.074	0.103	0.000	0.000	0.717	0.000	0.000	0.001	0.000	1.030	0.366	6.9	**2350+**
	2050	10.714	0.000	4.694	10.019	0.001	1.260	0.736	0.000	0.000	0.001	0.000	27.426	5.319		
Bosnia Herz.	2023	0.135	0.000	0.089	0.123	0.000	0.000	1.842	0.000	0.000	0.036	0.000	2.225	0.832	22.6	
	2024	0.219	0.000	0.089	0.123	0.000	0.000	1.868	0.000	0.000	0.036	0.000	2.335	0.877	23.8	**2087**
	2050	3.319	0.451	3.999	4.212	0.000	0.000	1.838	0.000	0.002	0.036	0.000	13.856	3.682		
Botswana	2023	0.000	0.000	0.004	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.022	0.003	0.2	
	2024	0.000	0.000	0.004	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.022	0.003	0.2	**2350+**
	2050	2.361	0.000	2.886	3.045	0.000	0.000	0.000	0.000	0.000	0.000	0.012	8.304	1.987		
Brazil	2023	29.113	0.000	15.897	22.043	0.000	0.000	109.92	0.000	0.000	0.363	13.108	190.442	61.037	18.1	
	2024	32.959	0.000	22.254	30.859	0.000	0.000	109.98	0.000	0.000	0.363	13.108	209.521	64.842	19.2	**2096**
	2050	762.360	47.414	390.689	278.535	0.033	0.000	109.90	0.844	0.200	0.363	13.108	1,603.45	337.024		

Country	Year	(a) On-shore wind (GW)	(b) Off-shore wind (GW)	(c) Roof PV (GW)	(d) Utility PV (GW)	(e) CSP (GW)	(f) Geo-elec (GW)	(g) Hydro (GW)	(h) Wave (GW)	(i) Tidal (GW)	(j) Geo-heat (GW)	(k) Solar heat (GW)	(l) Total WWS-name-plate (GW)	(m) Total WWS output (GW)	(n) Pct of 2050 met (%)	(o) Year to 100% WWS
Brunei Dar.	2023	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.0	
	2024	0.000	0.000	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.0	**2350+**
	2050	0.050	1.603	4.239	6.229	0.000	0.000	0.000	0.006	0.003	0.000	0.000	12.130	2.283		
Bulgaria	2023	0.704	0.000	1.218	1.690	0.000	0.000	2.486	0.000	0.000	0.109	0.125	6.332	1.810	13.1	
	2024	0.704	0.000	1.637	2.271	0.000	0.000	2.486	0.000	0.000	0.109	0.125	7.332	1.975	14.3	**2096**
	2050	9.964	1.584	10.950	10.266	0.000	8.219	2.526	0.000	0.010	0.109	0.125	43.754	13.851		
Cambodia	2023	0.000	0.000	0.204	0.283	0.000	0.000	1.332	0.000	0.000	0.000	0.000	1.819	0.623	6.4	
	2024	0.000	0.000	0.368	0.510	0.000	0.000	1.337	0.000	0.000	0.000	0.000	2.215	0.698	7.1	**2145**
	2050	1.570	6.292	18.983	21.962	0.000	0.000	1.791	0.000	0.012	0.000	0.000	50.609	9.779		
Cameroon	2023	0.000	0.000	0.026	0.037	0.000	0.000	0.814	0.000	0.000	0.000	0.000	0.877	0.260	2.8	
	2024	0.000	0.000	0.026	0.037	0.000	0.000	0.814	0.000	0.000	0.000	0.000	0.877	0.260	2.8	**2350+**
	2050	34.861	0.481	9.656	8.545	0.000	0.000	0.814	0.018	0.010	0.000	0.000	54.384	9.335		
Canada	2023	16.989	0.000	2.465	3.419	0.000	0.006	83.281	0.000	0.001	1.831	0.938	108.930	34.109	15.3	
	2024	18.376	0.000	2.558	3.547	0.000	0.006	83.281	0.000	0.001	1.831	0.938	110.538	34.768	15.6	**2310**
	2050	342.491	35.508	60.268	69.028	0.000	5.000	83.307	0.222	0.281	1.831	0.938	598.875	223.152		
Chile	2023	4.623	0.000	3.678	5.099	0.108	0.083	7.365	0.000	0.000	0.023	0.284	21.263	5.912	22.1	
	2024	4.807	0.000	4.584	6.356	0.114	0.095	7.419	0.000	0.000	0.023	0.284	23.682	6.424	24.0	**2064**
	2050	32.791	4.984	44.672	26.315	0.003	1.630	7.471	0.045	0.066	0.023	0.284	118.284	26.768		
China	2023	404.61	37.29	255.32	354.03	0.57	0.03	370.60	0.00	0.01	40.61	364.00	1,827.06	523.70	16.2	
	2024	482.65	39.10	371.80	515.56	0.57	0.03	385.00	0.00	0.01	40.61	364.00	2,199.32	616.38	19.0	**2052**
	2025	545.21	60.55	498.95	691.86	0.57	0.03	394.36	0.00	0.01	40.61	364.00	2,596.13	713.31	22.0	**2051**
	2050	2,751.57	832.68	2,347.81	5,613.84	1.76	1.86	370.60	8.37	2.00	40.61	364.00	12,335.1	3,239.20		
Columbia	2023	0.034	0.000	0.300	0.416	0.000	0.000	13.224	0.000	0.000	0.020	0.000	13.994	5.922	21.3	
	2024	0.034	0.000	0.583	0.809	0.000	0.000	13.224	0.000	0.000	0.020	0.000	14.670	6.060	21.8	**2181**
	2050	67.137	3.165	24.381	33.180	0.000	1.500	13.211	0.072	0.043	0.020	0.000	142.709	27.745		
Congo	2023	0.000	0.000	0.000	0.001	0.000	0.000	0.214	0.000	0.000	0.000	0.000	0.215	0.066	2.1	
	2024	0.000	0.000	0.000	0.001	0.000	0.000	0.214	0.000	0.000	0.000	0.000	0.215	0.066	2.1	**2350+**
	2050	12.115	0.695	3.163	2.219	0.000	0.000	0.214	0.006	0.004	0.000	0.000	18.415	3.177		
Congo DR	2023	0.000	0.000	0.010	0.015	0.000	0.000	3.188	0.000	0.000	0.000	0.000	3.213	0.983	4.2	
	2024	0.000	0.000	0.010	0.015	0.000	0.000	3.188	0.000	0.000	0.000	0.000	3.213	0.983	4.2	**2350+**
	2050	86.300	0.692	21.664	23.471	0.000	0.000	3.172	0.044	0.002	0.000	0.000	135.345	23.361		
Costa Rica	2023	0.408	0.000	0.031	0.042	0.000	0.263	2.372	0.000	0.000	0.002	0.000	3.118	1.091	23.1	
	2024	0.402	0.000	0.031	0.042	0.000	0.263	2.353	0.000	0.000	0.002	0.000	3.093	1.083	22.9	**2350+**
	2050	3.334	0.723	2.242	3.138	0.000	3.500	2.372	0.008	0.004	0.002	0.000	15.323	4.720		
Ivory Coast	2023	0.000	0.000	0.017	0.023	0.000	0.000	0.879	0.000	0.000	0.000	0.000	0.919	0.277	2.4	
	2024	0.000	0.000	0.017	0.023	0.000	0.000	0.879	0.000	0.000	0.000	0.000	0.919	0.277	2.4	**2350+**
	2050	37.489	1.908	15.754	10.577	0.000	0.000	0.879	0.027	0.013	0.000	0.000	66.646	11.456		
Croatia	2023	1.160	0.000	0.194	0.269	0.000	0.010	2.190	0.000	0.000	0.079	0.189	4.091	1.474	16.8	
	2024	1.191	0.000	0.360	0.500	0.000	0.010	2.190	0.000	0.000	0.079	0.189	4.519	1.552	17.7	**2116**
	2050	5.144	0.000	7.413	8.881	0.000	5.708	2.206	0.000	0.010	0.079	0.189	29.630	8.774		
Cuba	2023	0.016	0.000	0.117	0.163	0.000	0.000	0.069	0.000	0.000	0.000	0.000	0.365	0.092	1.2	
	2024	0.016	0.000	0.122	0.170	0.000	0.000	0.069	0.000	0.000	0.000	0.000	0.377	0.095	1.2	**2350+**
	2050	7.111	1.611	11.711	12.583	0.000	0.000	0.072	0.008	0.013	0.000	0.000	33.108	7.895		
Curacao	2023	0.047	0.000	0.005	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060	0.008	0.5	
	2024	0.070	0.000	0.006	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.084	0.011	0.7	**2350+**
	2050	0.172	0.673	0.243	5.959	0.000	0.000	0.000	0.000	0.004	0.000	0.000	7.049	1.572		
Cyprus	2023	0.158	0.000	0.243	0.338	0.000	0.000	0.000	0.000	0.000	0.010	0.584	1.333	0.215	13.2	
	2024	0.158	0.000	0.303	0.421	0.000	0.000	0.000	0.000	0.000	0.010	0.584	1.476	0.239	14.6	**2083**
	2050	0.711	0.712	2.706	2.897	0.000	0.000	0.000	0.006	0.004	0.010	0.584	7.630	1.638		
Czech Rep.	2023	0.343	0.000	1.362	1.889	0.000	0.000	1.117	0.000	0.000	0.325	0.792	5.828	1.345	6.2	
	2024	0.356	0.000	1.743	2.416	0.000	0.000	1.117	0.000	0.000	0.325	0.792	6.749	1.500	6.9	**2154**
	2050	20.769	0.000	15.854	47.519	0.000	3.539	1.116	0.000	0.000	0.325	0.792	89.913	21.636		
Denmark	2023	4.808	2.469	1.479	2.050	0.000	0.000	0.007	0.000	0.000	0.744	1.332	12.889	4.323	32.7	
	2024	4.808	2.813	1.653	2.292	0.000	0.000	0.007	0.000	0.000	0.744	1.332	13.649	4.571	34.6	**2059**
	2050	10.462	3.019	5.540	24.866	0.000	3.311	0.007	0.033	0.019	0.744	1.332	49.332	13.218		

Country	Year	(a) On-shore wind (GW)	(b) Off-shore wind (GW)	(c) Roof PV (GW)	(d) Utility PV (GW)	(e) CSP (GW)	(f) Geo-elec (GW)	(g) Hydro (GW)	(h) Wave (GW)	(i) Tidal (GW)	(j) Geo-heat (GW)	(k) Solar heat (GW)	(l) Total WWS-name-plate (GW)	(m) Total WWS output (GW)	(n) Pct of 2050 met (%)	(o) Year to 100% WWS
Dominican R.	2023	0.417	0.000	0.451	0.626	0.000	0.000	0.624	0.000	0.000	0.000	0.000	2.118	0.607	5.8	
	2024	0.433	0.000	0.596	0.827	0.000	0.000	0.625	0.000	0.000	0.000	0.000	2.481	0.691	6.6	**2140**
	2050	16.965	1.507	8.985	8.236	0.000	0.680	0.624	0.000	0.014	0.000	0.000	37.011	10.401		
Ecuador	2023	0.071	0.000	0.013	0.018	0.000	0.000	5.192	0.000	0.000	0.005	0.000	5.299	2.280	19.5	
	2024	0.071	0.000	0.013	0.019	0.000	0.000	5.215	0.000	0.000	0.005	0.000	5.323	2.290	19.6	**2350+**
	2050	27.944	1.238	8.742	15.773	0.000	1.000	5.192	0.014	0.018	0.005	0.000	59.926	11.711		
Egypt	2023	1.890	0.000	0.769	1.067	0.020	0.000	2.832	0.000	0.000	0.044	0.000	6.622	2.289	2.4	
	2024	2.199	0.000	1.077	1.493	0.020	0.000	2.832	0.000	0.000	0.044	0.000	7.665	2.601	2.7	**2323**
	2050	90.244	20.096	118.990	78.301	0.000	0.000	2.832	0.000	0.036	0.044	0.000	310.542	95.953		
El Salvador	2023	0.054	0.000	0.271	0.376	0.000	0.209	0.638	0.000	0.000	0.003	0.000	1.551	0.485	13.6	
	2024	0.054	0.000	0.272	0.376	0.000	0.209	0.643	0.000	0.000	0.003	0.000	1.557	0.487	13.6	**2350+**
	2050	3.506	0.661	2.612	3.764	0.000	2.000	0.573	0.009	0.005	0.003	0.000	13.133	3.580		
Eq. Guinea	2023	0.000	0.000	0.000	0.000	0.000	0.000	0.127	0.000	0.000	0.000	0.000	0.127	0.039	1.8	
	2024	0.000	0.000	0.000	0.000	0.000	0.000	0.127	0.000	0.000	0.000	0.000	0.127	0.039	1.8	**2350+**
	2050	3.142	1.120	4.843	3.093	0.000	0.000	0.127	0.007	0.004	0.000	0.000	12.335	2.128		
Eritrea	2023	0.001	0.000	0.010	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.005	1.3	
	2024	0.001	0.000	0.010	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.005	1.3	**2350+**
	2050	0.408	0.079	0.585	0.583	0.000	0.000	0.000	0.000	0.001	0.000	0.000	1.655	0.383		
Estonia	2023	0.337	0.000	0.341	0.472	0.000	0.000	0.010	0.000	0.000	0.063	0.014	1.237	0.309	12.3	
	2024	0.572	0.000	0.556	0.770	0.000	0.000	0.010	0.000	0.000	0.063	0.014	1.985	0.490	19.6	**2035**
	2050	2.519	0.505	2.150	4.188	0.000	0.228	0.008	0.000	0.004	0.063	0.014	9.679	2.503		
Ethiopia	2023	0.324	0.000	0.009	0.012	0.000	0.007	4.883	0.000	0.000	0.002	0.000	5.237	1.625	6.9	
	2024	0.324	0.000	0.009	0.013	0.000	0.007	5.683	0.000	0.000	0.002	0.000	6.038	1.874	8.0	**2111**
	2050	26.029	0.000	27.595	38.029	0.000	1.710	4.883	0.000	0.000	0.002	0.000	98.248	23.539		
Finland	2023	6.914	0.032	0.413	0.573	0.000	0.000	3.169	0.000	0.000	2.300	0.057	13.458	5.412	18.7	
	2024	8.328	0.032	0.504	0.699	0.000	0.000	3.191	0.000	0.000	2.300	0.057	15.111	6.036	20.9	**2061**
	2050	39.130	9.675	10.211	22.715	0.000	0.000	3.177	0.000	0.023	2.300	0.057	87.288	28.936		
France	2023	21.645	1.487	7.290	10.109	0.009	0.016	24.598	0.000	0.212	2.598	1.634	69.598	23.679	20.6	
	2024	23.105	1.487	9.020	12.508	0.000	0.016	24.641	0.000	0.212	2.598	1.634	75.221	24.968	21.8	**2094**
	2050	112.271	31.354	75.883	156.021	0.064	5.567	24.139	0.171	0.193	2.598	1.634	409.894	114.782		
Gabon	2023	0.000	0.000	0.000	0.001	0.000	0.000	0.331	0.000	0.000	0.000	0.000	0.332	0.102	0.8	
	2024	0.000	0.000	0.005	0.007	0.000	0.000	0.331	0.000	0.000	0.000	0.000	0.343	0.104	0.9	**2350+**
	2050	30.422	5.497	17.159	16.655	0.000	0.000	0.331	0.032	0.018	0.000	0.000	70.114	12.054		
Georgia	2023	0.021	0.000	0.027	0.037	0.000	0.000	3.450	0.000	0.000	0.069	0.000	3.604	1.152	38.6	
	2024	0.021	0.000	0.056	0.077	0.000	0.000	3.414	0.000	0.000	0.069	0.000	3.637	1.152	38.6	**2350+**
	2050	2.910	0.216	0.971	1.742	0.000	0.000	3.446	0.000	0.004	0.069	0.000	9.358	2.987		
Germany	2023	61.013	8.473	31.376	43.506	0.002	0.052	5.606	0.000	0.000	4.806	13.934	168.768	47.570	28.4	
	2024	63.608	9.215	37.686	52.257	0.000	0.044	5.844	0.000	0.000	4.806	13.934	187.394	51.589	30.8	**2053**
	2050	167.517	38.513	129.938	282.969	0.001	8.177	5.741	0.500	0.035	4.806	13.934	652.131	167.502		
Ghana	2023	0.000	0.000	0.079	0.109	0.000	0.000	1.584	0.000	0.000	0.000	0.004	1.776	0.518	4.2	
	2024	0.000	0.000	0.079	0.109	0.000	0.000	1.584	0.000	0.000	0.000	0.004	1.776	0.518	4.2	**2350+**
	2050	27.875	2.805	21.736	17.299	0.000	0.000	1.584	0.036	0.013	0.000	0.004	71.353	12.317		
Gibraltar	2023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	
	2024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	**2350+**
	2050	0.150	4.566	0.009	0.087	0.000	0.000	0.000	0.007	0.001	0.000	0.000	4.819	2.453		
Greece	2023	5.232	0.000	2.803	3.886	0.000	0.000	3.459	0.000	0.000	0.259	3.494	19.133	5.034	37.3	
	2024	5.357	0.000	3.884	5.385	0.000	0.000	3.437	0.000	0.000	0.259	3.494	21.816	5.502	40.7	**2041**
	2050	13.946	2.397	14.222	12.603	0.000	0.680	3.427	0.042	0.024	0.260	3.494	51.093	13.502		
Guatemala	2023	0.107	0.000	0.043	0.059	0.000	0.049	1.575	0.000	0.000	0.002	0.000	1.835	0.637	8.3	
	2024	0.107	0.000	0.043	0.059	0.000	0.049	1.575	0.000	0.000	0.002	0.000	1.835	0.637	8.3	**2350+**
	2050	12.941	1.750	6.340	9.182	0.000	0.359	1.574	0.022	0.011	0.002	0.000	32.181	7.640		
Guyana	2023	0.000	0.000	0.007	0.010	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.019	0.004	0.5	
	2024	0.000	0.000	0.007	0.010	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.020	0.005	0.6	**2350+**
	2050	3.018	0.126	0.865	1.303	0.000	0.000	0.002	0.000	0.002	0.000	0.000	5.316	0.861		

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Haiti	2023	0.000	0.000	0.002	0.002	0.000	0.000	0.078	0.000	0.000	0.000	0.000	0.082	0.030	1.3	
	2024	0.000	0.000	0.002	0.002	0.000	0.000	0.078	0.000	0.000	0.000	0.000	0.082	0.030	1.3	**2350+**
	2050	3.608	0.382	2.284	2.099	0.000	0.000	0.078	0.000	0.004	0.000	0.000	8.455	2.310		
Honduras	2023	0.239	0.000	0.222	0.307	0.000	0.039	0.910	0.000	0.000	0.002	0.000	1.719	0.516	11.5	
	2024	0.239	0.000	0.232	0.322	0.000	0.039	0.910	0.000	0.000	0.002	0.000	1.744	0.522	11.6	**2350+**
	2050	7.973	0.866	3.759	5.305	0.000	0.198	0.910	0.012	0.007	0.002	0.000	19.032	4.501		
Hong Kong	2023	0.001	0.000	0.140	0.193	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.335	0.065	0.3	
	2024	0.001	0.000	0.140	0.193	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.335	0.065	0.3	**2350+**
	2050	0.180	38.427	1.389	31.708	0.000	0.000	0.001	0.070	0.016	0.000	0.000	71.790	22.237		
Hungary	2023	0.324	0.000	2.476	3.434	0.000	0.003	0.060	0.000	0.000	1.024	0.266	7.587	1.666	11.5	
	2024	0.324	0.000	3.226	4.473	0.000	0.003	0.060	0.000	0.000	1.024	0.266	9.376	1.961	13.5	**2067**
	2050	8.945	0.000	19.610	39.737	0.000	0.804	0.060	0.000	0.000	1.024	0.266	70.446	14.491		
Iceland	2023	0.004	0.000	0.003	0.004	0.000	0.788	2.147	0.000	0.000	2.373	0.000	5.319	2.972	83.1	
	2024	0.004	0.000	0.003	0.004	0.000	0.788	2.147	0.000	0.000	2.373	0.000	5.319	2.972	83.1	**2350+**
	2050	0.707	0.000	0.000	0.000	0.000	1.139	2.114	0.002	0.002	2.373	0.000	6.336	3.575		
India	2023	44.74	0.00	30.38	42.13	0.34	0.00	47.33	0.00	0.00	0.36	11.48	176.76	48.73	4.1	
	2024	48.16	0.00	40.66	56.38	0.34	0.00	47.51	0.00	0.00	0.36	11.48	204.89	54.68	4.6	**2213**
	2025	54.78	0.00	57.12	79.21	0.34	0.00	47.51	0.00	0.00	0.36	11.48	250.80	64.43	5.5	**2139**
	2050	1,089.60	96.97	1,506.96	2,444.32	2.21	10.00	47.33	3.93	0.70	0.36	11.48	5,213.87	1,176.19		
Indonesia	2023	0.152	0.000	0.264	0.366	0.000	2.598	6.784	0.000	0.000	0.002	0.000	10.166	4.955	1.9	
	2024	0.000	0.000	0.341	0.474	0.000	2.688	7.225	0.000	0.000	0.002	0.000	10.730	5.223	2.0	**2350+**
	2050	39.254	217.047	558.664	515.066	0.000	9.790	6.784	0.404	0.269	0.002	0.000	1,347.28	258.571		
Iran	2023	0.365	0.000	0.249	0.346	0.000	0.000	11.679	0.000	0.000	0.082	0.000	12.721	5.216	2.2	
	2024	0.376	0.000	0.328	0.454	0.000	0.000	11.781	0.000	0.000	0.082	0.000	13.021	5.302	2.2	**2350+**
	2050	253.559	44.012	239.931	288.912	0.144	0.005	11.679	0.000	0.036	0.082	0.000	838.360	240.872		
Iraq	2023	0.000	0.000	0.018	0.024	0.000	0.000	1.557	0.000	0.000	0.000	0.000	1.599	0.661	1.5	
	2024	0.000	0.000	0.018	0.024	0.000	0.000	1.557	0.000	0.000	0.000	0.000	1.599	0.661	1.5	**2350+**
	2050	57.908	1.046	40.124	43.635	0.022	0.000	1.557	0.000	0.003	0.000	0.000	144.296	43.447		
Ireland	2023	4.714	0.025	0.372	0.516	0.000	0.000	0.237	0.000	0.000	0.201	0.243	6.308	2.305	20.9	
	2024	4.917	0.025	0.561	0.779	0.000	0.000	0.237	0.000	0.000	0.201	0.243	6.963	2.463	22.4	**2078**
	2050	9.674	2.752	5.631	24.999	0.000	0.505	0.237	0.012	0.018	0.201	0.243	44.272	11.011		
Israel	2023	0.343	0.000	2.210	3.064	0.242	0.000	0.006	0.000	0.000	0.082	3.449	9.396	1.965	8.7	
	2024	0.343	0.000	2.247	3.116	0.242	0.000	0.006	0.000	0.000	0.082	3.449	9.485	1.985	8.8	**2350+**
	2050	3.084	3.453	15.382	70.846	0.016	0.000	0.006	0.000	0.009	0.082	3.449	96.326	22.480		
Italy	2023	12.276	0.000	12.298	17.053	0.005	0.772	18.942	0.000	0.000	1.425	3.462	66.233	18.739	22.2	
	2024	12.961	0.000	15.087	20.921	0.005	0.772	18.969	0.000	0.000	1.425	3.462	73.602	20.127	23.9	**2070**
	2050	83.306	15.215	75.311	86.871	0.043	13.097	18.848	0.239	0.075	1.425	3.462	297.892	84.228		
Jamaica	2023	0.102	0.000	0.047	0.066	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.245	0.065	2.7	
	2024	0.102	0.000	0.049	0.068	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.249	0.066	2.8	**2350+**
	2050	0.357	1.188	4.334	3.130	0.000	0.000	0.030	0.000	0.005	0.000	0.000	9.043	2.382		
Japan	2023	5.153	0.190	37.323	51.754	0.000	0.428	28.216	0.000	0.000	2.570	2.404	128.038	30.888	15.3	
	2024	5.542	0.290	38.385	53.225	0.000	0.461	28.194	0.000	0.000	2.570	2.404	131.071	31.503	15.6	**2301**
	2050	10.814	255.211	38.012	389.838	0.000	1.460	28.216	0.614	0.349	2.571	2.404	729.488	201.633		
Jordan	2023	0.631	0.000	0.834	1.156	0.000	0.000	0.004	0.000	0.000	0.153	0.882	3.660	0.854	9.9	
	2024	0.631	0.000	0.870	1.207	0.000	0.000	0.004	0.000	0.000	0.153	0.882	3.747	0.872	10.1	**2350+**
	2050	11.551	0.469	7.804	8.140	0.004	0.000	0.004	0.000	0.002	0.153	0.882	29.009	8.650		
Kazakhstan	2023	1.440	0.000	0.547	0.759	0.000	0.000	2.903	0.000	0.000	0.000	0.000	5.649	1.787	4.6	
	2024	1.411	0.000	0.501	0.695	0.000	0.000	2.810	0.000	0.000	0.000	0.000	5.417	1.724	4.5	**2350+**
	2050	45.962	0.000	45.122	42.336	0.000	0.000	2.903	0.000	0.000	0.000	0.000	136.323	38.728		
Kenya	2023	0.436	0.000	0.155	0.214	0.000	0.985	0.860	0.000	0.000	0.019	0.000	2.669	1.098	8.5	
	2024	0.436	0.000	0.155	0.214	0.000	0.940	0.859	0.000	0.000	0.019	0.000	2.623	1.069	8.3	**2350+**
	2050	14.484	2.753	15.803	14.826	0.000	1.810	0.859	0.037	0.013	0.019	0.000	50.604	12.890		
North Korea	2023	0.002	0.000	0.054	0.075	0.000	0.000	4.890	0.000	0.001	0.000	0.000	5.022	2.269	7.1	
	2024	0.002	0.000	0.060	0.083	0.000	0.000	4.910	0.000	0.001	0.000	0.000	5.056	2.281	7.2	**2350+**
	2050	32.833	6.069	8.942	60.276	0.000	0.000	4.890	0.000	0.041	0.000	0.000	113.051	31.767		

Country	Year	(a) On-shore wind (GW)	(b) Off-shore wind (GW)	(c) Roof PV (GW)	(d) Utility PV (GW)	(e) CSP (GW)	(f) Geo-elec (GW)	(g) Hydro (GW)	(h) Wave (GW)	(i) Tidal (GW)	(j) Geo-heat (GW)	(k) Solar heat (GW)	(l) Total WWS-name-plate (GW)	(m) Total WWS output (GW)	(n) Pct of 2050 met (%)	(o) Year to 100% WWS
South Korea	2023	2.069	0.136	9.844	13.649	0.000	0.000	1.805	0.000	0.256	1.490	1.353	30.602	6.053	3.1	
	2024	2.165	0.136	11.164	15.481	0.000	0.000	1.803	0.000	0.255	1.490	1.353	33.847	6.570	3.4	**2350+**
	2050	2.137	174.863	186.137	581.409	0.000	0.000	1.805	0.000	0.308	1.490	1.353	949.503	195.691		
Kosovo	2023	0.137	0.000	0.008	0.012	0.000	0.000	0.122	0.000	0.000	0.000	0.000	0.279	0.107	6.3	
	2024	0.137	0.000	0.008	0.012	0.000	0.000	0.122	0.000	0.000	0.000	0.000	0.279	0.107	6.3	**2350+**
	2050	1.932	0.000	2.169	2.871	0.000	0.091	0.110	0.000	0.000	0.000	0.000	7.173	1.714		
Kuwait	2023	0.012	0.000	0.021	0.029	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.114	0.054	0.2	
	2024	0.012	0.000	0.021	0.029	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.114	0.054	0.2	**2350+**
	2050	1.193	9.001	4.959	111.209	0.020	0.000	0.000	0.000	0.013	0.000	0.000	126.395	28.249		
Kyrgyz Rep.	2023	0.000	0.000	0.000	0.000	0.000	0.000	3.210	0.000	0.000	0.000	0.000	3.210	0.962	27.4	
	2024	0.000	0.000	0.000	0.000	0.000	0.000	3.258	0.000	0.000	0.000	0.000	3.258	0.976	27.8	**2200**
	2050	3.302	0.000	2.844	2.525	0.002	0.000	3.210	0.000	0.000	0.000	0.000	11.883	3.509		
Laos	2023	0.000	0.000	0.024	0.034	0.000	0.000	9.756	0.000	0.000	0.000	0.000	9.814	3.909	91.9	
	2024	0.000	0.000	0.024	0.034	0.000	0.000	10.189	0.000	0.000	0.000	0.000	10.247	4.082	95.9	**2025**
	2050	0.129	0.000	0.808	1.042	0.000	0.000	9.756	0.000	0.000	0.000	0.000	11.735	4.256		
Latvia	2023	0.128	0.000	0.134	0.185	0.000	0.000	1.588	0.000	0.000	0.002	0.028	2.065	0.733	22.5	
	2024	0.128	0.000	0.195	0.271	0.000	0.000	1.588	0.000	0.000	0.002	0.028	2.212	0.757	23.2	**2127**
	2050	2.729	0.468	3.527	3.807	0.000	0.133	1.567	0.000	0.005	0.002	0.028	12.265	3.257		
Lebanon	2023	0.003	0.000	0.421	0.584	0.000	0.000	0.282	0.000	0.000	0.000	0.515	1.805	0.380	17.1	
	2024	0.003	0.000	0.421	0.584	0.000	0.000	0.282	0.000	0.000	0.000	0.515	1.805	0.380	17.1	**2350+**
	2050	0.822	0.869	3.377	3.239	0.000	0.000	0.282	0.000	0.005	0.000	0.515	9.110	2.219		
Libya	2023	0.000	0.000	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.002	0.0	
	2024	0.000	0.000	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.002	0.0	**2350+**
	2050	16.803	3.455	22.482	14.308	0.000	0.000	0.000	0.000	0.029	0.000	0.000	57.076	17.579		
Lithuania	2023	1.284	0.000	0.555	0.769	0.000	0.000	0.117	0.000	0.000	0.126	0.016	2.867	0.854	13.7	
	2024	1.828	0.000	1.076	1.491	0.000	0.000	0.089	0.000	0.000	0.126	0.016	4.626	1.271	20.3	**2036**
	2050	6.219	1.231	7.175	9.728	0.000	0.313	0.118	0.000	0.004	0.126	0.016	24.929	6.252		
Luxembourg	2023	0.207	0.000	0.165	0.229	0.000	0.000	0.034	0.000	0.000	0.000	0.048	0.683	0.167	6.2	
	2024	0.210	0.000	0.219	0.304	0.000	0.000	0.034	0.000	0.000	0.000	0.048	0.815	0.190	7.1	**2135**
	2050	0.995	0.000	0.402	12.600	0.000	0.126	0.034	0.000	0.000	0.000	0.048	14.204	2.689		
Macedonia	2023	0.074	0.000	0.212	0.294	0.000	0.000	0.713	0.000	0.000	0.047	0.087	1.427	0.425	21.2	
	2024	0.074	0.000	0.349	0.484	0.000	0.000	0.713	0.000	0.000	0.047	0.087	1.754	0.479	23.9	**2052**
	2050	1.641	0.000	2.679	3.543	0.000	0.000	0.696	0.000	0.000	0.047	0.087	8.694	2.002		
Madagascar	2023	0.000	0.000	0.024	0.034	0.000	0.000	0.193	0.000	0.000	0.003	0.000	0.254	0.080	1.0	
	2024	0.000	0.000	0.024	0.034	0.000	0.000	0.193	0.000	0.000	0.003	0.000	0.254	0.080	1.0	**2350+**
	2050	13.686	1.346	6.544	15.259	0.000	0.000	0.193	0.014	0.008	0.003	0.000	37.053	8.119		
Malaysia	2023	0.000	0.000	0.899	1.247	0.000	0.000	6.215	0.000	0.000	0.005	0.000	8.366	2.886	2.8	
	2024	0.000	0.000	0.966	1.340	0.000	0.000	6.227	0.000	0.000	0.005	0.000	8.538	2.920	2.8	**2350+**
	2050	2.838	107.081	168.884	254.081	0.000	0.000	6.215	0.265	0.054	0.005	0.000	539.424	103.439		
Malta	2023	0.000	0.000	0.095	0.131	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.278	0.042	2.8	
	2024	0.000	0.000	0.098	0.135	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.285	0.043	2.8	**2350+**
	2050	0.150	0.970	0.276	5.244	0.000	0.000	0.000	0.006	0.003	0.000	0.052	6.700	1.503		
Mauritius	2023	0.011	0.000	0.052	0.073	0.000	0.000	0.062	0.000	0.000	0.000	0.093	0.291	0.068	4.0	
	2024	0.011	0.000	0.058	0.081	0.000	0.000	0.062	0.000	0.000	0.000	0.093	0.305	0.071	4.2	**2350+**
	2050	0.100	1.090	0.631	4.629	0.000	0.000	0.061	0.003	0.003	0.000	0.093	6.609	1.704		
Mexico	2023	7.318	0.000	5.018	6.957	0.017	0.999	12.838	0.000	0.000	0.156	3.584	36.887	9.865	7.0	
	2024	7.318	0.000	5.018	6.957	0.017	0.999	12.838	0.000	0.000	0.156	3.584	36.887	9.865	7.0	**2350+**
	2050	222.790	46.141	129.832	177.296	0.000	7.231	13.304	0.442	0.100	0.156	3.584	600.876	140.965		
Moldova	2023	0.141	0.000	0.084	0.117	0.000	0.000	0.065	0.000	0.000	0.000	0.000	0.407	0.116	5.2	
	2024	0.123	0.000	0.144	0.200	0.000	0.000	0.065	0.000	0.000	0.000	0.000	0.532	0.133	5.9	**2155**
	2050	2.524	0.000	2.471	4.745	0.000	0.000	0.064	0.000	0.000	0.000	0.000	9.804	2.255		
Mongolia	2023	0.155	0.000	0.045	0.063	0.000	0.000	0.029	0.000	0.000	0.023	0.000	0.315	0.108	1.8	
	2024	0.156	0.000	0.060	0.083	0.000	0.000	0.029	0.000	0.000	0.023	0.000	0.351	0.116	2.0	**2350+**
	2050	6.897	0.000	4.459	11.237	0.000	0.000	0.029	0.000	0.000	0.023	0.000	22.645	5.894		

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Montenegro	2023	0.118	0.000	0.007	0.010	0.000	0.000	0.697	0.000	0.000	0.000	0.000	0.832	0.325	40.3	
	2024	0.118	0.000	0.013	0.017	0.000	0.000	0.697	0.000	0.000	0.000	0.000	0.845	0.327	40.6	**2247**
	2050	0.633	0.106	0.689	0.639	0.000	0.000	0.697	0.000	0.001	0.000	0.000	2.765	0.806		
Morocco	2023	1.858	0.000	0.165	0.229	0.540	0.000	1.306	0.000	0.000	0.005	0.627	4.730	1.497	6.7	
	2024	2.128	0.000	0.165	0.229	0.540	0.000	1.306	0.000	0.000	0.005	0.627	5.000	1.628	7.3	**2181**
	2050	20.362	3.731	28.124	19.355	0.000	0.000	1.306	0.033	0.030	0.005	0.627	73.572	22.268		
Mozambique	2023	0.000	0.000	0.043	0.060	0.000	0.000	2.194	0.000	0.000	0.000	0.002	2.299	0.736	9.0	
	2024	0.000	0.000	0.045	0.062	0.000	0.000	2.194	0.000	0.000	0.000	0.002	2.303	0.737	9.1	**2350+**
	2050	9.671	1.585	10.066	7.340	0.000	0.000	2.192	0.010	0.013	0.000	0.002	30.878	8.140		
Myanmar	2023	0.000	0.000	0.076	0.105	0.000	0.000	3.269	0.000	0.000	0.000	0.000	3.450	1.340	11.9	
	2024	0.000	0.000	0.091	0.125	0.000	0.000	3.269	0.000	0.000	0.000	0.000	3.485	1.347	12.0	**2350+**
	2050	4.613	7.132	22.193	20.732	0.000	0.000	3.269	0.051	0.029	0.000	0.000	58.020	11.223		
Namibia	2023	0.005	0.000	0.068	0.095	0.000	0.000	0.351	0.000	0.000	0.000	0.038	0.557	0.154	7.0	
	2024	0.005	0.000	0.068	0.095	0.000	0.000	0.351	0.000	0.000	0.000	0.038	0.557	0.154	7.0	**2350+**
	2050	2.346	0.446	3.160	2.217	0.000	0.000	0.351	0.003	0.004	0.000	0.038	8.565	2.186		
Nepal	2023	0.000	0.000	0.049	0.068	0.000	0.000	2.677	0.000	0.000	0.004	0.000	2.798	1.127	6.8	
	2024	0.000	0.000	0.073	0.102	0.000	0.000	3.293	0.000	0.000	0.004	0.000	3.472	1.392	8.4	**2082**
	2050	7.610	0.000	11.891	53.246	0.000	0.000	2.677	0.000	0.000	0.004	0.000	75.427	16.635		
Netherlands	2023	6.757	3.978	8.914	12.361	0.000	0.000	0.038	0.000	0.002	1.719	0.469	34.238	9.257	20.3	
	2024	6.932	4.748	10.076	13.972	0.000	0.000	0.038	0.000	0.002	1.719	0.469	37.956	10.186	22.3	**2062**
	2050	30.470	15.874	8.991	126.132	0.000	2.202	0.038	0.000	0.012	1.719	0.469	185.905	45.612		
New Zealand	2023	1.059	0.000	0.152	0.211	0.000	1.050	5.680	0.000	0.000	0.518	0.112	8.782	4.115	20.1	
	2024	1.263	0.000	0.239	0.331	0.000	1.275	5.680	0.000	0.000	0.518	0.112	9.418	4.427	21.6	**2075**
	2050	17.985	4.633	12.622	24.916	0.000	0.704	5.680	0.017	0.025	0.518	0.112	67.210	20.485		
Nicaragua	2023	0.186	0.000	0.008	0.010	0.000	0.165	0.160	0.000	0.000	0.000	0.000	0.529	0.185	10.2	
	2024	0.186	0.000	0.015	0.021	0.000	0.165	0.160	0.000	0.000	0.000	0.000	0.547	0.189	10.4	**2350+**
	2050	2.570	0.471	1.822	2.646	0.000	0.103	0.160	0.006	0.004	0.000	0.000	7.782	1.815		
Niger	2023	0.000	0.000	0.035	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.018	0.6	
	2024	0.000	0.000	0.035	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.018	0.6	**2350+**
	2050	2.596	0.000	4.589	3.906	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.091	3.115		
Nigeria	2023	0.000	0.000	0.060	0.083	0.000	0.000	2.861	0.000	0.000	0.001	0.010	3.015	0.904	1.6	
	2024	0.000	0.000	0.060	0.084	0.000	0.000	2.861	0.000	0.000	0.001	0.010	3.016	0.904	1.6	**2350+**
	2050	105.873	0.000	110.971	106.777	0.000	0.000	2.851	0.181	0.018	0.001	0.010	326.681	55.083		
Norway	2023	5.062	0.002	0.274	0.379	0.000	0.000	34.291	0.000	0.000	1.150	0.034	41.192	16.241	78.3	
	2024	5.062	0.090	0.336	0.466	0.000	0.000	34.698	0.000	0.000	1.150	0.034	41.836	16.471	79.4	**2043**
	2050	8.799	1.670	6.213	6.913	0.000	0.000	34.401	0.010	0.011	1.150	0.034	59.202	20.735		
Oman	2023	0.050	0.000	0.282	0.390	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.722	0.160	0.6	
	2024	0.050	0.000	0.282	0.390	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.722	0.160	0.6	**2350+**
	2050	20.713	7.873	21.951	47.359	0.000	0.000	0.000	0.099	0.032	0.000	0.000	98.028	26.370		
Pakistan	2023	1.845	0.000	0.521	0.722	0.000	0.000	10.636	0.000	0.000	0.000	0.000	13.724	4.280	3.8	
	2024	1.845	0.000	0.585	0.810	0.000	0.000	11.529	0.000	0.000	0.000	0.000	14.769	4.577	4.0	**2350+**
	2050	113.663	19.699	158.534	101.186	0.000	0.000	10.636	0.346	0.021	0.000	0.000	404.084	113.596		
Panama	2023	0.336	0.000	0.271	0.375	0.000	0.000	1.847	0.000	0.000	0.000	0.000	2.829	0.881	13.0	
	2024	0.336	0.000	0.311	0.432	0.000	0.000	1.848	0.000	0.000	0.000	0.000	2.927	0.902	13.3	**2300**
	2050	11.493	1.650	5.575	8.067	0.000	0.000	1.845	0.019	0.011	0.000	0.000	28.660	6.787		
Paraguay	2023	0.000	0.000	0.000	0.001	0.000	0.000	8.824	0.000	0.000	0.000	0.000	8.825	3.738	71.6	
	2024	0.000	0.000	0.000	0.001	0.000	0.000	8.824	0.000	0.000	0.000	0.000	8.825	3.738	71.6	**2350+**
	2050	3.413	0.000	2.260	2.132	0.000	0.000	8.810	0.000	0.000	0.000	0.000	16.615	5.224		
Peru	2023	1.015	0.000	0.187	0.260	0.000	0.000	5.523	0.000	0.000	0.003	0.000	6.988	2.623	14.9	
	2024	1.151	0.000	0.221	0.307	0.000	0.000	5.523	0.000	0.000	0.003	0.000	7.205	2.656	15.1	**2350+**
	2050	38.383	0.014	15.593	33.040	0.002	1.010	5.504	0.031	0.035	0.003	0.000	93.615	17.633		
Philippines	2023	0.443	0.000	0.755	1.047	0.000	1.952	3.090	0.000	0.000	0.002	0.000	7.289	3.356	5.4	
	2024	0.443	0.000	1.245	1.726	0.000	1.952	3.133	0.000	0.000	0.002	0.000	8.501	3.635	5.8	**2236**
	2050	12.594	11.679	61.199	170.572	0.000	2.256	3.090	0.138	0.078	0.002	0.000	261.607	62.708		

Country	Year	(a) On-shore wind (GW)	(b) Off-shore wind (GW)	(c) Roof PV (GW)	(d) Utility PV (GW)	(e) CSP (GW)	(f) Geo-elec (GW)	(g) Hydro (GW)	(h) Wave (GW)	(i) Tidal (GW)	(j) Geo-heat (GW)	(k) Solar heat (GW)	(l) Total WWS-name-plate (GW)	(m) Total WWS output (GW)	(n) Pct of 2050 met (%)	(o) Year to 100% WWS
Poland	2023	9.343	0.000	6.883	9.545	0.000	0.000	0.987	0.000	0.000	0.756	2.105	29.619	7.481	13.9	
	2024	10.059	0.000	8.463	11.736	0.000	0.000	0.988	0.000	0.000	0.756	2.105	34.107	8.396	15.6	**2074**
	2050	55.470	9.761	71.753	72.657	0.000	2.861	0.983	0.000	0.012	0.756	2.105	216.358	53.964		
Portugal	2023	5.513	0.025	1.693	2.347	0.000	0.029	8.187	0.000	0.000	0.021	0.872	18.687	6.257	40.3	
	2024	5.558	0.025	2.434	3.374	0.000	0.029	8.347	0.000	0.000	0.021	0.872	20.660	6.630	42.7	**2048**
	2050	15.702	2.035	13.922	12.827	0.000	0.607	8.188	0.019	0.021	0.021	0.872	54.213	15.508		
Qatar	2023	0.000	0.000	0.337	0.468	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.805	0.165	0.5	
	2024	0.000	0.000	0.704	0.976	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.680	0.345	1.1	**2190**
	2050	0.777	10.155	2.735	121.115	0.000	0.000	0.000	0.000	0.014	0.000	0.000	134.796	30.125		
Romania	2023	3.027	0.000	1.252	1.736	0.000	0.000	6.596	0.000	0.000	0.245	0.164	13.020	4.462	24.8	
	2024	3.096	0.000	1.964	2.724	0.000	0.000	6.589	0.000	0.000	0.245	0.164	14.782	4.768	26.5	**2067**
	2050	17.278	2.840	20.260	17.969	0.000	0.866	6.574	0.000	0.008	0.245	0.164	66.204	17.998		
Russia	2023	2.532	0.000	0.919	1.274	0.000	0.081	51.624	0.000	0.001	0.433	0.019	56.883	18.188	5.9	
	2024	2.567	0.000	1.070	1.484	0.000	0.081	49.096	0.000	0.004	0.433	0.019	54.754	17.459	5.6	**2350+**
	2050	515.580	7.366	110.782	255.899	0.000	0.500	50.571	0.514	0.350	0.433	0.019	942.013	310.200		
Rwanda	2023	0.000	0.000	0.012	0.016	0.000	0.000	0.124	0.000	0.000	0.000	0.000	0.152	0.044	1.5	
	2024	0.000	0.000	0.012	0.016	0.000	0.000	0.153	0.000	0.000	0.000	0.000	0.181	0.053	1.8	**2340**
	2050	1.630	0.000	3.796	7.887	0.000	0.111	0.124	0.000	0.000	0.000	0.000	13.548	2.893		
Saudi Arabia	2023	0.403	0.000	1.062	1.473	0.050	0.000	0.000	0.000	0.000	0.045	0.000	3.033	0.756	0.4	
	2024	0.403	0.000	1.798	2.492	0.050	0.000	0.000	0.000	0.000	0.045	0.000	4.788	1.116	0.6	**2350+**
	2050	237.985	29.088	174.227	169.642	0.104	0.000	0.000	0.000	0.038	0.045	0.000	611.127	185.313		
Senegal	2023	0.159	0.000	0.097	0.134	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.398	0.066	1.5	
	2024	0.159	0.000	0.114	0.159	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.440	0.073	1.6	**2350+**
	2050	13.114	0.925	7.466	5.037	0.000	0.000	0.000	0.016	0.009	0.000	0.008	26.574	4.515		
Serbia	2023	0.510	0.000	0.083	0.114	0.000	0.000	2.511	0.000	0.000	0.115	0.000	3.333	1.286	14.5	
	2024	0.604	0.000	0.101	0.140	0.000	0.000	2.513	0.000	0.000	0.115	0.000	3.473	1.333	15.0	**2186**
	2050	5.677	0.000	14.425	19.097	0.000	0.000	2.494	0.000	0.000	0.115	0.000	41.808	8.885		
Singapore	2023	0.000	0.000	0.385	0.534	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.919	0.171	0.1	
	2024	0.000	0.000	0.485	0.672	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.157	0.216	0.2	**2350+**
	2050	0.020	551.436	4.427	20.632	0.000	3.450	0.000	0.000	0.007	0.000	0.000	579.972	119.713		
Slovakia	2023	0.004	0.000	0.248	0.345	0.000	0.000	1.615	0.000	0.000	0.230	0.127	2.569	0.860	9.9	
	2024	0.004	0.000	0.363	0.504	0.000	0.000	1.615	0.000	0.000	0.230	0.127	2.843	0.905	10.4	**2197**
	2050	8.718	0.000	10.244	14.842	0.000	0.424	1.616	0.000	0.000	0.230	0.127	36.201	8.698		
Slovenia	2023	0.003	0.000	0.432	0.599	0.000	0.000	1.171	0.000	0.000	0.266	0.104	2.575	0.773	18.8	
	2024	0.003	0.000	0.548	0.761	0.000	0.000	1.192	0.000	0.000	0.266	0.104	2.874	0.827	20.1	**2085**
	2050	4.141	0.662	4.362	4.091	0.000	0.172	1.162	0.000	0.003	0.266	0.104	14.962	4.116		
South Africa	2023	3.442	0.000	2.374	3.291	0.500	0.000	0.752	0.000	0.000	0.002	1.745	12.106	3.100	3.6	
	2024	3.442	0.000	2.586	3.585	0.500	0.000	0.752	0.000	0.000	0.002	1.745	12.612	3.205	3.8	**2350+**
	2050	66.190	20.908	141.986	117.616	0.104	0.000	0.752	0.130	0.039	0.002	1.745	349.471	85.107		
South Sudan	2023	0.000	0.000	0.007	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.003	0.6	
	2024	0.000	0.000	0.013	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.006	1.1	**2226**
	2050	0.532	0.000	0.831	1.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.512	0.552		
Spain	2023	30.863	0.005	12.409	17.207	2.304	0.000	16.809	0.000	0.005	0.544	3.296	83.442	26.346	36.1	
	2024	31.806	0.005	15.203	21.082	2.302	0.000	16.809	0.000	0.005	0.544	3.296	91.052	27.830	38.1	**2054**
	2050	82.937	12.546	68.651	73.754	0.075	3.535	16.809	0.099	0.123	0.544	3.296	262.369	73.036		
Sri Lanka	2023	0.267	0.000	0.401	0.557	0.000	0.000	1.843	0.000	0.000	0.000	0.000	3.068	1.028	9.0	
	2024	0.267	0.000	0.608	0.842	0.000	0.000	1.846	0.000	0.000	0.000	0.000	3.563	1.126	9.8	**2129**
	2050	14.547	1.566	13.432	15.987	0.000	0.000	1.843	0.037	0.022	0.000	0.000	47.435	11.460		
Sudan	2023	0.000	0.000	0.080	0.110	0.000	0.000	1.482	0.000	0.000	0.000	0.000	1.672	0.496	3.9	
	2024	0.000	0.000	0.080	0.110	0.000	0.000	1.482	0.000	0.000	0.000	0.000	1.672	0.496	3.9	**2350+**
	2050	12.446	2.366	19.440	18.835	0.000	0.000	1.482	0.000	0.018	0.000	0.000	54.588	12.639		
Suriname	2023	0.000	0.000	0.003	0.005	0.000	0.000	0.180	0.000	0.000	0.000	0.000	0.188	0.080	13.8	
	2024	0.000	0.000	0.004	0.006	0.000	0.000	0.180	0.000	0.000	0.000	0.000	0.190	0.080	13.9	**2350+**
	2050	1.657	0.152	0.464	0.717	0.000	0.000	0.180	0.002	0.001	0.000	0.000	3.173	0.581		

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Eswatini	2023	0.000	0.000	0.004	0.006	0.000	0.000	0.062	0.000	0.000	0.000	0.000	0.072	0.022	1.5	
	2024	0.000	0.000	0.004	0.006	0.000	0.000	0.062	0.000	0.000	0.000	0.000	0.072	0.022	1.5	**2350+**
	2050	0.922	0.000	2.634	3.174	0.000	0.000	0.062	0.000	0.000	0.000	0.000	6.793	1.523		
Sweden	2023	16.031	0.193	1.673	2.320	0.000	0.000	16.406	0.000	0.000	6.680	0.365	43.668	17.145	43.3	
	2024	17.046	0.193	2.079	2.884	0.000	0.000	16.506	0.000	0.000	6.680	0.365	45.753	17.760	44.8	**2060**
	2050	42.684	8.950	14.453	31.187	0.000	0.114	16.399	0.000	0.048	6.680	0.365	120.879	39.601		
Switzerland	2023	0.088	0.000	2.553	3.541	0.000	0.000	16.220	0.000	0.000	2.197	1.204	25.803	8.617	56.0	
	2024	0.102	0.000	3.266	4.528	0.000	0.000	16.220	0.000	0.000	2.197	1.204	27.517	8.903	57.8	**2047**
	2050	9.184	0.000	10.924	14.611	0.000	0.417	15.279	0.000	0.000	2.197	1.204	53.816	15.399		
Syria	2023	0.001	0.000	0.025	0.035	0.000	0.000	1.490	0.000	0.000	0.000	0.000	1.551	0.637	10.1	
	2024	0.001	0.000	0.025	0.035	0.000	0.000	1.490	0.000	0.000	0.000	0.000	1.551	0.637	10.1	**2350+**
	2050	6.153	1.443	6.646	5.255	0.000	0.000	1.490	0.000	0.007	0.000	0.000	20.993	6.290		
Taiwan	2023	0.914	1.763	5.203	7.215	0.000	0.007	2.104	0.000	0.000	0.000	1.271	18.477	4.248	4.2	
	2024	0.927	2.963	5.984	8.297	0.000	0.007	2.123	0.000	0.000	0.000	1.271	21.572	5.035	5.0	**2145**
	2050	3.284	82.073	108.414	218.990	0.000	33.640	2.104	0.283	0.027	0.000	1.271	450.087	100.558		
Tajikistan	2023	0.000	0.000	0.000	0.000	0.000	0.000	5.737	0.000	0.000	0.003	0.000	5.740	1.721	61.4	
	2024	0.000	0.000	0.000	0.000	0.000	0.000	5.737	0.000	0.000	0.003	0.000	5.740	1.721	61.4	**2350+**
	2050	1.373	0.000	1.164	1.142	0.000	0.000	5.763	0.000	0.000	0.003	0.000	9.444	2.802		
Tanzania	2023	0.002	0.000	0.008	0.012	0.000	0.000	0.680	0.000	0.000	0.000	0.000	0.702	0.215	1.1	
	2024	0.002	0.000	0.008	0.012	0.000	0.000	1.385	0.000	0.000	0.000	0.000	1.407	0.434	2.3	**2109**
	2050	26.225	4.018	24.083	23.334	0.000	0.000	0.599	0.057	0.032	0.000	0.000	78.348	19.097		
Thailand	2023	1.544	0.000	1.381	1.914	0.005	0.000	3.110	0.000	0.000	0.129	0.110	8.193	2.089	1.7	
	2024	1.544	0.000	1.416	1.963	0.005	0.000	3.133	0.000	0.000	0.129	0.110	8.300	2.114	1.7	**2350+**
	2050	4.422	121.903	233.406	285.344	0.000	0.120	3.110	0.000	0.043	0.129	0.110	648.585	123.255		
Togo	2023	0.000	0.000	0.028	0.039	0.000	0.000	0.067	0.000	0.000	0.000	0.000	0.134	0.032	1.4	
	2024	0.000	0.000	0.028	0.039	0.000	0.000	0.067	0.000	0.000	0.000	0.000	0.134	0.032	1.4	**2350+**
	2050	6.664	0.494	3.124	3.095	0.000	0.000	0.067	0.007	0.003	0.000	0.000	13.454	2.295		
Trin. Tobago	2023	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.0	
	2024	0.000	0.000	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.0	**2350+**
	2050	0.264	3.212	3.790	23.028	0.000	0.000	0.000	0.027	0.010	0.000	0.000	30.332	6.827		
Tunisia	2023	0.245	0.000	0.212	0.294	0.000	0.000	0.066	0.000	0.000	0.044	0.804	1.665	0.363	2.7	
	2024	0.245	0.000	0.324	0.449	0.000	0.000	0.066	0.000	0.000	0.044	0.804	1.932	0.421	3.1	**2248**
	2050	13.678	2.265	16.980	10.135	0.000	0.000	0.066	0.000	0.022	0.044	0.804	43.994	13.595		
Türkiye	2023	11.806	0.000	4.731	6.561	0.001	1.691	31.962	0.000	0.000	3.488	18.426	78.666	25.776	23.3	
	2024	12.973	0.000	8.331	11.551	0.001	1.734	32.386	0.000	0.000	3.488	18.426	88.890	28.257	25.6	**2057**
	2050	108.738	3.584	82.415	84.514	0.046	14.429	31.779	0.000	0.072	3.488	18.426	347.491	110.593		
Turkmenistan	2023	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.001	0.0	
	2024	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.001	0.0	**2350+**
	2050	27.000	0.000	23.766	22.287	0.000	0.000	0.002	0.000	0.000	0.000	0.000	73.055	21.232		
Uganda	2023	0.000	0.000	0.036	0.049	0.000	0.000	1.429	0.000	0.000	0.000	0.000	1.514	0.459	2.1	
	2024	0.000	0.000	0.036	0.049	0.000	0.000	1.634	0.000	0.000	0.000	0.000	1.719	0.523	2.4	**2350+**
	2050	14.350	0.000	25.363	59.221	0.000	0.450	1.033	0.000	0.000	0.000	0.000	100.416	21.587		
Ukraine	2023	1.761	0.000	3.378	4.684	0.000	0.000	4.488	0.000	0.000	1.607	0.000	15.918	4.617	13.1	
	2024	1.761	0.000	2.305	3.196	0.000	0.000	1.250	0.000	0.000	1.607	0.000	10.118	2.922	8.3	**2350+**
	2050	36.456	6.234	47.020	41.145	0.000	0.000	4.488	0.000	0.039	1.607	0.000	136.989	35.177		
UAE	2023	0.099	0.000	2.267	3.144	0.600	0.000	0.000	0.000	0.000	0.000	0.000	6.110	1.603	1.6	
	2024	0.099	0.000	2.267	3.144	0.600	0.000	0.000	0.000	0.000	0.000	0.000	6.110	1.603	1.6	**2350+**
	2050	35.645	23.774	22.773	342.244	0.070	0.000	0.000	0.000	0.024	0.000	0.000	424.530	100.857		
United King.	2023	15.418	14.745	6.819	9.456	0.000	0.000	2.190	0.000	0.010	0.525	1.042	50.205	17.879	18.4	
	2024	16.157	14.745	7.376	10.227	0.000	0.000	2.190	0.000	0.010	0.525	1.042	52.272	18.401	18.9	**2175**
	2050	66.615	58.220	49.445	164.844	0.000	4.795	2.190	0.128	0.169	0.525	1.042	347.972	97.152		
U.S.	2023	147.98	0.04	47.70	95.76	1.48	2.67	84.32	0.00	0.00	20.71	18.19	418.85	115.55	8.7	
	2024	152.98	0.17	56.27	137.16	1.48	2.70	84.17	0.00	0.00	20.71	18.19	473.84	127.03	9.6	**2128**
	2025	161.49	0.17	62.98	164.68	1.48	2.70	84.18	0.00	0.00	20.71	18.19	516.57	136.62	10.3	**2149**
	2050	1,398.13	499.93	631.75	2,759.78	0.56	6.52	86.66	1.66	0.35	20.71	18.19	5,424.24	1,322.97		

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Uruguay	2023	1.524	0.000	0.138	0.192	0.000	0.000	1.538	0.000	0.000	0.000	0.060	3.452	0.991	21.5	
	2024	1.524	0.000	0.138	0.192	0.000	0.000	1.538	0.000	0.000	0.000	0.060	3.452	0.991	21.5	**2350+**
	2050	6.760	0.702	7.207	4.916	0.000	0.000	1.538	0.016	0.009	0.000	0.060	21.208	4.600		
Uzbekistan	2023	0.001	0.000	0.199	0.276	0.000	0.000	2.415	0.000	0.000	0.000	0.000	2.891	0.815	3.0	
	2024	0.501	0.000	0.953	1.322	0.000	0.000	2.391	0.000	0.000	0.000	0.000	5.167	1.383	5.1	**2070**
	2050	33.515	0.000	29.736	28.664	0.000	0.000	2.415	0.000	0.000	0.000	0.000	94.330	27.319		
Venezuela	2023	0.050	0.000	0.002	0.002	0.000	0.000	16.914	0.000	0.000	0.001	0.000	16.969	7.376	31.8	
	2024	0.050	0.000	0.002	0.002	0.000	0.000	16.914	0.000	0.000	0.001	0.000	16.969	7.376	31.8	**2350+**
	2050	54.647	2.361	16.167	24.369	0.000	0.000	16.811	0.061	0.035	0.001	0.000	114.451	23.209		
Vietnam	2023	4.784	1.104	7.788	10.800	0.000	0.000	22.639	0.000	0.000	0.018	0.000	47.133	13.230	10.9	
	2024	5.081	1.104	7.821	10.846	0.000	0.000	23.707	0.000	0.000	0.018	0.000	48.577	13.701	11.3	**2253**
	2050	2.870	83.372	204.212	306.925	0.000	0.000	22.639	0.399	0.045	0.018	0.000	620.481	121.638		
Yemen	2023	0.000	0.000	0.172	0.238	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.415	0.087	4.2	
	2024	0.000	0.000	0.172	0.238	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.415	0.087	4.2	**2350+**
	2050	1.668	0.417	3.054	2.374	0.000	0.100	0.000	0.008	0.004	0.005	0.000	7.629	2.072		
Zambia	2023	0.000	0.000	0.056	0.078	0.000	0.000	3.165	0.000	0.000	0.000	0.000	3.299	1.058	10.2	
	2024	0.000	0.000	0.082	0.114	0.000	0.000	3.165	0.000	0.000	0.000	0.000	3.361	1.071	10.4	**2350+**
	2050	11.380	0.000	13.143	13.831	0.000	0.090	3.165	0.000	0.000	0.000	0.000	41.609	10.338		
Zimbabwe	2023	0.000	0.000	0.019	0.027	0.000	0.000	1.080	0.000	0.000	0.000	0.054	1.180	0.367	6.2	
	2024	0.000	0.000	0.029	0.041	0.000	0.000	1.080	0.000	0.000	0.000	0.054	1.204	0.372	6.3	**2350+**
	2050	6.920	0.000	7.877	8.212	0.000	0.000	1.080	0.000	0.000	0.000	0.054	24.143	5.910		
150 Countries	2023	944.7	74.2	578.6	832.0	6.9	15.0	1,262	0.0	0.5	107.7	490.9	4,312.5	1,274.2	11.4	
	2024	1,054.3	79.4	759.9	1,112.8	6.9	15.4	1,277	0.0	0.5	107.7	490.9	4,904.6	1,414.3	12.6	**2094**
	2025	1,132.0	100.9	910.2	1,339.4	6.9	15.4	1,286	0.0	0.5	107.7	490.9	5,390.1	1,530.6	13.7	**2108**
	2050	10,446.0	3,783.5	9,719.5	19,003.0	5.3	193.7	1,262	21.5	7.5	107.7	490.9	45,040.4	11,202.5		

Nameplate capacities for 2023 and 2024 are from Refs. 15 and 16. Nameplate capacities for 2025 for China are from Ref. 17; those for India are from Ref. 18; and those for the U.S. are from Refs. 19 and 20, each extrapolated linearly from 10, 9, or 7 months, respectively, of 2025 to all of 2025. 2050 nameplate capacities required for each country to meet 100% of all-sector energy demand while keeping the grid stable are from Ref. 14. Estimated outputs from the WWS generators in 2023, 2024, 2025, and 2050 are calculated by multiplying the nameplate capacities given by the capacity factors for each generator and world region the country resides in (Table S3) [14] and by the estimated 2050 transmission/distribution efficiency (98.5% for roof PV, 97% for solar thermal, and 92.5% for all other generators). Table S2 provides the countries in each grid region. The 2050 output, which is the output needed, when summed over all countries in a grid region, to keep the grid stable in the region, is the same as in Ref. 14 (e.g., columns f minus b of Table S18a of that paper). The 2050 outputs needed in each country for keeping the grid stable are, on average ~25% greater than the annual-average end-use power demand in the country, which are provided in Table S4a of Ref. 14. The year by which each country can reach 100% WWS is calculated as the year 2024 or 2025 plus the difference of 100% and the percent WWS already achieved in either 2024 or 2025, from column (n), all divided by the 2023-to-2024 (for 2024 numbers) or 2024-to-2025 (for 2025 numbers) growth rates of WWS output from column (n). If the growth rate is less than or equal to zero or results in a project transition year greater than 2350, the year 2350+ is used. The 2025 values for the 150-country totals include additions from only China, India, and the U.S.

Table S2. The 29 world grid regions and the 150 countries within those regions treated in the grid stability study in Ref. 14.

Region	Country or Countries Within Each Region
Africa-East (8)	Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, Uganda
Africa-North (6)	Algeria, Egypt, Libya, Morocco, Niger, Tunisia
Africa-South (8)	Angola, Botswana, Eswatini, Mozambique, Namibia, South Africa, Zambia, Zimbabwe
Africa-West (11)	Benin, Cameroon, Congo, Democratic Republic of the Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Ghana, Nigeria, Senegal, Togo
Australia (1)	Australia
Canada (1)	Canada
Central America (7)	Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama
Central Asia (6)	Kazakhstan, Kyrgyz Republic, Pakistan, Tajikistan, Turkmenistan, Uzbekistan
China region (4)	China, Hong Kong, Democratic People's Republic of Korea, Mongolia
Cuba (1)	Cuba
Europe (40)	Albania, Austria, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Gibraltar, Greece, Hungary, Ireland, Italy, Kosovo, Latvia, Lithuania, Luxembourg, Macedonia, Malta, Moldova Republic, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom
Haiti region (2)	Dominican Republic, Haiti
Iceland (1)	Iceland
India region (4)	Bangladesh, India, Nepal, Sri Lanka
Israel (1)	Israel
Jamaica (1)	Jamaica
Japan (1)	Japan
Madagascar (1)	Madagascar
Mauritius (1)	Mauritius
Mideast (15)	Armenia, Azerbaijan, Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Türkiye, United Arab Emirates, Yemen
New Zealand (1)	New Zealand
Philippines (1)	Philippines
Russia region (2)	Georgia, Russia
South America-NW (9)	Bolivia, Colombia, Curacao, Ecuador, Guyana, Peru, Suriname, Trinidad and Tobago, Venezuela
South America-SE (5)	Argentina, Brazil, Chile, Paraguay, Uruguay
Southeast Asia (9)	Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Singapore, Thailand, Vietnam
South Korea (1)	Korea, Republic of
Taiwan (1)	Taiwan
United States (1)	United States

Numbers in parentheses are the number of countries in each region.

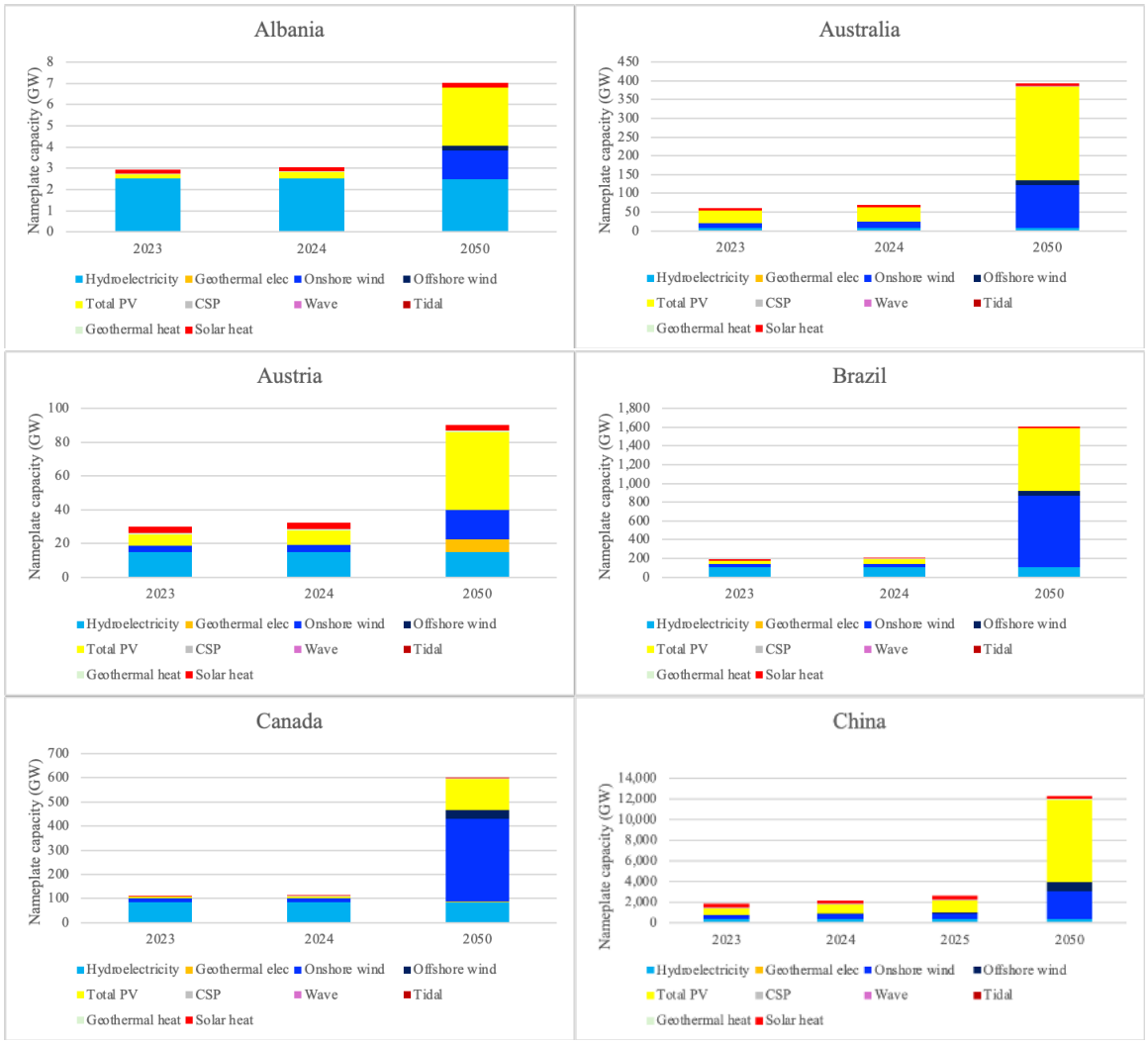
Table S3. Simulation-averaged 2050-2052 capacity factors (percentage of nameplate capacity produced as electricity before transmission, distribution, maintenance, storage, or curtailment losses) by region.

Region	Onshore wind	Off-shore wind	Roof PV	Utility PV	CSP with storage	Geo-thermal elec,	Hydro	Wave	Tidal	Solar heat	Geo-thermal heat
Africa-East	0.343	0.383	0.193	0.212	0	0.672	0.335	0.127	0.225	0	0.54
Africa-North	0.526	0.446	0.213	0.246	0	0.865	0.36	0.149	0.222	0.113	0.54
Africa-South	0.346	0.503	0.203	0.232	0.821	0.835	0.352	0.324	0.236	0.113	0.54
Africa-West	0.185	0.224	0.17	0.177	0.544	0	0.332	0.124	0.217	0.098	0.54
Australia	0.391	0.505	0.185	0.238	0	0.904	0.475	0.332	0.247	0.102	0.54
Canada	0.485	0.555	0.167	0.184	0	0.862	0.318	0.297	0.235	0.091	0.54
Central America	0.251	0.328	0.21	0.241	0	0.528	0.388	0.127	0.225	0.116	0.54
Central Asia	0.501	0.49	0.184	0.214	0.803	0	0.324	0.121	0.216	0	0.54
China region	0.439	0.437	0.185	0.217	0.735	0.896	0.496	0.139	0.244	0.102	0.54
Cuba	0.293	0.359	0.216	0.25	0	0	0.397	0.374	0.229	0	0
Europe	0.443	0.562	0.161	0.183	0.776	0.58	0.425	0.192	0.24	0.088	0.54
Haiti region	0.337	0.477	0.222	0.251	0	0.532	0.404	0	0.231	0	0
Iceland	0.493	0	0	0	0	0.925	0.559	0	0.26	0	0.54
India region	0.321	0.394	0.187	0.225	0.794	0.857	0.445	0.133	0.233	0.105	0.54
Israel	0.387	0.343	0.218	0.252	0.914	0	0.504	0	0.252	0.121	0.54
Jamaica	0.299	0.489	0.228	0.263	0	0	0.36	0	0.203	0	0
Japan	0.378	0.468	0.161	0.183	0	0.909	0.478	0.141	0.249	0.088	0.54
Madagascar	0.242	0.381	0.198	0.229	0	0	0.376	0.147	0.252	0	0.541
Mauritius	0.499	0.531	0.201	0.224	0	0	0.484	0.337	0.265	0.112	0
Mideast	0.471	0.417	0.203	0.226	0.809	0.798	0.453	0.136	0.235	0.108	0.54
New Zealand	0.483	0.562	0.173	0.199	0	0.885	0.466	0.355	0.243	0.095	0.54
Philippines	0.28	0.385	0.219	0.247	0	0.858	0.451	0.133	0.234	0	0.54
Russia region	0.48	0.603	0.151	0.185	0	0.863	0.344	0.256	0.236	0.083	0.54
South Am-NW	0.132	0.412	0.201	0.226	0.814	0.571	0.471	0.166	0.232	0	0.54
South Am-SE	0.188	0.444	0.205	0.224	0.788	0.872	0.458	0.148	0.238	0.114	0.54
Southeast Asia	0.11	0.22	0.187	0.203	0	0.878	0.432	0.18	0.234	0.109	0.54
South Korea	0.325	0.464	0.161	0.165	0	0	0.485	0	0.251	0.088	0.54
Taiwan	0.287	0.389	0.183	0.203	0	0.269	0.489	0.144	0.255	0.101	0.54
United States	0.371	0.307	0.192	0.212	0.849	0.891	0.275	0.294	0.244	0.102	0.54
Average	0.381	0.366	0.187	0.212	0.782	0.61	0.43	0.162	0.239	0.102	0.54

Data from Ref. 14. Capacity factors of offshore and onshore wind turbines account for array losses (extraction of kinetic energy by turbines). Capacity factors are determined before transmission, distribution, maintenance, storage, or curtailment losses. A zero indicates no installation of the technology. Roof PV panels are fixed-tilt at the optimal tilt angle of the country they reside in; utility PV panels are half fixed optimal tilt and half single-axis horizontal tracking.

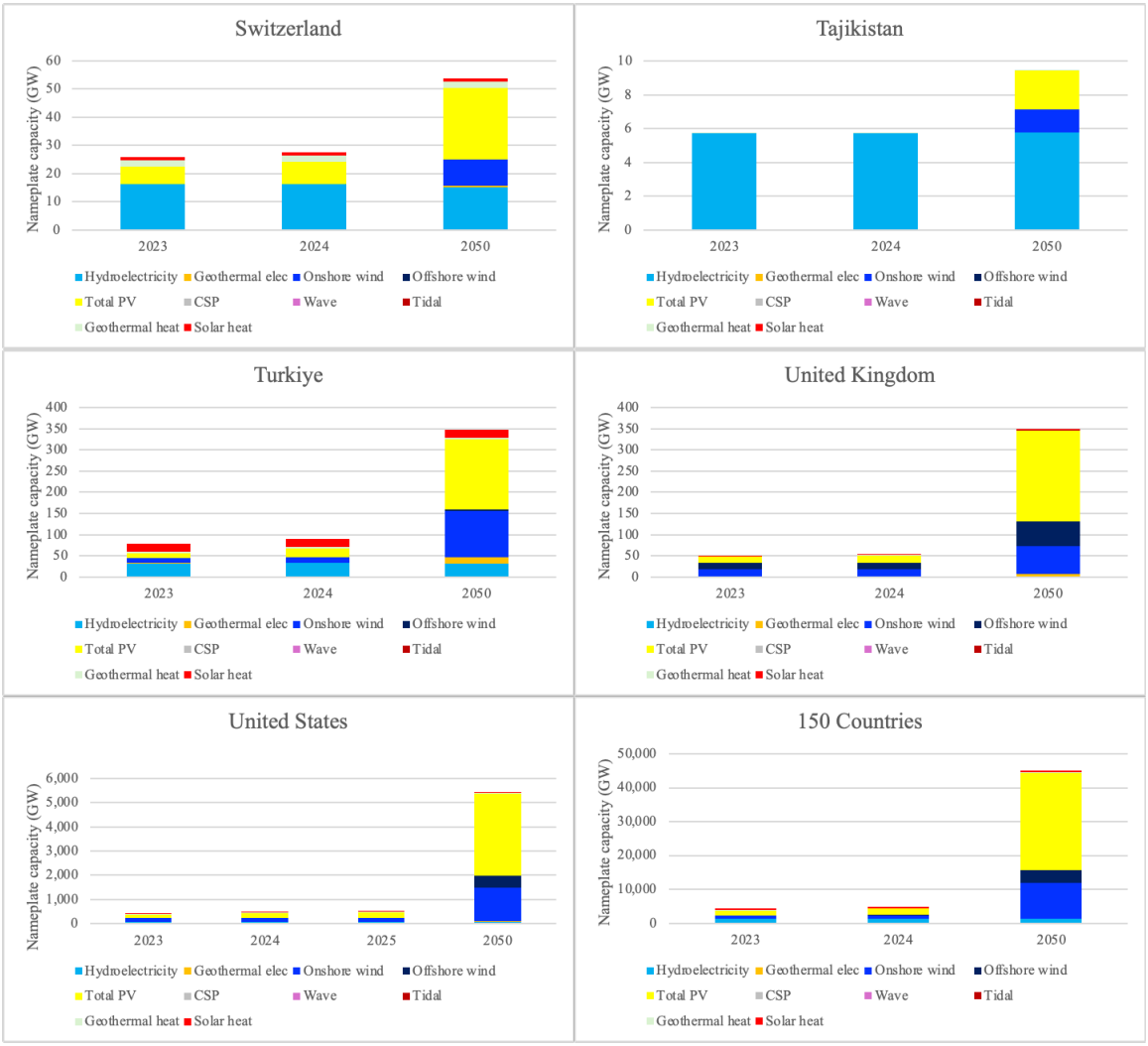
Supplementary Figure

Figure S1. Comparison, for selected countries, of estimated 2050 WWS nameplate capacities needed to power 100% of all-sector energy demand with WWS after electrification of all energy sectors, and accounting for grid stability, with actual WWS nameplate capacities installed in 2023, 2024, and (for China, the U.S., and India) 2025. Data from Table S1.




Denmark
Nameplate capacity (GW)
0
10
20
30
40
50
60
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Estonia
Nameplate capacity (GW)
0
2
4
6
8
10
12
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Germany
Nameplate capacity (GW)
0
100
200
300
400
500
600
700
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Greece
Nameplate capacity (GW)
0
10
20
30
40
50
60
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Iceland
Nameplate capacity (GW)
0
1
2
3
4
5
6
7
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
India
Nameplate capacity (GW)
0
1,000
2,000
3,000
4,000
5,000
6,000
2023
2024
2025
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Japan
Nameplate capacity (GW)
0
100
200
300
400
500
600
700
800
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Laos
Nameplate capacity (GW)
0
2
4
6
8
10
12
14
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat


Lithuania
Nameplate capacity (GW)
0
5
10
15
20
25
30
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Macedonia
Nameplate capacity (GW)
0
2
4
6
8
10
12
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
New Zealand
Nameplate capacity (GW)
0
10
20
30
40
50
60
70
80
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Norway
Nameplate capacity (GW)
0
10
20
30
40
50
60
70
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Paraguay
Nameplate capacity (GW)
0
2
4
6
8
10
12
14
16
18
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Portugal
Nameplate capacity (GW)
0
10
20
30
40
50
60
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Spain
Nameplate capacity (GW)
0
50
100
150
200
250
300
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Sweden
Nameplate capacity (GW)
0
20
40
60
80
100
120
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat


Switzerland
Nameplate capacity (GW)
60
50
40
30
20
10
0
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Tajikistan
Nameplate capacity (GW)
10
8
6
4
2
0
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
Turkiye
Nameplate capacity (GW)
400
350
300
250
200
150
100
50
0
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
United Kingdom
Nameplate capacity (GW)
400
350
300
250
200
150
100
50
0
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
United States
Nameplate capacity (GW)
6,000
5,000
4,000
3,000
2,000
1,000
0
2023
2024
2025
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat
150 Countries
Nameplate capacity (GW)
50,000
40,000
30,000
20,000
10,000
0
2023
2024
2050
Hydroelectricity
Geothermal elec
Onshore wind
Offshore wind
Total PV
CSP
Wave
Tidal
Geothermal heat
Solar heat