International Renewable Energy Agency

FUTURE OF WIND

Deployment, investment, technology, grid integration and socio-economic aspects

Executive summary

A Global Energy Transformation paper

OCTOBER 2019

EXECUTIVE SUMMARY

DECARBONISATION OF THE ENERGY SECTOR AND THE REDUCTION OF CARBON EMISSIONS TO LIMIT CLIMATE CHANGE IS AT THE HEART OF THE INTERNATIONAL RENEWABLE ENERGY AGENCY (IRENA)'S ENERGY TRANSFORMATION ROADMAPS. These roadmaps examine and provide an assertive yet technically and economically feasible pathway for the deployment of low-carbon technology towards a sustainable and clean energy future.

IRENA HAS EXPLORED TWO ENERGY DEVELOPMENT PATHWAYS TO THE YEAR 2050 AS PART OF THE 2019 EDITION OF ITS GLOBAL ENERGY TRANSFORMATION REPORT. The first is an energy pathway set by current and planned policies (Reference Case). The second is a cleaner climate-resilient pathway based largely on more ambitious, yet achievable, uptake of renewable energy and energy efficiency measures (REmap Case), which limits the rise in global temperature to well below 2 degrees and closer to 1.5 degrees above pre-industrial levels and is aligned within the envelope of scenarios presented in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C.

THIS REPORT OUTLINES THE ROLE OF WIND POWER IN THE TRANSFORMATION OF THE GLOBAL ENERGY SYSTEM BASED ON IRENA'S CLIMATE-RESILIENT PATHWAY (REMAP CASE), specifically the growth in wind power deployments that would be needed in the next three decades to achieve the Paris climate goals.

KEY FINDINGS:

- **ACCELERATED DEPLOYMENT OF RENEWABLES, COMBINED WITH DEEP ELECTRIFICATION AND INCREASED ENERGY EFFICIENCY, CAN ACHIEVE OVER 90% OF THE ENERGY-RELATED CARBON DIOXIDE (CO_2) EMISSIONS REDUCTIONS NEEDED BY 2050 TO SET THE WORLD ON AN ENERGY PATHWAY TOWARDS MEETING THE PARIS CLIMATE TARGETS.** Among all low-carbon technology options, accelerated deployment of wind power when coupled with deep electrification would contribute to more than one-quarter of the total emissions reductions needed (nearly 6.3 gigatonnes of carbon dioxide (Gt CO_2) annually) in 2050.

- **ACHIEVING THE PARIS CLIMATE GOALS WOULD REQUIRE SIGNIFICANT ACCELERATION ACROSS A RANGE OF SECTORS AND TECHNOLOGIES**. Wind power, along with solar energy, would lead the way for the transformation of the global electricity sector. Onshore and offshore wind would generate more than one-third (35%) of total electricity needs, becoming the prominent generation source by 2050.

- **SUCH A TRANSFORMATION IS ONLY POSSIBLE BY GREATLY SCALING UP WIND CAPACITY INSTALLATIONS IN THE NEXT THREE DECADES**. This entails increasing the global cumulative installed capacity of onshore wind power more than three-fold by 2030 (to 1 787 gigawatts (GW)) and nine-fold by 2050 (to 5 044 GW) compared to installed capacity in 2018 (542 GW). For offshore wind power, the global cumulative installed capacity would increase almost ten-fold by 2030 (to 228 GW) and substantially towards 2050, with total offshore installation nearing 1 000 GW by 2050.

- **THE WIND INDUSTRY WOULD NEED TO BE PREPARED FOR SUCH A SIGNIFICANT GROWTH IN THE WIND MARKET OVER THE NEXT THREE DECADES.** Annual capacity additions for onshore wind would increase more than four-fold, to more than 200 GW per year in the next 20 years, compared to 45 GW added in 2018. Even higher growth would be required in annual offshore wind capacity additions – around a ten-fold increase, to 45 GW per year by 2050 from 4.5 GW added in 2018.

- **AT A REGIONAL LEVEL, ASIA WOULD LARGELY DRIVE THE PACE OF WIND CAPACITY INSTALLATIONS, BECOMING THE WORLD LEADER IN WIND ENERGY**. Asia (mostly China) would continue to dominate the onshore wind power industry, with more than 50% of global installations by 2050, followed by North America (23%) and Europe (10%). For offshore wind, Asia would take the lead in the coming decades with more than 60% of global installations by 2050, followed by Europe (22%) and North America (16%).

- **SCALING UP WIND ENERGY INVESTMENTS IS KEY TO ACCELERATING THE GROWTH OF GLOBAL WIND POWER INSTALLATIONS OVER THE COMING DECADES**. This would imply increasing global average annual onshore wind power investments by more than two-fold from now until 2030 (USD 146 billion/year) and more than three-fold over the remaining period to 2050 (USD 211 billion/year) compared to 2018 investments (USD 67 billion/year). For offshore wind, global average annual investments would need to increase three-fold from now until 2030 (USD 61 billion/year) and more than five-fold over the remaining period to 2050 (USD 100 billion/year) compared to 2018 investments (USD 19 billion/year).

- **INCREASING ECONOMIES OF SCALE, MORE COMPETITIVE SUPPLY CHAINS AND FURTHER TECHNOLOGICAL IMPROVEMENTS WILL CONTINUE TO REDUCE THE COSTS OF WIND POWER**. Globally, the total installation cost of onshore wind projects would continue to decline in the next three decades with the average cost falling in the range of USD 800 to 1 350 per kilowatt (kW) by 2030 and USD 650 to 1 000/kW by 2050, compared to the global-weighted average of USD 1 497/kW in 2018. For offshore wind projects, the average total installation cost would further drop in coming decades to between USD 1 700 and 3 200/kW by 2030 and between USD 1 400 and 2 800/kW by 2050.

  The levelised cost of electricity (LCOE) for onshore wind is already competitive compared to all fossil fuel generation sources and is set to decline further as installed costs and performance continue to improve. Globally, the LCOE for onshore wind will continue to fall from an average of USD 0.06 per kilowatt-hour (kWh) in 2018 to between USD 0.03 to 0.05/kWh by 2030 and between USD 0.02 to 0.03/kWh by 2050. The LCOE of offshore wind is already competitive in certain European markets (for example, Germany, the Netherlands with zero-subsidy projects, and lower auction prices). Offshore wind would be competitive in other markets across the world by 2030, falling in the low range of costs for fossil fuels (coal and gas). The LCOE of offshore wind would drop from an average of USD 0.13/kWh in 2018 to an average between USD 0.05 to 0.09/kWh by 2030 and USD 0.03 to 0.07/kWh by 2050.

- **ONGOING INNOVATIONS AND TECHNOLOGY ENHANCEMENTS TOWARDS LARGER-CAPACITY TURBINES AS WELL AS INCREASED HUB HEIGHTS AND ROTOR DIAMETERS HELP IMPROVE YIELDS FOR THE SAME LOCATION**. The ongoing increase in wind turbine size for onshore applications is set to continue, from an average of 2.6 megawatts (MW) in 2018 to 4 to 5 MW for turbines commissioned by 2025. For offshore applications, the largest turbine size of around 9.5 MW today will soon be surpassed, with expectations that projects to be commissioned in 2025 would comprise of turbines with ratings of 12 MW and above (although some legacy projects with long lead times may have lower ratings). Research and development will likely lead to a potential to increase this to 15 to 20 MW in a decade or two.

  The combination of improved wind turbine technologies, deployment of higher hub heights and longer blades with larger swept areas leads to increased capacity factors for a given wind resource. For onshore wind plants, global weighted average capacity factors would increase from 34% in 2018 to a range of 30% to 55% in 2030 and 32% to 58% in 2050. For offshore wind farms, even higher progress would be achieved, with capacity factors in the range of 36% to 58% in 2030 and 43% to 60% in 2050, compared to an average of 43% in 2018.

- **TECHNOLOGICAL DEVELOPMENTS IN WIND TURBINE FOUNDATIONS ARE A KEY FACTOR ENABLING THE ACCELERATED DEPLOYMENT OF OFFSHORE WIND, PERMITTING ACCESS TO BETTER WIND RESOURCES**. Floating foundations are potentially a "game-changing" technology to effectively exploit abundant wind potential in deeper waters and thus could lead the way for rapid future growth in the offshore wind power market. By 2030, industry experts estimate that around 5 GW to 30 GW of floating offshore capacity could be installed worldwide and that, based on the pace of developments across various regions, floating wind farms could cover around 5% to 15% of the global offshore wind installed capacity (almost 1 000 GW) by 2050.

- **TECHNOLOGICAL SOLUTIONS ACCOMPANIED BY ENABLING MARKET CONDITIONS AND INNOVATIVE BUSINESS MODELS, ARE ESSENTIAL TO PREPARE FUTURE POWER GRIDS TO INTEGRATE RISING SHARES OF WIND POWER**. To effectively manage large-scale variable renewable energy sources, flexibility must be harnessed in all sectors of the energy system, from power generation to transmission and distribution systems, storage (both electrical and thermal) and increasingly flexible demand (demand side management and sector coupling). Globally, to integrate 60% variable renewable generation (35% from wind) by 2050 as is envisioned in the REmap Case, average annual investments in grids, generation adequacy and some flexibility measures (e.g. storage) would need to rise by more than one-quarter to USD 374 billion/year, compared to investments made in electricity networks and battery storage in 2018 of USD 297 billion/yr.

- **IF ACCOMPANIED BY SOUND POLICIES, THE TRANSFORMATION CAN BRING SOCIO-ECONOMIC BENEFITS**. The wind industry can employ 3.74 million people by 2030 and more than 6 million people by 2050, a figure nearly three times higher and five times higher respectively than the 1.16 million jobs in 2018. To maximise outcomes of the energy transition, however, a holistic policy framework is needed. Deployment policies will need to co-ordinate and harmonise with integration and enabling policies. Under the enabling policy umbrella, particular focus is needed on industrial, labour, financial, education and skills policies to maximise the transition benefits. Education and skills policies can allow for the retention and reallocation of existing expertise in the oil and gas sector to support the installation of offshore wind foundation structures. Similarly, sound industrial and labour policies that build upon domestic supply chains can enable income and employment growth by leveraging existing economic activities in support of wind industry development.

- **UNLEASHING THE MASSIVE POTENTIAL OF WIND IS CRUCIAL TO ACHIEVE THE PARIS CLIMATE TARGETS**. This is only possible by mitigating the existing barriers at different scales (technology, economic, socio-political and environmental) that could hinder the deployment of wind capacities in the next three decades. Grid access, public acceptance, planning procedures and planning uncertainties, economies of scale, access to finance, subsidies for traditional energy are among the key barriers. Mitigating the existing barriers immediately, through a range of supportive policies and implementation measures including innovative business models, financial instruments is vital to boost future deployment of wind capacities to enable the transition to a low-carbon, sustainable energy future.

Figure ES 1. Wind roadmap to 2050: tracking progress of key wind energy indicators to achieve the global energy transformation.

CO_2 EMISSIONS (ENERGY-RELATED) AND REDUCTION POTENTIAL BY WIND POWER

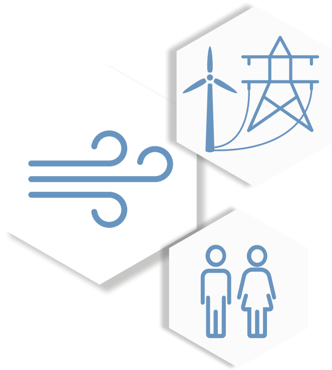
	2010	2018	2030	2050	ON/OFF TRACK
Energy-related CO_2 emissions under current plans and planned policies (Reference Case) (Gt CO_2/yr)	29.7	34.5	35	33.1	
Energy-related CO_2 emissions under IRENA's climate resilient pathway (REmap Case) (Gt CO_2/yr)	29.7	34.5	24.9	9.8	Off track
Avoided emissions due to accelerated deployment of wind power coupled with deep electrification (Gt CO_2/yr)				6.3	

	2010	2018	REMAP CASE 2030	REMAP CASE 2050	ON/OFF TRACK
WIND POWER IN TOTAL GENERATION MIX					
Onshore and offshore wind generation share (%)	1.7%	6%	21%	35%	Progress
TOTAL INSTALLED CAPACITY					
Onshore wind (GW)	178	542	1 787	5 044	Off track
Offshore wind (GW)	3	23	228	1 000	Progress
ANNUAL DEPLOYMENT*					
Onshore wind (GW/yr)	30	45	147	202	Off track
Offshore wind (GW/yr)	0.9	4.5	28	45	Progress

	2010	2018	REMAP CASE 2030	REMAP CASE 2050	ON/OFF TRACK
TOTAL INSTALLATION COST					
Onshore wind (USD/kW)	1 913 (average)	1 497 (average)	800 – 1 350 (average range)	650 – 1 000 (average range)	On track
Offshore wind (USD/kW)	4 572 (average)	4 353 (average)	1 700 – 3 200 (average range)	1 400 – 2 800 (average range)	Progress
LEVELISED COST OF ELECTRICITY (LCOE)					
Onshore wind (USD/kWh)	0.08 (average)	0.06 (average)	0.03 – 0.05 (average range)	0.02 – 0.03 (average range)	On track
Offshore wind (USD/kWh)	0.16 (average)	0.13 (average)	0.05 – 0.09 (average range)	0.03 – 0.07 (average range)	Progress
AVERAGE ANNUAL INVESTMENT					
Onshore wind (USD billion/yr)	57	67	146	211	Off track
Offshore wind (USD billion/yr)	4.2	19.4	61	100	Progress
CAPACITY FACTORS					
Onshore wind (%)	27 (average)	34 (average)	30 – 55 (average range)	32 – 58 (average range)	Progress
Offshore wind (%)	38 (average)	43 (average)	36 – 58 (average range)	43 – 60 (average range)	On track
EMPLOYMENT					
Onshore and offshore wind (million)	0.75**	1.12	3.74	6.06	Off track

* The data includes new capacity additions and replacement of end-of-lifetime capacity

**The data denotes wind sector jobs by 2012



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