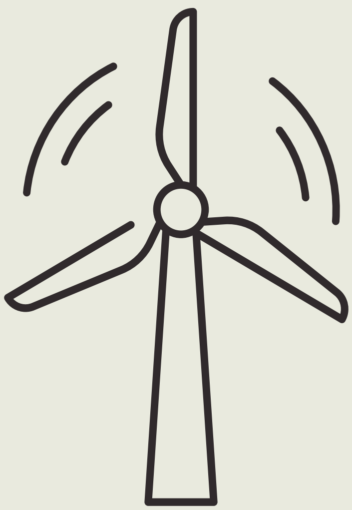
Global Innovation Needs Assessment

Wind power

October 12, 2021



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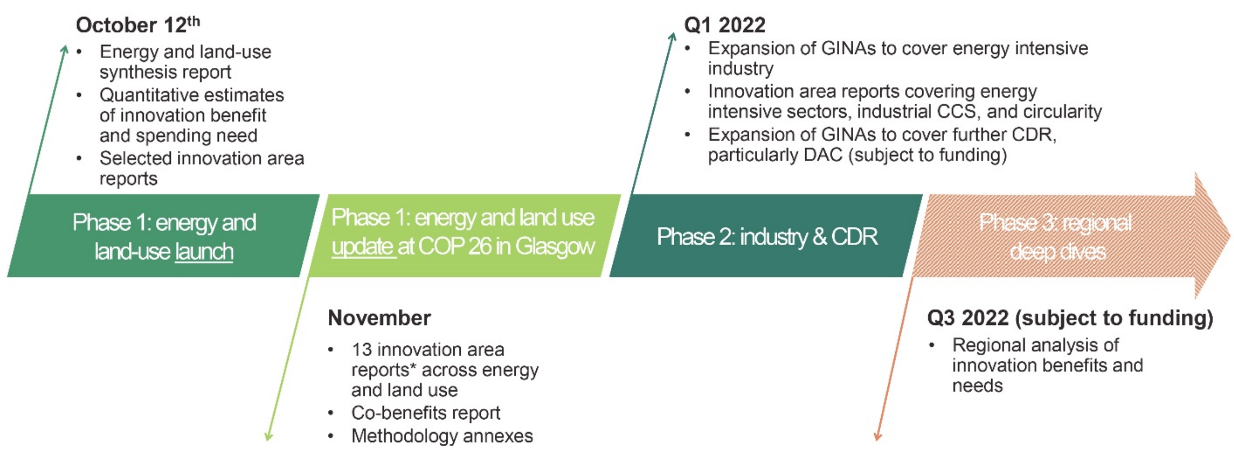
The findings and views expressed across this project do not necessarily reflect the views of the ClimateWorks Foundation, the Government of the United Kingdom, or Mission Innovation.

The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) is a first of a kind platform for assessing the case for low carbon innovation. The GINAs take a system wide perspective, explicitly modelling the impact of innovations across the global economy. Uniquely, the analysis quantifies the economic benefits of low carbon innovation and identifies the public investment levels — from research and development to commercialization — needed to unlock these benefits. The analysis is divided into 3 Phases: Phase 1 on global energy and land use, Phase 2 on global industry, and Phase 3 on regional deep dives. This synthesis report forms part of Phase 1.

The analyses do not assess all relevant technologies, nor do they evaluate all relevant factors for policy judgements. Instead, the work is intended to provide a novel evidence base to better inform policy decisions. The Phase 1 analysis looks across a broad range of climate mitigation technologies in energy and land-use, ranging from demand response to protein diversification, to model the economic value of related innovation investment. Later phases expand the research. As with all technologies, there are risks and potential downsides to their adoption, and some remain controversial. Which innovations to invest in is ultimately a policy judgement, and this analysis does not provide policy recommendations to invest in any specific technologies.

Phases of the Global Innovation Needs Assessments



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Phase 1 GINA outputs

The suite of reports across innovation areas methodological annexes and a synthesis report for GINAs are available on the GINA website at: https://www.climateworks.org/report/ginas/.

The suite of outputs for Phase 1 of the Global Innovation Needs Assessments

1. **Energy and land use synthesis report –** *slide based summary for policymakers and executives*
   Synthesis of the findings across the innovations considered in energy and land use

2. **Energy and land use & agriculture innovation reports –** *in depth quantitative analysis for industry and policy analysts*

   - **Wind power** – Offshore and onshore wind turbines
   - **Low carbon hydrogen** – Electrolysers and gas reforming with CCS
   - **Solar power** – Utility-scale and distributed PV
   - **Low carbon fuels** – 2nd generation biofuels, synthetic fuels (H_2 + CO_2)
   - **Nuclear power** – Small modular and large-scale advanced reactors
   - **System flexibility** – Battery storage, power-to-X, demand response
   - **Buildings** – Heat pumps, building fabric
   - **Power CCS** – CCS in power generation (coal, gas and biomass)
   - **Zero-carbon road transport** – Battery electric vehicles, fuel cell electric vehicles
   - **Protein diversity** – Replacement food and novel vegan food
   - **Decarbonizing agrochemical inputs** – Innovative fertilisers and pesticides
   - **Yield enhancing technologies** – Digital agriculture and vertical farming
   - **Irrigation** – Improved irrigation methods and systems

   The selected innovation areas were selected for their potential for further innovation and the potential magnitude of the associated system benefits. Their selection here is because they could play a key role in a net zero pathway but does not imply that an optimal net zero pathway necessarily includes them. Further notes on the rationale behind their selection is provided in the methodology annex on the GINA website

3. **Co-benefits of innovation report –** *qualitative analysis of the environmental and other non-economic benefits of net-zero innovation*
4. **European case study –** *Analysis of jobs and growth benefits in Europe specifically*
5. **Methodology annex–** *A description of the modelling approach taken for analysts*

Executive Summary

Wind power is vital to decarbonizing the global energy system as electricity becomes an ever-larger share of final energy demand. Wind power, which includes onshore wind (698 GW in 2020) and offshore wind (34 GW in 2020), currently supplies about 5.9% of global electricity.(1) Modelling scenarios consistent with 1.5°C warming indicate that this share needs to increase to about 32%-41% by 2050, requiring between 7,000GW and 10,000GW of wind power capacity in total.(2,3) Onshore wind is already the cheapest source of electricity in many locations, including North America, the UK, Brazil, and Poland.(4) Offshore wind is relatively expensive but has become competitive against fossil fuel power generation. In both onshore and offshore wind, further commercialization remains crucial to bring improved technologies to market and scale up rapidly.

Stronger innovation and commercialization could reduce the cost of onshore and offshore wind further by around 40% and 50%, respectively by 2050. Wind power is a capital-intensive industry, with upfront capex representing about 73% of lifetime costs for onshore wind and up to 77% for offshore wind.[1] There are multiple ways to reduce the costs of wind power, primarily through increases in turbine size (MW per turbine), alongside large blades and higher hub heights that improve capacity factors. Other improvements in areas such as floating foundations and two-piece blades could further improve its deployment potential. However, RD&D alone is not sufficient. Commercialization is vital to help the latest technologies scale-up and drive down deployment costs in the market.

This could reduce global energy system costs by $260 billion per year (3% of total) on average between now and 2050. The supply of cheaper, low-carbon electricity in greater quantities would reduce the cost of decarbonization in industry, transport, and buildings, where electrification is a key method for reducing emissions. By 2050, the (undiscounted) value of cost savings could reach $400 billion per year. The discounted cumulative benefits between now and 2050 reach a total of $13 trillion.

To unlock these substantial public benefits, public commercialization spending needs to double, while public RD&D spending can be sustained at current levels. While wind energy is a mature supply chain, the private sector alone is unlikely to invest in innovation at a pace and scale to maximize benefits in a net zero transition given positive externalities and various market barriers (e.g., uncertainty in electricity prices under changing electricity market regimes). Targeted public spending can alleviate these barriers and mobilize further private investment. Between 2021 and 2030, the high-innovation scenario in this report suggests that governments could spend around $11 billion per year on the commercialization of wind power to maximize benefits. Annual public spending on RD&D meanwhile, would average at $5 billion per year, which is three times the current levels.[2] Government spending should complement a broader package of market pull policies to deploy wind power at an accelerated timescale. In particular, robust carbon pricing, simpler permitting processes, electricity sector reforms, and

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[1] Based on cost assumptions compiled from the literature, assuming 5% interest rate
[2] Global annual public RD&D spending on wind power is estimated to be $1.2 billion per year, based on the IEA RD&D database and additional records for non-IEA countries. (16,17)

coal phase-out could all help pull deployment of wind power forward, reducing the cost of public commercialization spending.

Private investments in innovation can help companies secure a share of this large and growing market, with annual investments in wind power projected to triple and reach $430 billion by 2050. The direct GVA in construction and operation of wind farms could represent $220 billion per year by 2050, of which around 70% is attributed to onshore wind. Within this entire supply chain, the most high-value and trade-exposed economic activities lie in the manufacturing of wind turbines. A large share of the value lies with the OEMs because wind turbines represent the largest share of upfront capital expenditure for both onshore wind (69%) and offshore wind (38%) projects. Overall, the wind industry could directly employ 2.3 million workers each year by 2050, supporting the local economy while reaping the benefits of innovation.

Public benefits (i.e., energy system cost savings)	Cumulative 2021-50, undiscounted: $8 trillion Cumulative 2021-50, discounted at 5% p.a.: $3 trillion Annual average 2021-50, undiscounted: $260 billion
Business opportunities	2035: $180 billion GVA, 2.2 million direct jobs 2050: $220 billion GVA, 2.3 million direct jobs
Public spending required	Commercialization, annual average 2021-35: $11 billion RD&D, annual average 2021-35: $5 billion

1. Wind power and the energy system

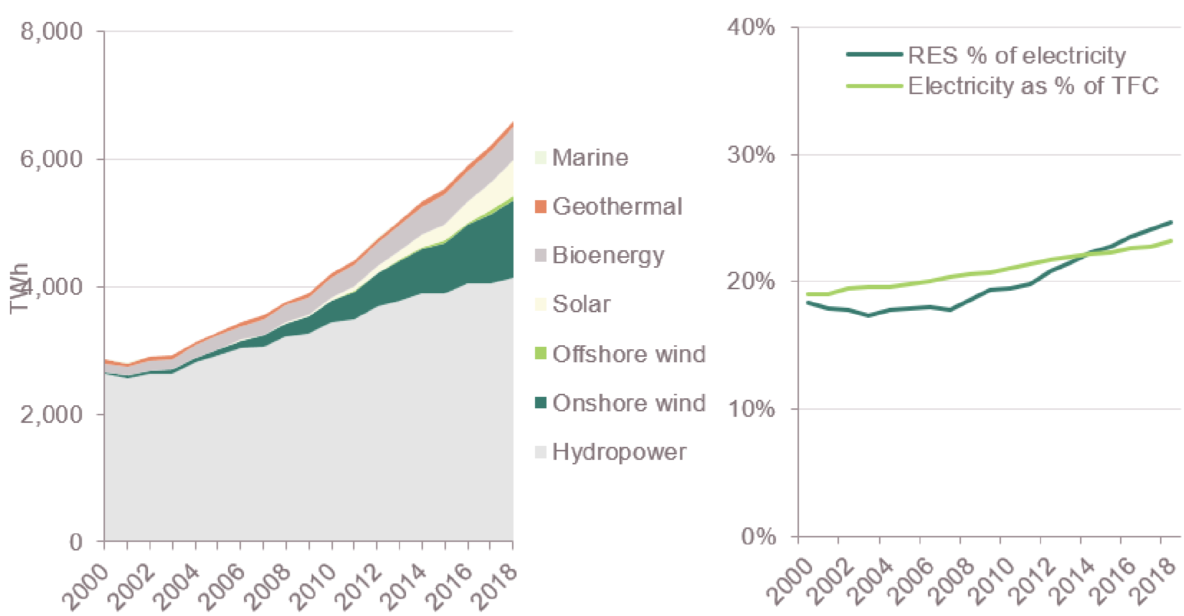
1.1. Current role in the energy system

Low-carbon electricity is a key lever to decarbonizing the global economy, with renewable energy such as wind power playing an important role. Currently, the power sector is responsible for 13 $GtCO_2$ of carbon dioxide emissions, which is around 30% of global GHG emissions. These emissions mainly come from the combustion of coal and gas for power generation. Shifting the power sector towards renewable energy sources (RES) is the primary way to mitigate emissions.

Wind power current meets a relatively small fraction of our energy needs (1.1% of final energy consumption and 5.9% of electricity generation) but is a rapidly growing and relatively mature industry. Renewable electricity has traditionally been supplied mainly by hydropower, which is relatively expensive and constrained by availability of suitable sites. Alongside solar power, wind power became leading source for low-carbon electricity at a relatively low cost, even becoming competitive against traditional fossil fuel power in many locations. The costs of electricity from onshore wind on average has fallen to $40/MWh by 2020, while offshore wind remains more expensive at around $84/MWh.(4) Nevertheless, offshore wind has higher capacity factors and is already cost-competitive against fossil fuel power in many markets.

- Onshore wind: mature technology with extensive global supply chains. Installed capacity reached 698GW in 2020 with an annual growth rate of 12% between 2015 and 2020.(5)
- Offshore wind: high-growth technology that has greater potential for cost reductions. Installed capacity reached 34GW in 2020 with an annual growth rate of 24% between 2015 and 2020. (5)

Figure 1 Global electricity generation from renewable energy sources (RES), 2000-18



Source: Vivid Economics based on IRENA and IEA(2,6)

1.2. Future role and deployment potential

To enable decarbonization of end-use sectors, global electricity demand is expected to more than double by 2050 and wind power will be critical to meeting this increase in demand. All end-use sectors, including industry, buildings, and transport, are expected to decarbonize partly via electrification of existing energy use. Renewables will play a vital role in supplying low-carbon electricity in all major economies by 2050.

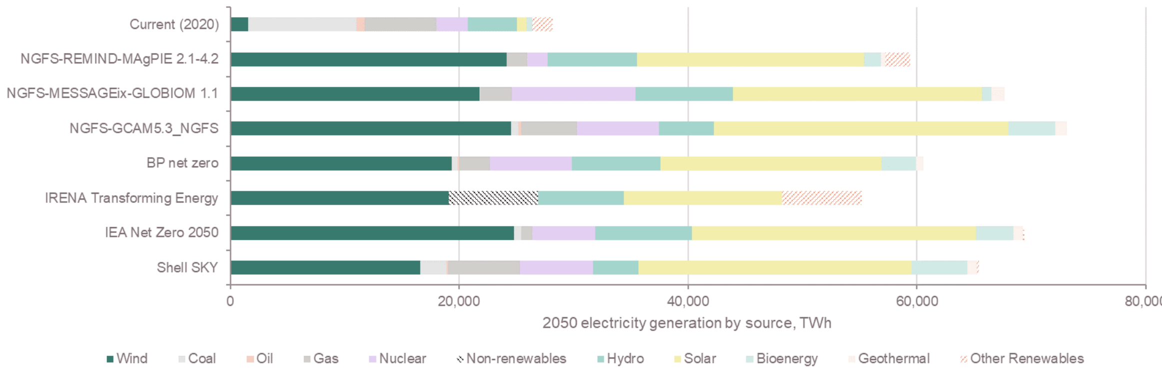
Amongst scenarios that limit global warming to 1.5°C, wind power generation increases to supply 32-41% of global electricity by 2050, up from 5.9% today. Figure 2 below displays the 2050 electricity mix from a range of selected scenarios compatible with the Paris Agreement.[3] The scenarios vary in terms of the pace at which global emissions decline, as well as the relative size of mitigations across sectors and energy sources. Despite these differences, wind power is clearly one of the major driving forces for power sector decarbonization across all scenarios. On average, annual wind power generation grows from 1,400 TWh currently towards 22,000 TWh by 2050, meeting 35% of total electricity demand.

Under such scenarios, installed capacity for wind power would grow by 230-290 GW per year on average between 2020 and 2050, more than doubling the current build rate of 110 GW in 2020. This requires significant growth in the entire supply chain, as 2020 was already the year with the fastest build rate on record for wind power. Over 90% of capacity additions in the future are projected to be in onshore wind rather than offshore wind due to its lower cost and commercial viability in more geographies.

The significant scale of wind power in the future means that even relatively small innovations can significantly reduce energy system costs. Innovations in wind power would allow it to provide low-carbon electricity in more locations, displacing coal- and gas-fired power generation more rapidly. This will provide cheaper, low-carbon electricity in greater quantities to end-use sectors. As wind power could provide between 32% and 41% of global electricity in 2050, even minor cost reductions will represent substantial benefits to the energy system. The different channels through which innovation in wind power can benefit the broader energy system are explored in greater detail in Section 3.1.

[3] Shell Sky and IRENA Transforming Energy Scenario are ‘Below 2 Degrees’ scenarios. The other scenarios shown are ‘1.5°C’ scenarios, generally featuring net zero emissions between 2050 and 2060.

Figure 2 Electricity generation by source in 2050 across selected scenarios compared to current levels



Source: Vivid Economics based on IEA, IRENA, BP, Shell, and NGFS scenarios (2,3,6–8)

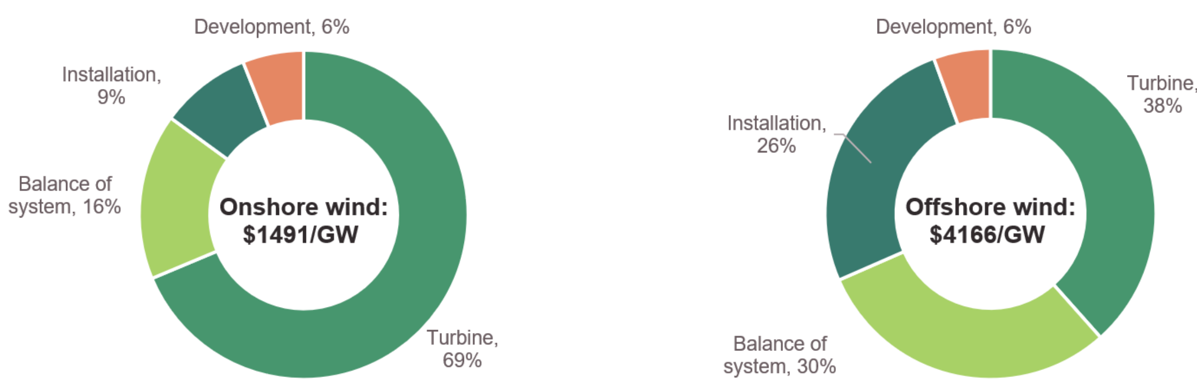
2. Innovation opportunities

2.1. Costs and deployment barriers

Commercialization of wind power and its latest innovations are affected by high-investment costs and other deployment barriers. Wind power is already known to be one of the cheapest sources of electricity in countries with relatively abundant wind resources. However, high upfront investment costs, as well as the lack of developed supply chains, market frameworks and policy support in some markets, have slowed down the process of commercialization. As a result, demonstrated technologies such as larger turbines and floating offshore wind take longer to reach scale in the market.

Reductions in initial capital expenditure, and particularly the turbine component, have the largest potential to lower the lifetime costs of a wind farm. Recent cost estimates suggest that the upfront capex accounts for about 70-80% of the levelized cost of electricity (LCOE) of both onshore and offshore wind projects, with the remainder being decommissioning costs and fixed operational expenditure (opex, both operations and maintenance).(9,10) Within the upfront capex, wind turbines are the most expensive component in constructing wind farms, representing 69% of onshore wind capex and 38% of offshore wind capex. Cost reductions in wind turbines therefore have the greatest potential to lower the costs of wind power. Capital expenditure per MW for offshore wind is about 170% more costly than onshore wind, due to additional costs for offshore foundations, cables, and installation processes. Offshore wind also has higher fixed operating costs due to the logistical requirements for offshore activities. The breakdown of onshore wind and offshore wind upfront capex is shown below in Figure 3.

Figure 3 Breakdown of upfront capital expenditure of wind power – current estimates



Source: Vivid Economics

Other deployment barriers also need to be addressed to in scaling up wind power:

- **Output variability:** Wind energy is intermittent and its LCOE depends crucially on its capacity factor in addition to its capex. Turbine designs to increase capacity factors would allow wind power to be deployed in locations with lower wind speeds. Higher capacity factors will also address doubts from some stakeholders regarding the reliability of wind energy.

- **Difficulties in grid integration:** Offshore electricity transmission is often costly, preventing offshore wind deployment further away from shore in deeper waters. The lack of energy storage on the grid also leads to the curtailment of wind power, affecting the return on investment for project developers.

2.2. Key innovations

Stronger innovation in wind technologies could lead to further cost reductions of 37% for onshore wind and 47% for offshore wind by 2050.[4] Table 1 below summarizes the 2020 cost estimates for both technologies, alongside 2050 estimates under the high- and low-innovation scenarios.[5] The scenarios are constructed from an extensive review of cost reduction studies for onshore and offshore wind.[6] There is some cost reduction even in the low-innovation scenario due to market-driven technological improvements and commercialization in the near term. The high-innovation scenario sees additional cost reductions to 2050 both in capital and operating costs.

Table 1 Onshore and offshore wind cost assumptions under high- and low-innovation scenarios

Technology	Cost assumption	2020	2050 Low-innovation scenario	2050 High-innovation scenario	% further cost reduction under high-innovation scenario	% further LCOE reduction under high-innovation scenario
Onshore wind	Capex, $m/GW	1497	1000	650	35%	37%
	Fixed Opex, $m/GW/year	42	41	24	41%	
Offshore wind	Capex, $m/GW	4166	2800	1400	50%	47%
	Fixed Opex, $m/GW/year	95	52	33	37%	

Note: Fixed opex = operations and maintenance. LCOE reduction compares low- and high-innovation scenarios.
Source: Vivid Economics based on NREL, IRENA, IEA(11–13)

Stronger cost reductions are achieved not only by inventing new technologies, but also through commercializing technologies that are already demonstrated today. Over the past decade, the global average LCOE for onshore wind and offshore wind have already fallen by 40% and 30%, respectively, thanks to (a) reduced capital cost per MW, and (b) increased capacity factor. Experts generally agree that

[4] Refers to LCOE cost declines, assuming fixed 5% interest rate
[5] The scenarios do not explicitly identify the individual technology drivers behind cost reductions. Instead, the scenarios represent an informed judgment on the scope of cost reductions with and without government support on RD&D and commercialisation.
[6] The review surveys all existing cost reduction studies available. In this report, the high innovation scenario is comparable to the IRENA scenario with 2018-2030 LCOE reductions of 25% for onshore wind and 55% for offshore wind.

cost reductions can be achieved mainly through these two areas, as well as reduced operating costs, longer project lifetimes, and reductions in financing costs. Importantly, this expectation is not driven by speculative beliefs about technologies still under development but based on an informed understanding of the full potential of technologies that have already been demonstrated and could be commercialized to achieve scale in the coming years. Without stronger commercialization, RD&D is insufficient to yield the significant cost reductions shown under the high-innovation scenario.

The largest cost reductions could be achieved by commercializing various improvements to wind turbine technologies:

- **Larger turbine size:** the ongoing increase in turbine size will remain the key driver to lower capital costs of wind farms. The average onshore wind turbine size commissioned in 2018 was just 2.6MW, but this could already grow to 4-5MW for turbines commissioned in 2025.(12) For offshore wind turbines, the largest turbine size today is about 9.5MW, compared to about 12MW and above for those to be commissioned in 2025. Further R&D could deliver turbines up to 15MW to 20MW in the 2030s, which need to be commercialized to achieve scale.
- **Higher hub heights and longer blades:** improvements in materials and blade design are enabling taller turbines with longer blades. This increases the capacity factor of wind turbines, making them commercially viable even in areas with lower wind speeds. According to IRENA, global weighted average capacity factors for onshore wind will increase from 34% in 2018 to a range of 30-55% in 2030 and 32-58% in 2050.(12) For offshore wind farms, even higher progress would be achieved, with capacity factors in the range of 36-58% in 2030 and 43-60% in 2050, compared to an average of 43% in 2018.(1)

Commercialization of other innovative technologies could also speed up wind deployment:

- **Improved on-site manufacturing** decreases transport costs during installation and reduces the logistical challenge of deployment. Here, much of the challenge is about putting the best available technologies, processes, and infrastructure in place where large-scale deployment needs to occur.
- **Two-piece blades:** As hub heights grow taller, the increasing length of blades poses a logistical challenge that increases the cost of installations. A recent innovation overcomes this deployment barrier by manufacturing two-piece blades that can be assembled onsite. However, this technology has only been launched to the market in 2019/20 by GE Renewable Energy. Further commercialization could see this being deployed by other OEMs.
- **Floating foundations and support structures (offshore wind):** Floating foundations allow wind turbines to be installed further offshore to exploit higher wind speeds. Although the technology has been demonstrated in multiple sites in Europe, it has remained relatively expensive compared to conventional offshore wind with fixed moorings. Today, just 1% of the total installed capacity for offshore wind globally has floating foundations. Commercialization of floating offshore wind will significantly improve the deployment potential of offshore wind.
- **Long distance transmission (offshore wind):** As turbines get larger and further from shore, standard AC transmission may not be fit for purpose due to the large capex requirements, grid compliance, and transmission losses. Technical solutions such as high-voltage direct current (HVDC) subsea cables can lower costs significantly and have been demonstrated already – but progress will rely on further commercialization.

3. Benefits of innovation

3.1. Low-cost decarbonized energy

Box 1 System benefits and low-cost decarbonized energy

Lower energy costs are unlocked by the system benefits of innovation. System benefits of innovation refer to the net reduction in costs across the entire energy system as a result of stronger RD&D *and* commercialization of technologies. In the context of this report, system benefits are calculated as the difference in total system costs between a high-innovation scenario and a low-innovation scenario, where:

- System costs: all capital, operating and fuel costs within the global energy system.[7]
- Low-innovation scenario: market-driven progress under a lack of government support
- High-innovation scenario: optimistic progress where governments help drive cost reductions by supporting RD&D and deployment (i.e., commercialization)
- System costs: all capital, operating and fuel costs within the global energy system.[8]
- Low-innovation scenario: market-driven progress under a lack of government support
- High-innovation scenario: optimistic progress where governments help drive cost reductions by supporting RD&D and deployment (i.e., commercialization)
- Low-innovation scenario: market-driven progress under a lack of government support
- High-innovation scenario: optimistic progress where governments help drive cost reductions by supporting RD&D and deployment (i.e., commercialization)

This metric provides an aggregate estimate of how innovations in selected technologies can reduce system costs after least-cost optimization of all energy carriers and technologies from both the supply and demand sides.

Strong innovation in wind power could reduce annual system costs by $260 billion per year (3% of total) on average between now and 2050. In both the low- and high-innovation scenarios, global energy system costs start at around $10 trillion a year in 2021, then begin to diverge noticeably after 2025. By 2030, the (undiscounted) annual system costs in the high-innovation scenario are $130 billion lower than those in the low-innovation scenario. This gap increases steadily over time, reaching around $400 billion

[7] System benefits may be calculated on an annual basis, or cumulatively between 2020 and 2050 (with or without discounting).
[8] System benefits may be calculated on an annual basis, or cumulatively between 2020 and 2050 (with or without discounting).

by 2050. Table 2 reports the system benefits for 2021/50 in the high-innovation scenario for wind power, measured as the cost savings against that of the low-innovation scenario.

Table 2 System benefits of innovation in wind power

System benefits	2021-50, cumulative, undiscounted	2021-50, cumulative, discounted 5%	2021-50, annual average, undiscounted
High innovation in wind power	$8 trillion	$3 trillion	$260 billion

Note: Discounting reduces the present value of future benefits
Source: Vivid Economics

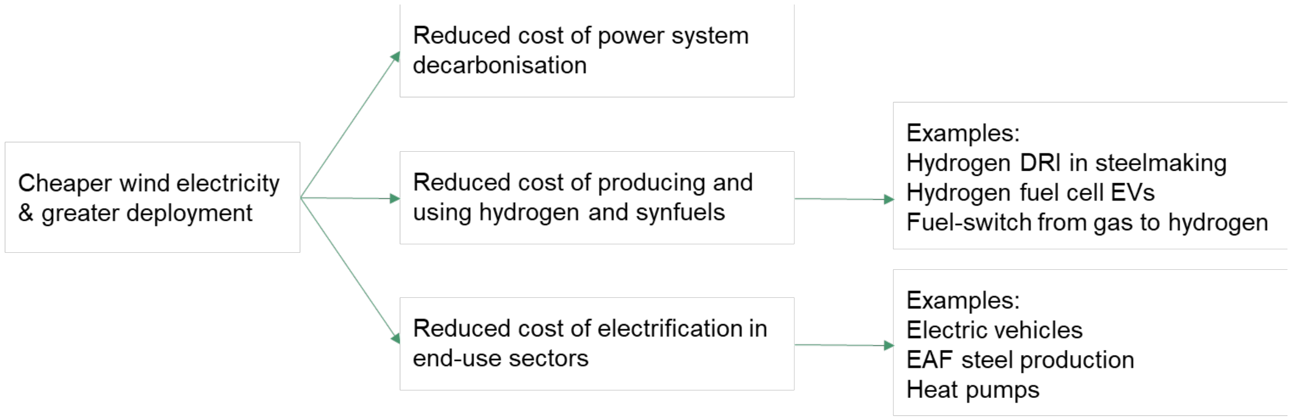
Strong innovation in wind power benefits all sectors by reducing the cost of low-carbon electricity. Like innovations in other power technologies, innovations in wind power have widespread benefits for the energy system via reductions in electricity costs. The sheer scale of wind deployment means that the size of total system benefits is large. As illustrated in Figure 4, system benefits from innovations in wind power are driven through three main channels:

1. **Reduced cost of power system decarbonization**
   Directly via cheaper wind power, and indirectly by displacing other more expensive power generation technologies. This outweighs the additional investments required in energy storage and transmission capacity needed to accommodate higher shares of wind generation, thus reducing power system costs. At a global scale, the levelized cost of electricity is 9% lower in the high-innovation scenario.

2. **Reduced cost of fuel production (e.g., hydrogen)**
   Cheaper low-carbon electricity enables greater deployment of hydrogen and synfuels at lower costs. In the high-innovation scenario, production of hydrogen via electrolysis is on average 4% higher between 2020 and 2050. This has knock-on effects on the energy system, such as doubling the amount of hydrogen used for power generation, although this remains limited as a share of the generation mix.

3. **Reduced cost of electrification in end-use sectors**
   Cheaper low-carbon electricity facilitates fuel-switching, e.g., adoption of EVs and heat pumps. For instance, in the high-innovation scenario, heat pump deployment is 6% higher in 2040.

Figure 4 Impact of innovation on the energy system



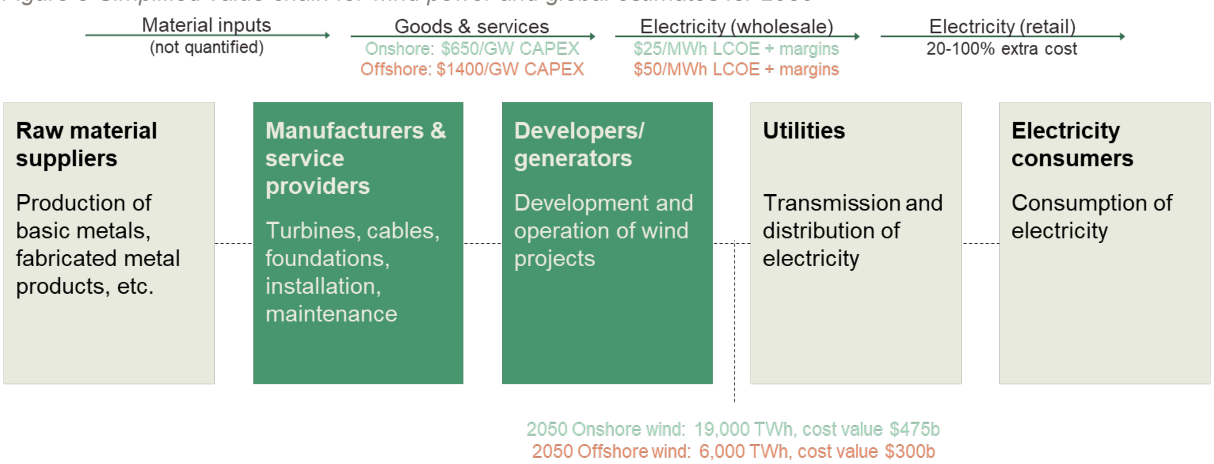
Source: Vivid Economics

3.2. Jobs and Growth

The market for wind power provides significant business opportunities along the supply chain, with annual investments already standing at around $100 billion in 2020.(14) Figure 5 presents a simplified value chain for the wind industry. Much of the value lies in the manufacturing of wind turbines because they represent the largest share of upfront capital expenditure for both onshore wind (69%) and offshore wind (38%) projects. Globally, 85% of the wind turbine market is shared among the top 10 original equipment manufacturers (OEMs).[9] However, profit margins are falling in the manufacturing of wind turbines because competitive auctions have driven down bid prices in recent years. Most of the largest OEMs now provide various specialized operations and maintenance services, which yield higher profit margins. Meanwhile, depending on local regulations and market frameworks, wind project developers could seek to generate revenue from wholesale energy markets, ancillary services markets, corporate power purchase agreements, or specific policy mechanisms that support revenues (e.g., feed-in-tariffs).

The rapid deployment of wind power could significantly increase annual investments in wind power to reach $430 billion in 2050. This is estimated from the high-innovation scenario described in Section 3.1, which is comparable to other 1.5°C warming scenarios in terms of the scale of wind power generation. Under this scenario, the average annual build rate for wind power would reach about 270 GW per year between 2021 and 2050, up from 110GW in 2020. Wind power generation would be around 25,000 TWh in 2050, with an economic value of around $775 billion in 2050.[10]

Figure 5 Simplified value chain for wind power and global estimates for 2050



Note: The blocks in green represent the scope of business opportunities quantified in this section
Source: Vivid Economics

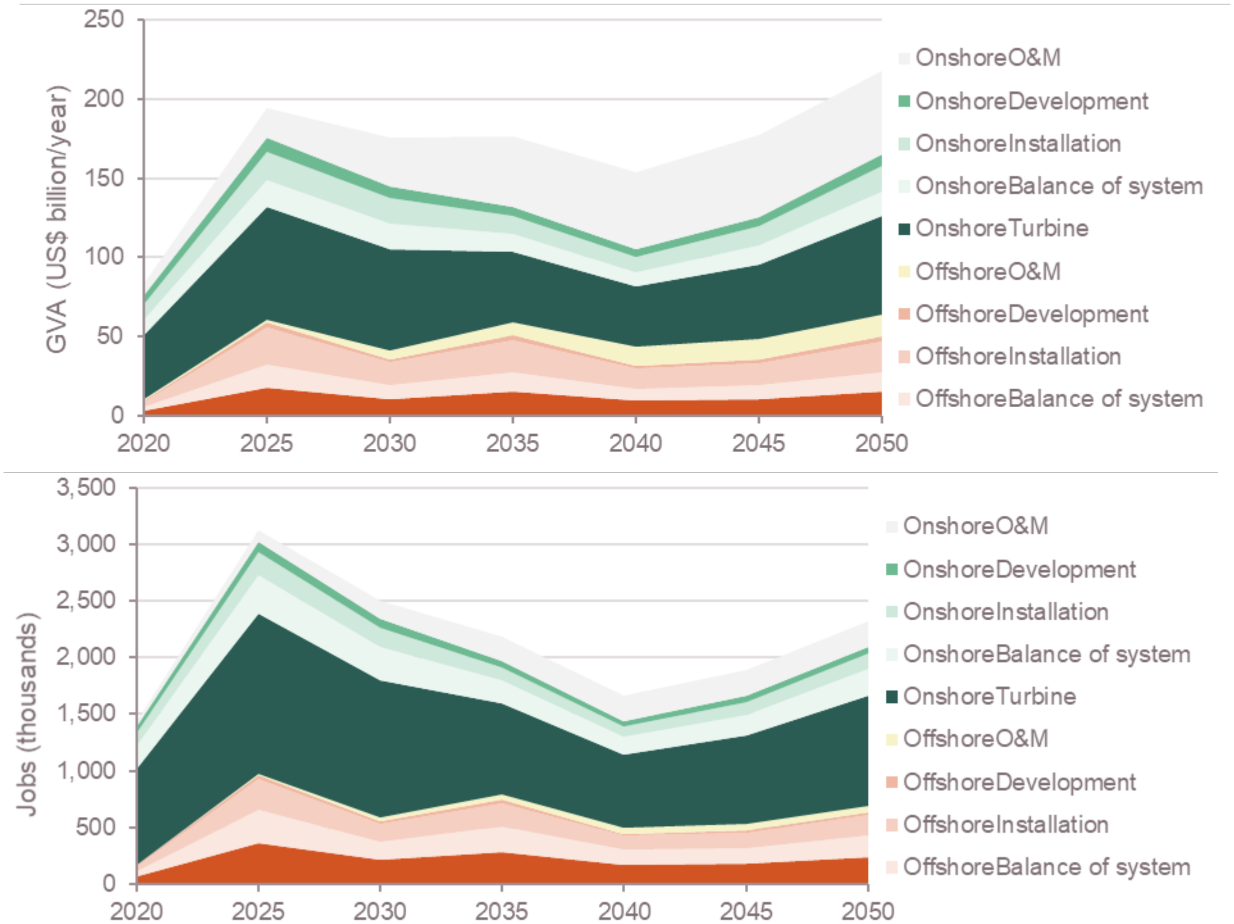
[9] The top ones being Vestas, Goldwind, Siemens Gamesa, and GE.(18)
[10] This is the cost-based estimate of the economic value, which does not directly translate into revenues, which depend on the structure of, for example, wholesale market arrangements, PPA contracts, feed-in-tariff rates.

This represents substantial business opportunities for innovative companies along the supply chain, with direct GVA in construction and operation alone reaching $218 billion per year in 2050. Of this annual total in 2050, the GVA directly associated with turbine manufacturing is worth $76 billion, while that of operations and maintenance is estimated at $67 billion. Around 70% of this value is attributed to the deployment of onshore wind. This is a sizable opportunity for the small number of OEMs in the market. By investing heavily in ways to reduce costs and improve technology performance, they stand to benefit by seizing a greater share of the sizable market, both in the manufacturing segment and the O&M segment. The trends in both GVA and jobs directly associated with deployment of wind power are shown in Figure 6. Overall, the growth in labor employment is slower relative to GVA due to improvements in labor productivity over time.

Deployment of wind power could directly support over 2.3 million jobs in construction and operation, which could be developed from upskilling available workers in relevant industries.[11] For comparison, the wind industry currently employs about 1.2 million workers currently.(15) Jobs in the wind industry are varied, some of them requiring highly-skilled workers with technical expertise. Manufacturing and installation of wind turbines is relatively labor-intensive and represents about 66% of the jobs supported by the wind industry by 2050. Meanwhile, the O&M of wind projects requires more specialized workers. For example, remote surveying of assets both onshore and offshore will rely on workers specifically trained in the latest robotics. For offshore wind, as O&M of offshore assets requires overlapping skills in the offshore oil and gas industry, there is an opportunity to retrain and upskill workers in the offshore oil and gas industry.

[11] These estimates focus only on the construction, operation, and maintenance of wind projects, which is where key innovations occur. While wind power could support further economic activity in the value chain, they are excluded from the scope of this analysis.

Figure 6 GVA and jobs directly supported by global deployment of onshore and offshore wind



Note: Employment declines relative to GVA due to assumed productivity growth in the wind industry
Source: Vivid Economics

4. The case for supporting innovation

To realize the full benefits of wind power, public spending on RD&D and commercialization needs to increase to $4 billion per year, and $11 billion per year respectively. For RD&D spending, this represents tripling the current global public RD&D budget for wind power. RD&D activities remain important for continuous improvements in both onshore and offshore wind technologies, such as larger and improved turbines and better support structures. For example, floating offshore foundations, will require substantial funding for demonstration projects, as there are several possible designs that need to be tested further. As for commercialization spending, the estimated amount is necessary to push early stage (or recently demonstrated) technologies to achieve market maturity. There are plentiful opportunities to deploy wind innovations, both in the transportation of parts and in the construction and operation of wind farms. Yet, these need to be commercialized as they are not yet widely deployed. As the wind industry overall has already become mature, public spending required to commercialize newer wind technologies will likely be a small share of total investments in wind power, which has already reached $100 billion per year.

Although sizeable, the estimated RD&D and commercialization spending requirements are small relative to the benefits. Modelling analysis indicates that stronger innovation in wind power, enabled by government RD&D and commercialization support, could bring at least $260 billion in annual benefits, measured in terms of discounted energy system costs in 2021/50. Furthermore, the estimated RD&D spending of $4 billion per year is still lower than the $4.5 billion in RD&D spending that IEA member countries have spent on nuclear power (both fission and fusion) each year.

Without strong government support for innovation, progress within the wind industry will slow down. The dramatic cost reductions seen in both onshore wind and offshore wind over the past decade were a result of significant economies of scale, but more importantly, the continuous introduction of larger and better turbines. While the wind industry can still grow in the absence of innovation support (as many existing wind technologies are cost competitive), the pace at which new technologies are introduced and adopted will slow down. Government spending on RD&D and commercialization is justified as wind innovations merit greater investments than what the private sector alone could provide –because of positive spillover effects of innovation as well as the deployment barriers that exist in the market.

Government support for RD&D and commercialization will need to be accompanied by 'pull' policies that ultimately drive deployment. Pull policies drive deployment and, hence, pull innovations forward. For example, these policies may include carbon pricing or renewable obligations (that favors wind power over fossil fuel power generation) and contracts for difference (which provide revenue stability to wind developers, thereby lowering financing costs). Together, an effective combination of push and pull policies can ensure sufficient investments in wind innovations, and that they are deployed rapidly to achieve the scale required for cost-effective decarbonization of the energy system.

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