Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

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ONSHORE WIND POWER

1. State of the art and current development in different world regions

All technologies
Rotors of medium to large wind turbines are all pitch-regulated. That means the blade is able to rotate around its axis to change its angle against wind. Despite the complexity in the hub —pitch actuators, controller, etc.— turbines featuring a hub display a better control of the blade and power output versus the wind speed and rotor rotation speed.

The load factor varies greatly according to the location —from 15 to 50% (average 20-25%)— leading to LCOE between €50 to €120/MWh.

Other wind technologies —e.g. vertical axis wind turbines, high-altitude wind power etc.— will not play a significant role on the market before 2050. This is why they are not assessed in this template.

Technology 1: Gear drive
In the 1980s, gear drive turbines (the "Danish concept") were the first commercially successful wind turbines. This technology currently represents around 75% of installed wind turbines. The classical 3-stage gearbox is increasing the rotor rotation speed with a ratio up to 1:100. With this configuration a robust, prominent and cheaper "high speed" asynchronous generator can be implemented. Nevertheless reliability problems still occur with gearbox.

Technology 2: Direct drive
Direct-drive concepts were designed to improve the Danish concept by operating turbines without a gearbox in order to increase efficiency —turbines were 3% more powerful— and reliability. Therefore new generators rotating at the same speed as the rotor were needed. With first developments of synchronous annular generator in the mid-1990s and despite higher cost and weight, this technology is gaining market share.

Technology 3: Hybrid
The German hybrid technology is another attempt to improve the Danish technology. German hybrid wind power plants involve a synchronous permanent magnet generator associated with a one-stage gearbox to reduce reliability problems. This technology was introduced in 2004.

2. Maturity level and technological perspectives

Maturity of onshore wind power

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Gear drive	5	5	5	5	5
Direct drive	5	5	5	5	5
Hybrid	4	5	5	5	5

On-shore wind turbines technologies are mature —even if there are minor innovations. The hybrid technology is not very used yet —and this probably won't be the case in the future either. Costs associated with wind turbines will remain stable despite of increased tower heights and rotor diameter in the years to come. However on-shore wind turbines are rapidly starting to compete with conventional electricity-generating technologies like natural gas and coal.

Potential development of on shore wind power

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
All technologies	2	3	3	4

Wind turbines account for a considerable reduction of greenhouse gas emissions. The potential is large and it will keep on growing.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

Technology		Research & technological bottlenecks	Economy and Financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts (including scarcity of raw materials, water, land, climate)	Safety & security (impacts on health, people and security assets)	Socio-technical feasibility
All technologies	Rank	3	5	6	2	1	4
	Key-words	Smart blades Control reliability	Costs Low ROI[1]	Rules and frame		Noise Climate consequences	Visual impact Acceptance Radar

Not all technologies are currently competing with other large sources of energy —i.e. nuclear, coal, gas— and their development is directly linked to the regulations imposed by different states, especially incentive systems such as feed-in prices, feed-in premiums, auctions, etc.

Furthermore wind turbines are not always locally accepted because of their visual impact, the noise they generate and the fear of climate consequences. Large development of this technology can also be slowed down because of resources problems with specific materials required for the electricity generator and for the blades.

The last point to be mentioned is wind energy: indeed as it is fluctuant, the development of wind turbines at very large scale is linked to the development of demand/response programs, large electricity storage capacity and super grids.

Technology 1: Gear drive turbines are a well-proven technology. However it is hindered by its lack of reliability, especially concerning the gearbox. Smart blades and better controls algorithms could lower the level of load changes in the gearbox, which is the main cause of failure for geared turbines.

Technology 2: Direct drive turbines are a proven technology. Its main drawback is higher investments costs. One obstacle to the development of this technology is the heavy use of specific materials —e.g. for permanent magnet— for the electricity generator.

[1] ROI: Return on Investment

4. Potential radical and incremental innovations

<u>*Methodological information:*</u>

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Economy and Financial innovations** (investment, risk)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
All technologies	I or R	I	I	R	I	I	I
	Key-words	Large rotor for low wind speeds, high towers		Specific state policies for a large development, stability	Raw materials	Better knowledge on global and local climate consequences	Stealth turbine