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Wind power has become one of the world’s leading sources ofrenewable energy, contributing to the energy transition and the fight against climate change. However, to fully assess the environmental and social impact of wind turbines, it is crucial to consider their entire life cycle, from design to dismantling. This article examines the different stages in the life cycle of wind turbines, as well as the innovations, regulations and environmental standards in force in this sector.

The life cycle of a wind turbine comprises several stages, including design and planning, component manufacture, transport and logistics, installation and commissioning, operation and maintenance, and finally dismantling and recycling. Each of these stages has a specific environmental and social impact, which needs to be assessed for an overall understanding of the sustainability of wind turbines.

The design and planning phase is crucial to optimizing the efficiency and sustainability of wind turbines. Engineers and designers work on aerodynamic models, innovative materials and control systems to improve wind turbine performance. They also take into account environmental factors such as wind speed and direction, as well as social considerations such as local acceptability and impact on wildlife.

CO2 emissions associated with this stage are generally low, in the order of 0.1 to 0.5 g CO2/kWh. These emissions are mainly due to energy consumption for technical studies, computer simulations and administrative activities.

Transporting wind turbine components, particularly blades and towers, is a logistical challenge due to their size and weight. It also generates CO2 emissions due to the fuel consumption of transport vehicles. Emissions vary according to transport distance and the mode of transport used (road, rail or sea), and are generally estimated at between 0.5 and 3 g CO2/kWh.

Installing wind turbines involves building foundations, assembling components and connecting them to the power grid. This phase can temporarily disrupt the local ecosystem, and requires careful planning to minimize environmental and social impacts. CO2 emissions from foundation construction, component assembly and grid connection range from 1 to 4 g CO2/kWh, depending on site conditions and construction methods used.

During operation, wind turbines require regular maintenance to guarantee their performance and longevity. CO2 emissions linked to these activities are relatively low: around 0.1 to 0.5 g CO2/kWh. These emissions are mainly due to fuel consumption by vehicles and energy used for maintenance operations.

At the end of their service life, wind turbines are dismantled and their components recycled or recovered. This stage generates CO2 emissions and waste, but it also recovers materials and limits the overall environmental impact of the wind turbine’s life cycle. Emissions are linked to the dismantling of structures, transport

of waste and recycling processes, and are estimated at between 0.5 and 2 g CO2/kWh, depending on the dismantling and recycling methods used.

Recycling a wind turbine is a complex process that involves dismantling, transporting and processing the various components. Here are the main stages in recycling a wind turbine and the associated challenges:

The most difficult parts of a wind turbine to recycle are the blades and permanent magnets of the generators. Blades pose challenges due to the complexity of recycling composite materials, while permanent magnets require specific processes to recover rare metals. Developing more efficient and sustainable recycling solutions for these components is crucial to reducing the environmental impact of wind turbines at the end of their life.

Wind energy is already a major contributor to the U.S. energy system (9.2% of all electricity in 2020) and is expected to become even more so in the future. Boosted by advancing technology, economies of scale, and plummeting costs, the U.S. industry had an exceptional year in 2020, with wind power capacity additions of 14.2 gigawatts (GW).