# Improved Modelling of Offshore Wind Generation Using Machine Learning. On a Reliable Supply of Electricity in Future Power Systems

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Energy is the bedrock of modern economies and societies, yet its production and consumption are also responsible for 75% of greenhouse gas emissions, making it the primary driver of climate change. But global warming is not the only negative impact that human activity has on our planet. The energy transition must aim not only at counteracting climate change, but also at returning us below the 9 planetary boundaries that describe limits beyond which the environment may not be able to self-regulate anymore. Equally important is that the energy transition must be fair, allowing everyone to thrive in an environment respectful of the Earth. In other words, we need to find the safe space between the 9 planetary boundaries and a social foundation of well-being that no one should fall below. Encompassed within the basics needs of life is notably access to energy.

Renewable energy sources are expected to play a significant role in the energy transition, because of their low emissions of greenhouse gases over their lifetime. However, they affect other planetary boundaries as they require a lot of raw materials and a considerable surface area, potentially jeopardizing biodiversity and impacting land use. Therefore, the operation of those energy sources must be optimized to produce electricity in the most efficient way and avoid spillage of electricity. Moreover, renewable energy sources are inherently intermittent, fluctuating, and highly unpredictable, thus posing many challenges to ensure a reliably supply of electricity. A detailed planning and usage throughout the year will be necessary to guarantee access to electricity for everyone, at all times, and at an affordable price.

This thesis does not have the ambition to tackle all the challenges of the energy transition, but aims at discussing the impact of the massive installation of renewable energy sources, targeting one type in particular: offshore wind energy. This work is focused on developing enhanced models of offshore wind generation, with the purpose of improving the integration of future offshore wind farms in power systems by assessing their impact on the reliability of supply and their ability to provide balancing services. Machine Learning techniques are leveraged to build a fast, accurate and topology-aware surrogate for offshore wind farms, able to capture complex aerodynamic phenomena and to generalize to any layout configuration while keeping a reasonable computation time. This model is then directly integrated within adequacy studies aimed at evaluating the reliability of electricity supply in future power systems with a high share of offshore wind generation. It allows to assess the impact of an improved modelling of offshore wind power on reliability indices. The generalization abilities enable the consideration of the uncertainty related to the topology of future wind farms, as their layout (turbine position, power density, turbine technology) is still unknown. Thanks to the topology-aware abilities of the wind farm surrogate, the same model can be used to consider many possible farm configurations without hindering the tractability of the computation process. Outcomes show that disregarding power losses due to aerodynamics phenomena arising in offshore wind farms leads to an underestimation of reliability indices, thereby concealing adequacy issues and preventing the right investments to ensure a sufficient reliability of the system. Finally, we focused on the foreseen participation of offshore wind farms to reserve markets, aimed at restoring balance within the system in case of sudden perturbations. We explored how the layout of future wind farms can be optimized to account for their participation to ancillary frequency services. The developed surrogate is especially appropriate for a wind farm layout optimization problem, where a different layout is seen at each iteration, justifying the need for a topology-aware model, applicable to any wind farm configuration.