WS5: Future ORE Concepts
Complementarity analysis of a wave wind farm for offshore hydrogen production.

Dr Abel Arredondo-Galeana[a], Dr Shona Pennock[b], Dr Daniel Nibblet[c], Katarzyna Patryniak[a], Professor Maurizio Collu[a], Professor Feargal Brennan[a]
[a] NAOME, Faculty of Engineering, University of Strathclyde
b CorPower Ocean, Stockholm, Sweden
c Electrochemical Engineering, School of Engineering, University of Newcastle, UK

Engineering and Physical Sciences Research Council
Supergen Offshore Renewable Energy

Wave wind farm

The schematic of a co-located wave–wind farm is depicted in Figure 1. The offshore farm consists of a 5 MW wind turbine mounted on the OC4-DeepCwind semi-submersible platform (Robertson et al., 2014). A total of five single-buoy wave energy converters (WECs), each rated at 400 kW [1], are arranged in front of the floating wind turbine to supply power to a hydrogen plant rated at 5 MW. The diameter (D) of the WECs is 9 meters, and the lateral spacing between devices is $3D$. The back row of WECs is positioned $10D$ upstream of the front pontoon of the platform. Further details of the farm are available via the QR code below.

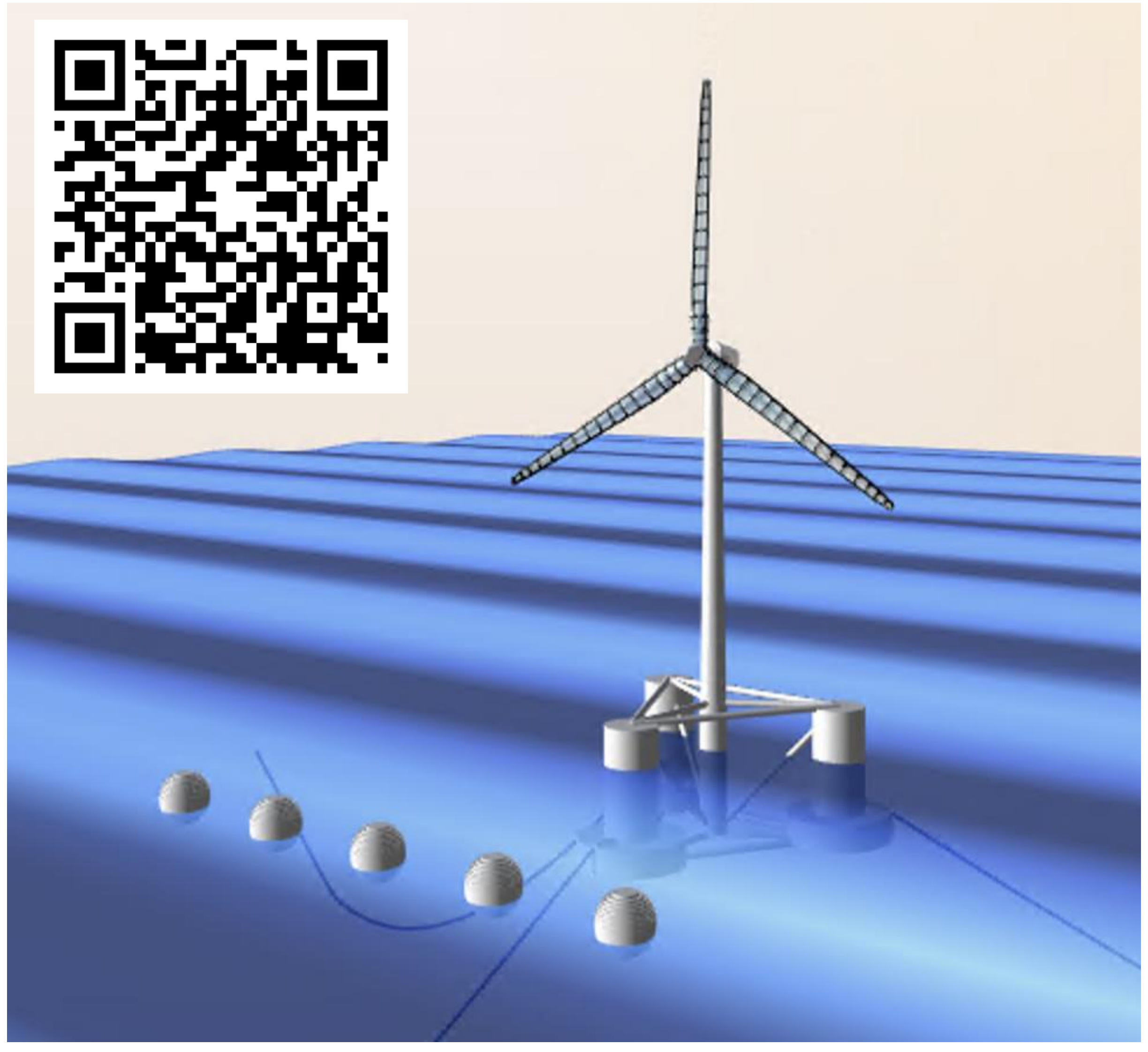

Figure 1– Wind-wave farm array layout with a WEC fence facing the dominant wave direction.

Hydrogen production

The power output of the 5 MW wind turbine, the five wave energy converters (WECs) rated at 400 kW each, and their combined output are shown in Figure 4a using two months of hourly data (January-February 2024). Wind power is shown in black, wave power in red, and the combined output in blue. The results highlight the complementary nature of these resources in swell-dominated regions, where wind and wave conditions exhibit low correlation. The grey regions in Figure 4a indicate periods when wind power drops below a specified power threshold, while wave power (green regions) remains above the threshold, which is set to 1 MW in this case. Additionally, the yellow regions highlight periods when both wind and wave resources are available simultaneously, increasing the overall energy yield. Figure 4b presents the corresponding cumulative hydrogen production. The wind-only case (black) shows intermittent growth, with flat regions during periods of absent wind power. In contrast, the combined system (blue) eliminates these gaps and increases the overall rate of production. Notably, although wave energy has less than half the installed capacity of wind (2 MW vs. 5 MW), its contribution increases hydrogen production by 50% by the end of the two-month period, due to both gap-filling and periods of simultaneous resource availability.

Wave height attenuation

Figure 2a shows the wave surface elevation around the wave farm at a dimensionless time period $T^* = 10.9\ (\omega = 1.8\ \mathrm{rad/s})$. The transmission coefficient K_T ,defined as the ratio of downstream to upstream wave height, is used to evaluate wave attenuation for a single WEC and a WEC fence of 10 devices. Figure 2b shows that the multi-WEC configuration demonstrates significantly stronger attenuation, reducing K_T to approximately 0.4 for dimensionless wave periods $10 \le T^* < 15$,followed by a gradual increase toward $K_T \approx 1$ as T^* increases. A single WEC provides minimal attenuation, with $K_T \approx 0.9–1$ across $10 \le T^* < 15$. For long wave periods $(T^* \ge 25)$, both configurations converge to $K_T \approx 1$,indicating negligible attenuation. Overall, WEC arrays are substantially more effective than individual devices at reducing downstream wave energy, particularly or intermediate wave periods $(10 \le T^* < 15)$.

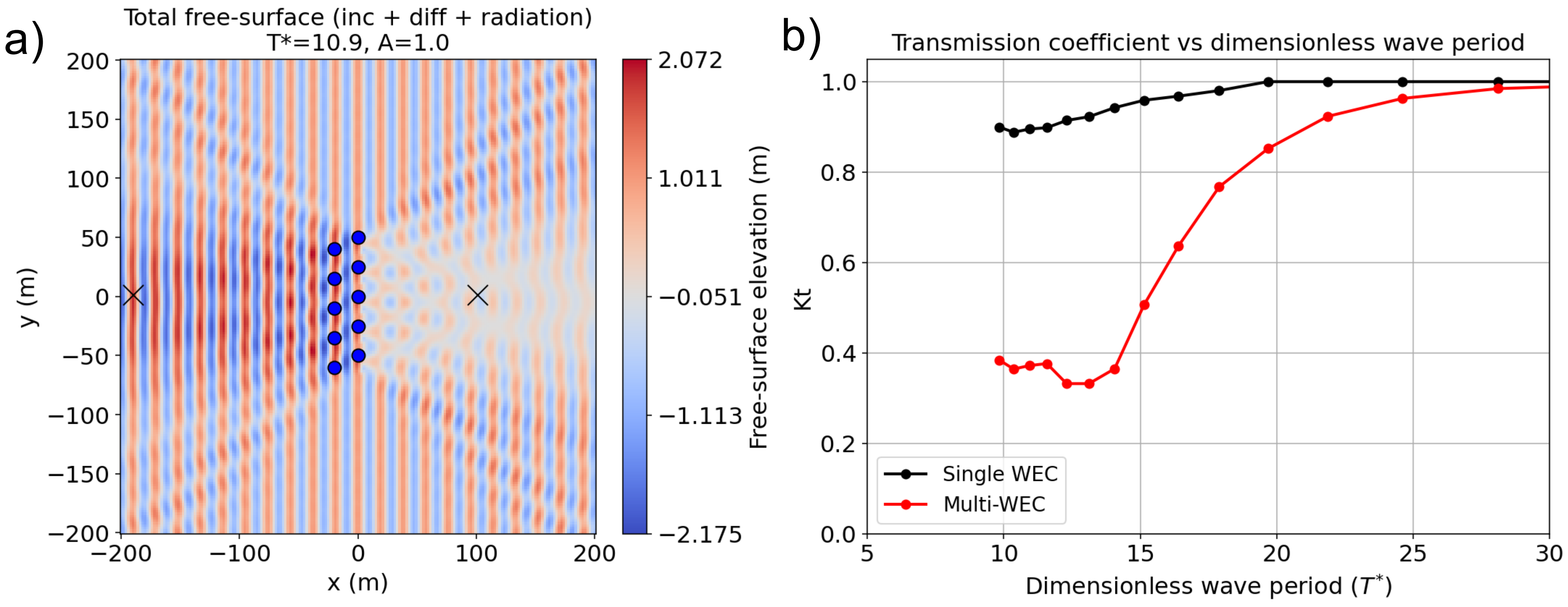

Figure 2 – a) Surface wave elevation around a WEC fence consisting of two rows; b) Transmission coefficient (K_T) for a single WEC and for 10 WECs distributed in two rows.

Wind turbine (WT) controller effort

Figure 3 shows the standard deviation of the aerodynamic (orange markers) and electrical power (blue markers) of the wind turbine at different dimensionless wave periods (T^*). We find that 10 WECs reduce variability in turbine aerodynamic power through wave attenuation over the range of $10 \le T^* < 15$. However, electrical power variability remains low across all cases $(10 \le T^* < 35)$ due to effective turbine control (blue markers).

This indicates that power quality is governed by the control system rather than wave conditions. Wave attenuation does not directly improve electrical power quality for hydrogen electrolysers. Nevertheless, the reduction in aerodynamic variability implies a lower control effort, as less pitch activity is required to maintain a stable power output. Three regions of control effort are identified in the figure, corresponding to low, medium, and high effort, shown in green, yellow, and red, respectively.

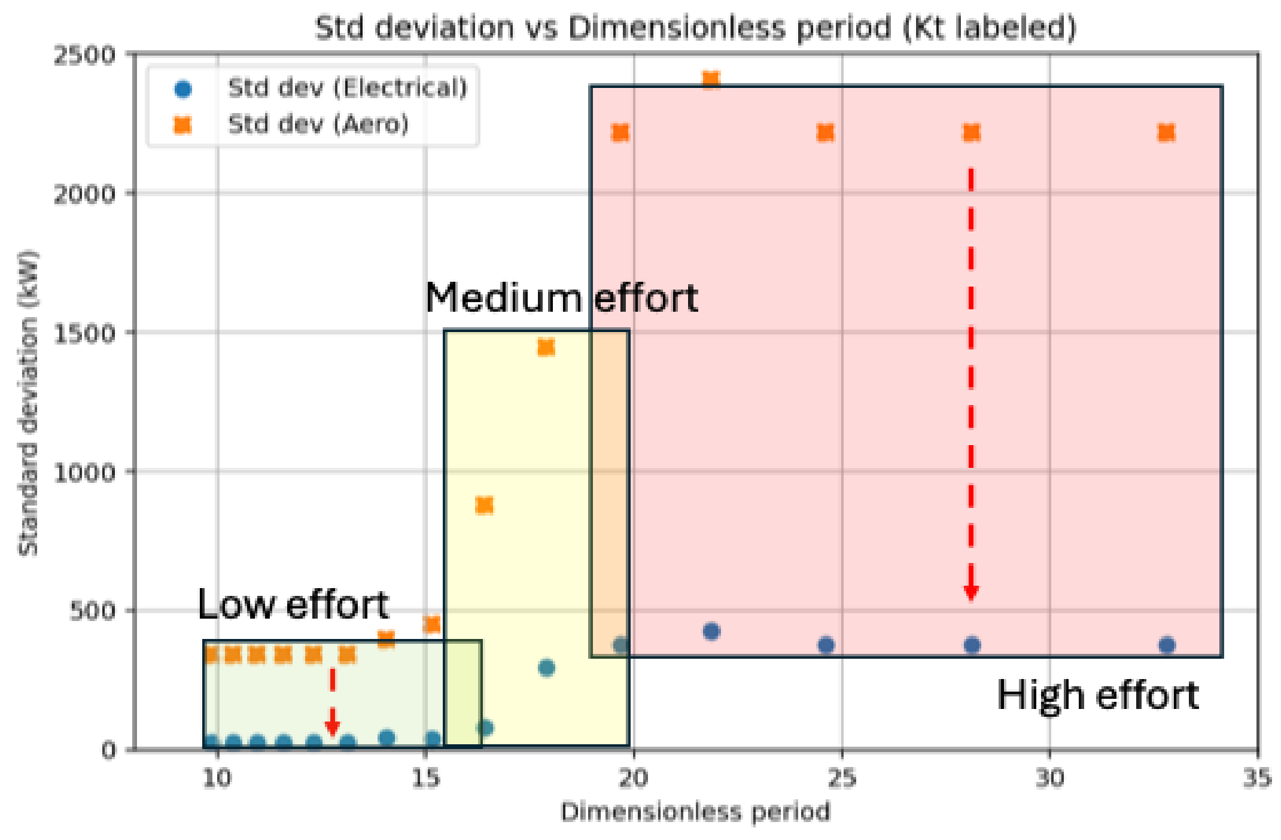

Figure 3 – Standard deviation of aerodynamic and electrical power of WT at different T^*

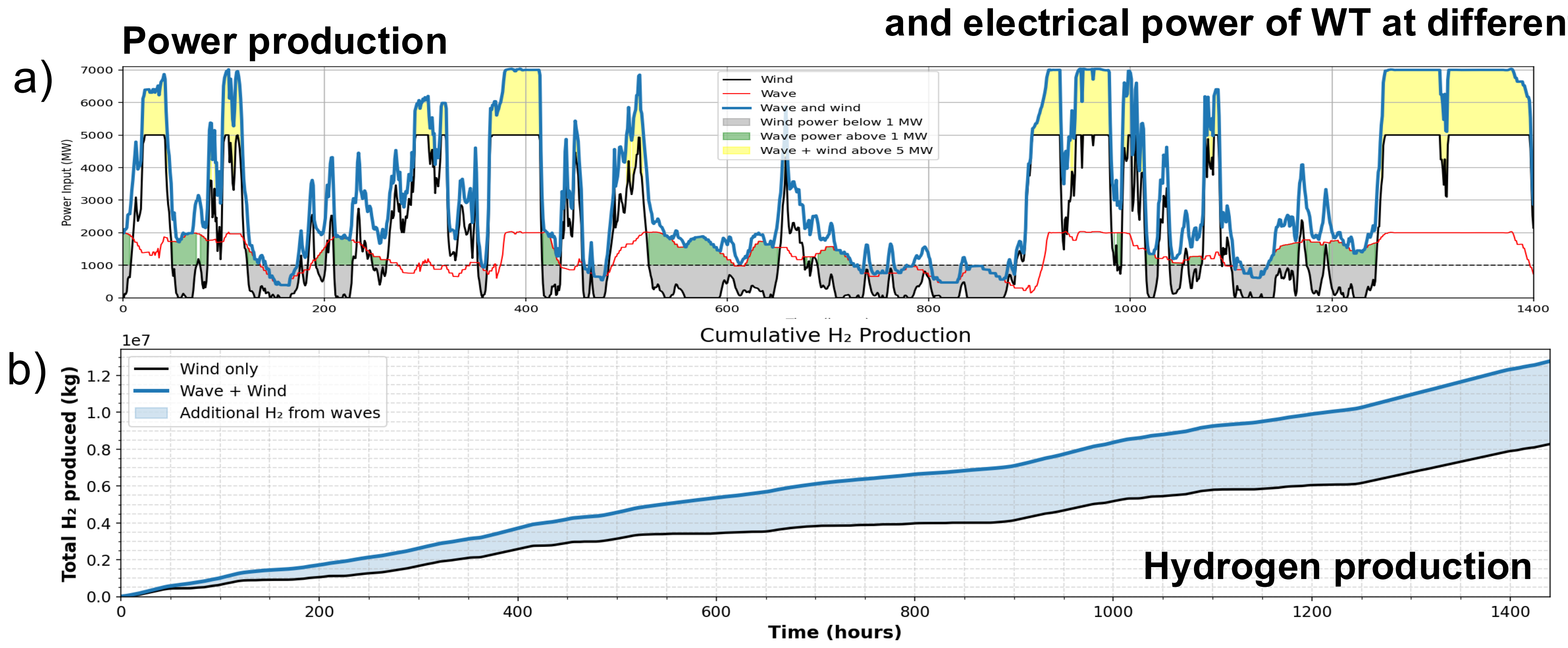

Figure 4 – a) Power time series of wind, wave, and wind + wave and b) Cumulative hydrogen production from wind only and wind + wave combined.

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[1] Blech, E. M. (2023). *Developing a cost model For combined offshore farms: The advantages of co-located wind and wave energy* (Master's thesis, Universitat Politècnica de Catalunya, KTH Department of Technology).
[2] Niblett, D., 2023. powertoelectrolysis. https://github.com/DNiblett/powerToElectrolysis. GitHub repository. Ocean Refuel. University of Newcastle, UK.

Ocean REFuel
University of Strathclyde
Newcastle University
CorPower Ocean