Physics-guided ML to build digital twin for wind-assisted propulsion ships

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Problem and Purpose

Wind-assisted propulsion systems (WAPS) (Figure 1) are receiving renewed attention as the shipping industry confronts stricter greenhouse gas (GHG) emission regulations on the pathway toward net-zero emissions by 2050.

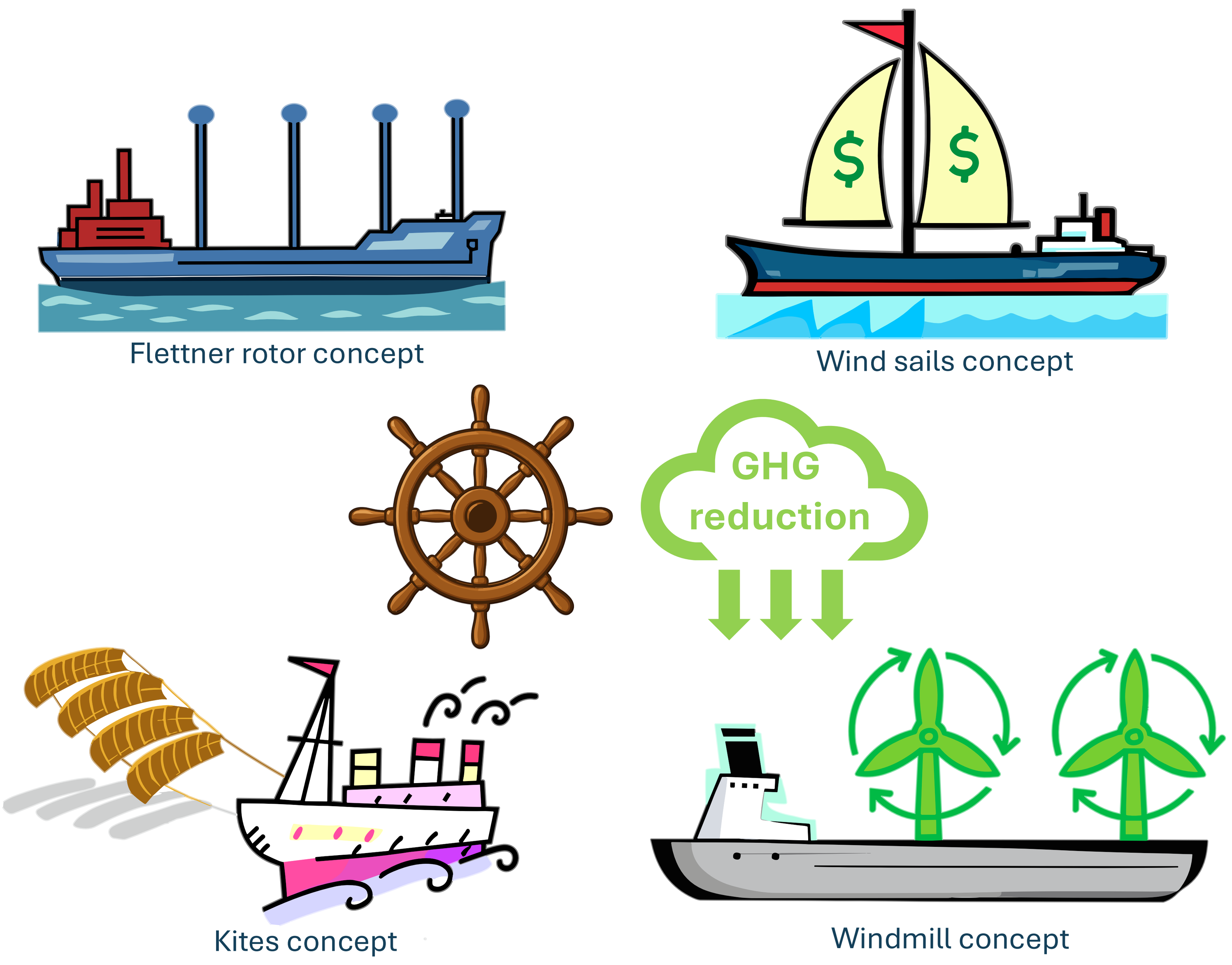

Figure 1: Illustration of key wind-assisted propulsion concepts.

This project aims to **pioneer physics-informed machine learning (PIML)-based WAPS ship modeling**[1,2] by using key technological enablers, such as physics-informed neural networks (PINNs), and by addressing the following research questions (Figure 2):

1) How can a **PIML framework** be developed to combine physical principles with real-world sailing data for WAPS ships?
2) How can **WAPS devices be controlled** to optimize WAPS ship operation?
3) How can **onboard crews be trained** to operate the new WAPS ships efficiently and safely?

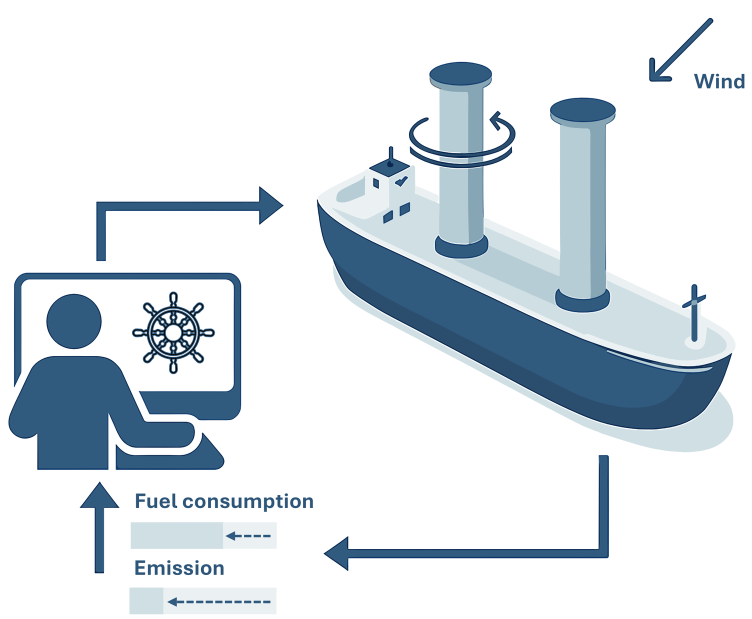

Figure 2: Illustration of how onboard crews control the WAPS device to maximize wind-assisted thrust, leading to reduced fuel consumption and emissions.

Realization

This project establishes four research steps with cross-disciplinary methods (Figure 3). **PIML approaches** will develop the ship performance models. The models will be embedded into the **weather routing**[3] system, combined with **control algorithms**[4] to enable optimal control. The **human factor** of the WAPS ship operation will also be investigated.

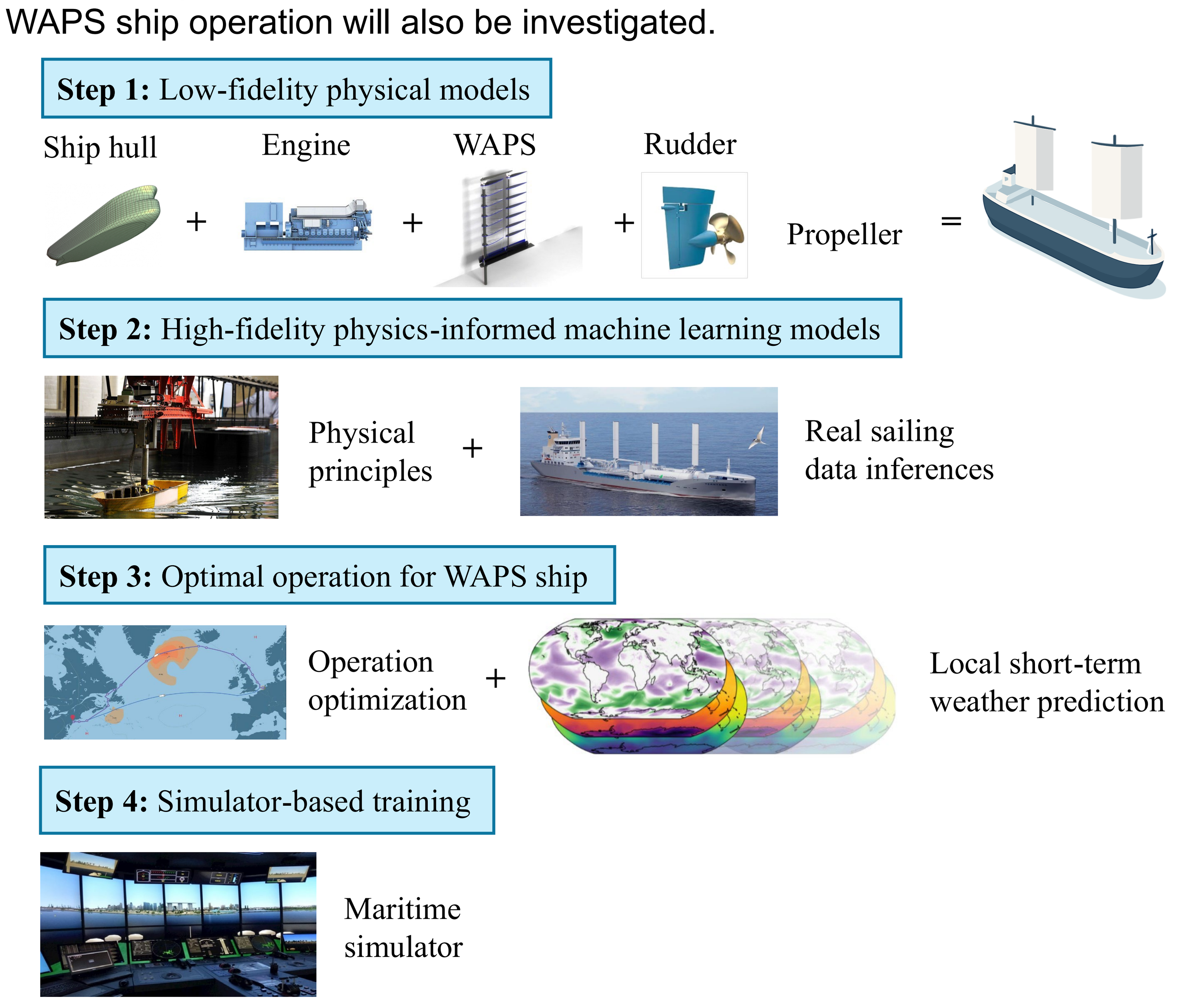

Figure 3: Schematic of the four research steps framework for PIML-based WAPS ship modeling and optimal operation.

Multiple industry partners cooperatively support this project. The reference ship and full-scale measurements are provided by **Terntank** and **Odfjell**. **Berg Propulsion** is responsible for the engine and propeller modeling, while **DNV** offers guidance on industry standards and ensures a transparent evaluation. **Chalmers' maritime simulators** and **Wärtsilä** will support the virtual training.

Results

At present, the physical model has been established and embedded into a decision support system to optimize the control of the WAPS and the controllable pitch propeller (CPP) settings, thereby minimizing the power demand from the main engine. Figure 4 presents a 10-day case study voyage for the reference ship.

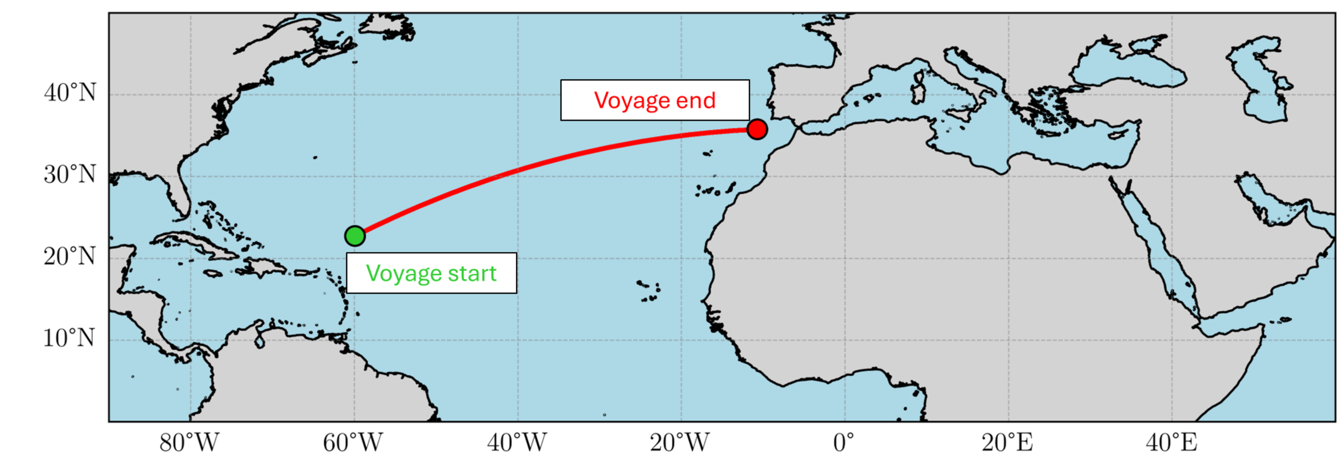

Figure 4: A 10-day case study voyage showing the trajectory of the reference ship from voyage start to voyage end.

For the case study voyages, if two suction sails are installed, **without active control** of the WAPS and the CPP settings, the thrust contributed by the WAPS can reach up to **20%** of the total required thrust when the wind direction is favorable (see Figure 5, upper). When the two installed suction sails are **actively controlled** to rotate for maximum thrust, and combined with CPP pitch control, the thrust contribution from the WAPS can increase to as much as **50%** of the total required thrust (see Figure 5, lower).

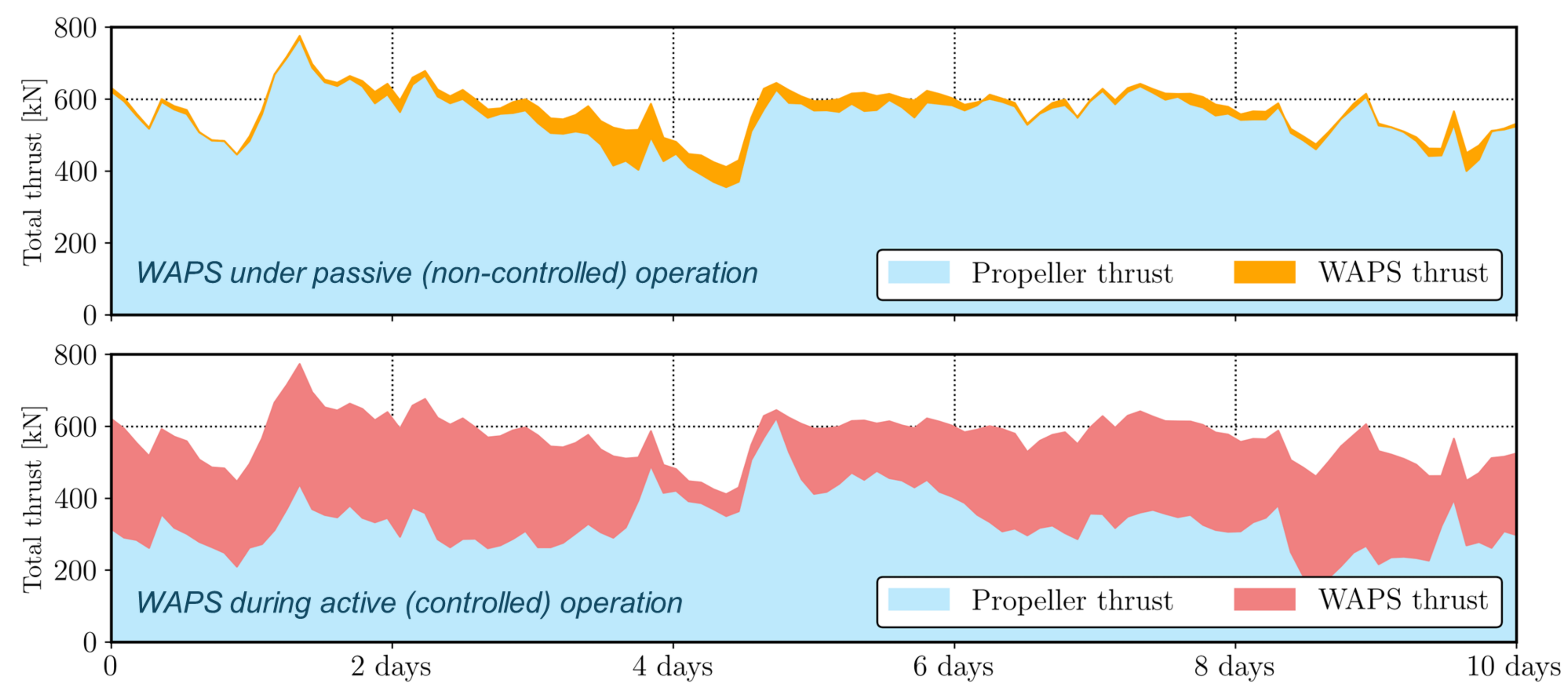

Figure 5: Thrust distribution of WAPS under passive (non-controlled) operation with two suction sails installed (upper); thrust distribution of WAPS under active (controlled) operation with two suction sails (lower).

For the entire voyage, the accumulated GHG emissions during active (controlled) WAPS operation can be **reduced by up to 50%**, when combined with optimized WAPS and CPP settings, as illustrated in Figure 6.

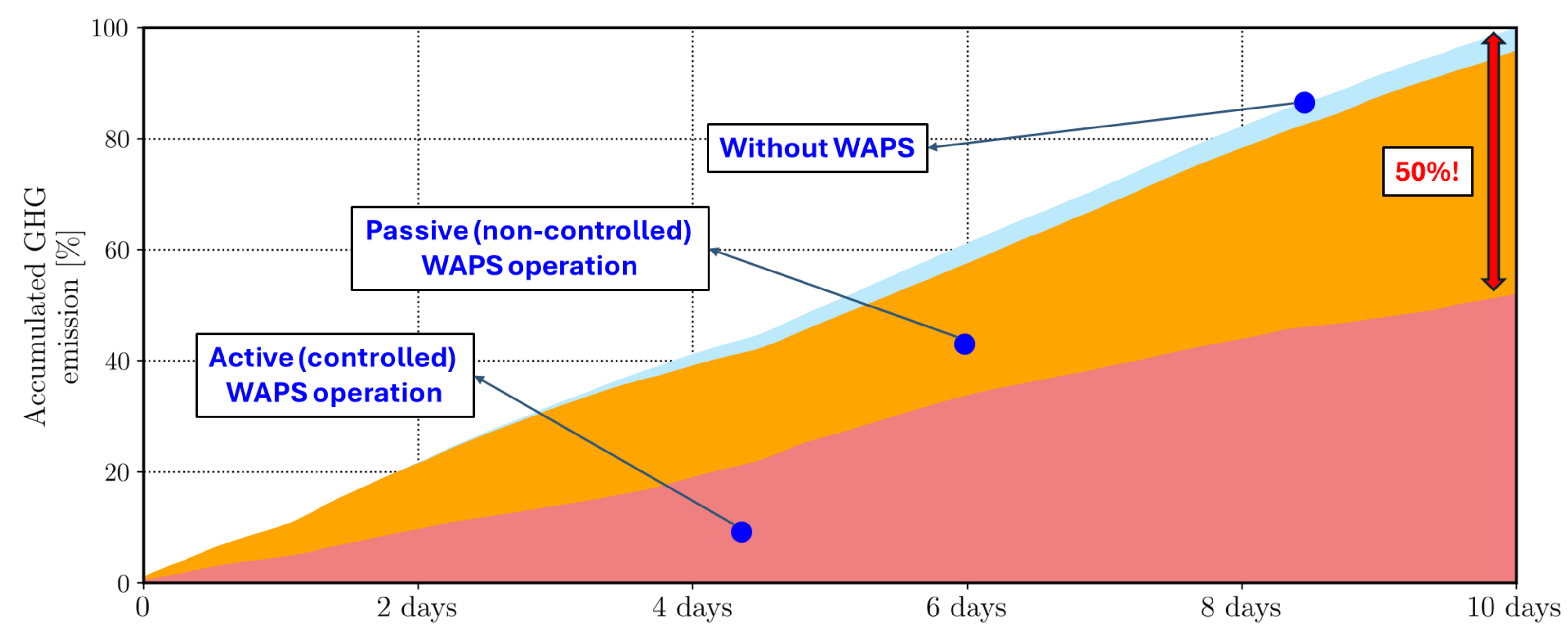

Figure 6: Accumulated GHG emissions for the entire voyage under three scenarios: baseline without WAPS, passive (non-controlled) WAPS operation, and active (controlled) WAPS operation.

References

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