Adopting different wind-assisted ship propulsion technologies as fleet retrofit: An Agent-based modeing approach

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Purpose of the study

- To complement and expand on previous research about the diffusion of Wind propulsion technologies (WPTs) in international shipping

"In which scenarios will the heterogeneous global shipping fleet adopt different types of WPT as a retrofit alternative?"

- To develop an agent-based model by integrating Bass diffusion theory and social networks through the model of an **heterogeneous sample of vessels and three different types of WPT**.
- To model the diffusion potential of WPTs, scenarios are developed considering currently discussed policies in international shipping (EU and IMO),
  - such as the carbon levy, but also
  - the variation of fuel prices in international markets

Details of the computer simulation

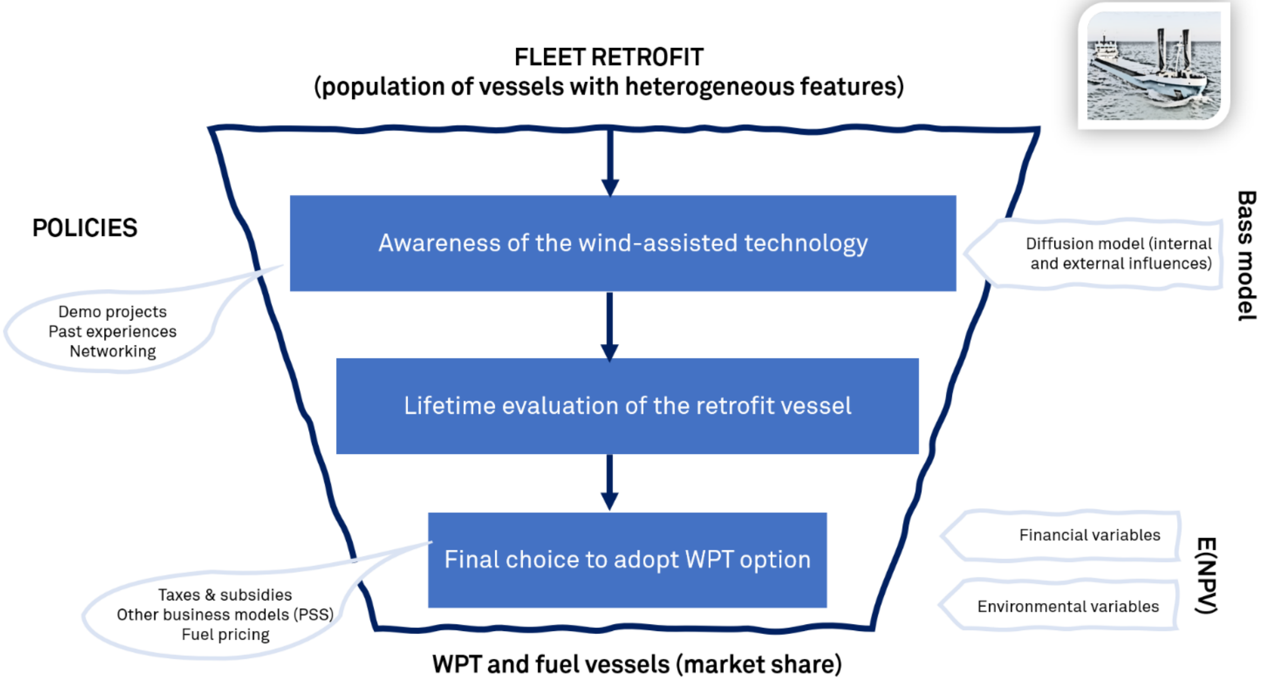
- We run the model for 30 independent MC runs.
- All the results shown in this paper are averaged from these 30 independent MC runs.
- Time step is monthly, we set T = 120 synchronous time-steps, meaning 30 years of simulation.
- We set Y , the maximum lifetime of a vessel, to 30 years as done in previous studies.

Real data and experimental setup

Pilot name	DWT	Installation costs (K_j)	Monthly maintenance costs (C_j)	Fuel savings (σ_j)
Flettner rotor (vessel pilot #1)	5023	750,000€	1,208.33€	15%
Wingsail twinfoil (vessel pilot #2)	2300	500,000€	833.33€	13.85%
Ventifoil (vessel pilot #3)	3638	321,151€	535.25€	4.94%

General structure

- Population of vessels Z, with heterogeneous features for each $j \in O$ (i.e. Flettner rotor, Ventifoil and Wing sail).
- The default case is fuel-based technology.
- All vessels start with a 100% fuel-based approach
- When WPT is adopted it is not common to reverse the technology back
- The eco-innovation is given by the ABM Bass model in two steps.
- The model mimics the adoption of WPT options over time for T time-steps in a terminating simualtion model
- Each time step t, represents a month as done in similar models.



Main features of the vessels and WPT options

- The population of vessels *Z* with size *N* include heterogeneous vessels that belong to different shipowners and are connected through a social network of vessels.

$y_i^0 \in \{1, ..., Y\}$:	The age of the vessel in years. This age is considered to calculate the remaining months of use of the retrofit population (ri) by considering a global maximum lifetime of 30 years for a retrofit vessel (Y = 30).
κi:	The expected fuel consumption of the vessel i under average climatic conditions and maritime operations.
$ai \in \{0, 1\}$:	1}: a binary variable for those vessels that have knowledge or awareness about the WPT. This variable is activated by the Bass diffusion model
$oi \in \{1, ..., \|O\|\}$:	is the technological option selected by the vessel. These options include the fuel-based option and all the WPT eco-innovations

Apart from the population of vessels, we also define a set of wind-base clean technological options *O*.

Cj : the monthly maintenance cost when having alternative *j* in a vessel.
Kj : the installation or capital costs for the *j* alternative, set equal for all the vessels in the population.
$\sigma j \in [0, 1]$: the fuel consumption reduction ratio when the WPT option is installed in a vessel.

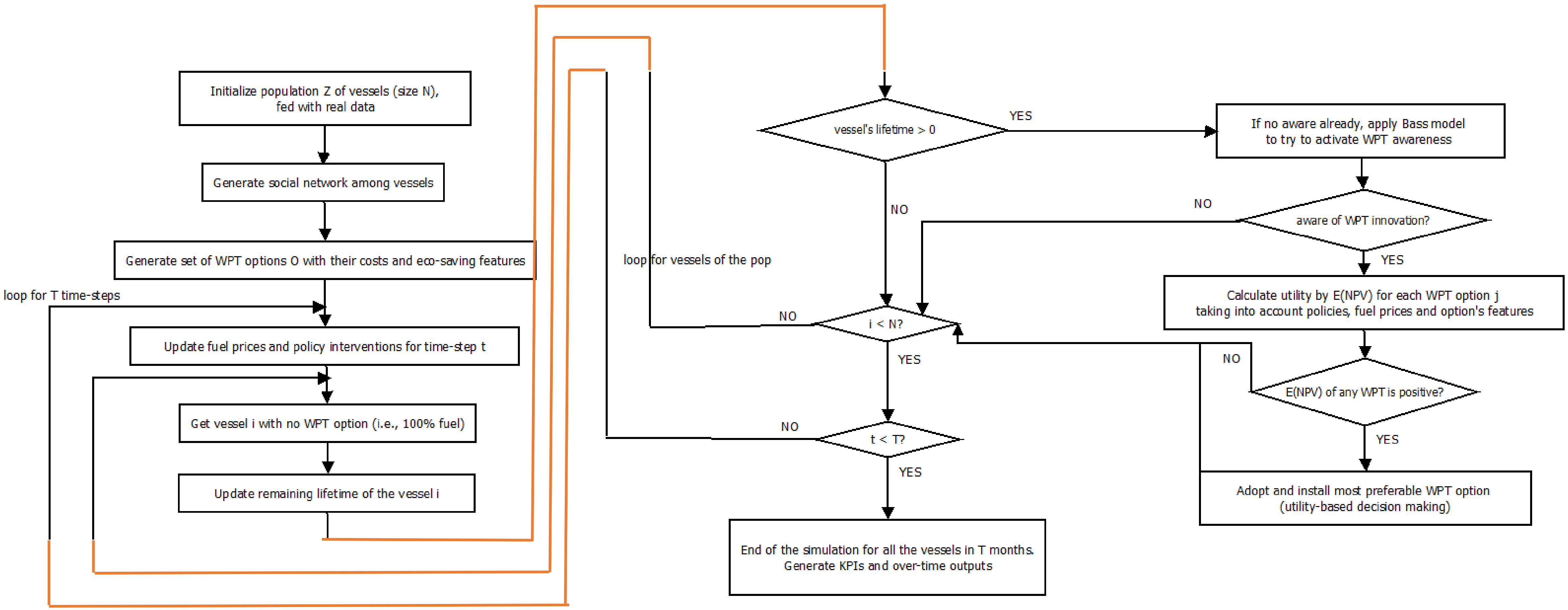
Social network of vessels

- A social network defines as WOM processes
- We assume WOM by vesels to increase granulairty of the process. It is common to aproximate a real social network with synthetically generated attachment network when no data about the features of the network.
- Scale free approach
- Degree distribution, power-law distribution, most of the nodes have few connections but few nodes a lot of them.
- Barabasi-Albert preferential attachment algorithm
- (m) parameter modulates the growth rate of the network and its final density.
- The BA algorithm starts with a fully connected graph with m0 initial nodes but at every step, the generation algorith adds a new node to the network and connecting it to m existing nodes.
- This procedures contines until the network reaches the desired size.
- The final average degree is calculated as $\langle k \rangle = 2m$.

Awareness of the innovation through the Bass model

- The Bass model is an innovation diffusion model of adoption, well-accepted in the eco-marketing literature
- The ABM assumes independence of the internal (adopter-to-adopter interactions through WOM) and external effects.
- Bass-ABM is a discrete-time model, each agent has one of two states at each time step t (non-adopter or unaware of the eco-innovation; or adopter/ aware of.
- At each time step (one month in the simulation), a vessels has the opportunity to become aware of the tehcnology
- The probability that an agent becomes aware of the WPT due to WOM increases as a function of the fraction of tis neighbors who became co-adopters in previous time steps.

Model: adopting different WASP as fleet retrofit



- **Baseline scenario and model validation**

- For the diffusion process and innovation Bass model for the awareness of the technology, two parameters p and q need to be set.
- As these two coefficients (together with the potential market M) determine the shape of the diffusion curve, they shall be, whenever possible, calibrated on historical data.
- In order to solve this issue we have studied previous literature in the use of the Bass model for adoption of energy efficient technologies and eco-innovations.
- Concretely, [6] used p = 0.000618 and q = 0.8736 M = 1, 305, 055 from fitting with real data in [15] also reports p = 0.0015, 0.002 and q = 0.3, 0.35 for solar water heating in Portugal. [9] reported that these coefficients are sensitive to the adoption.

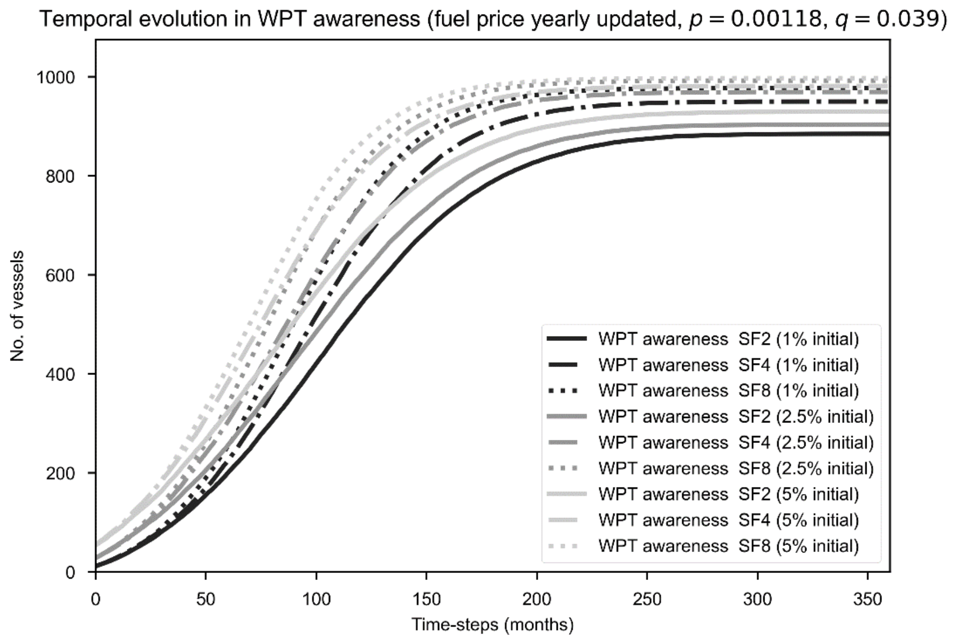
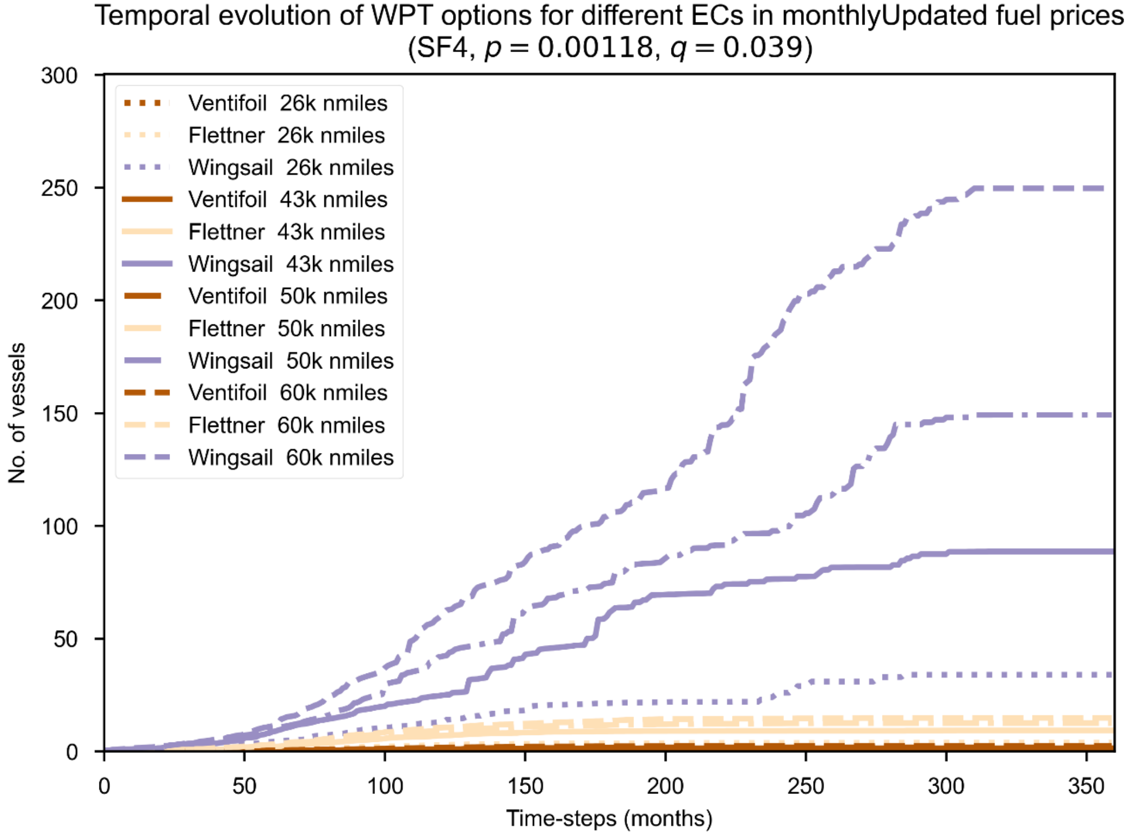
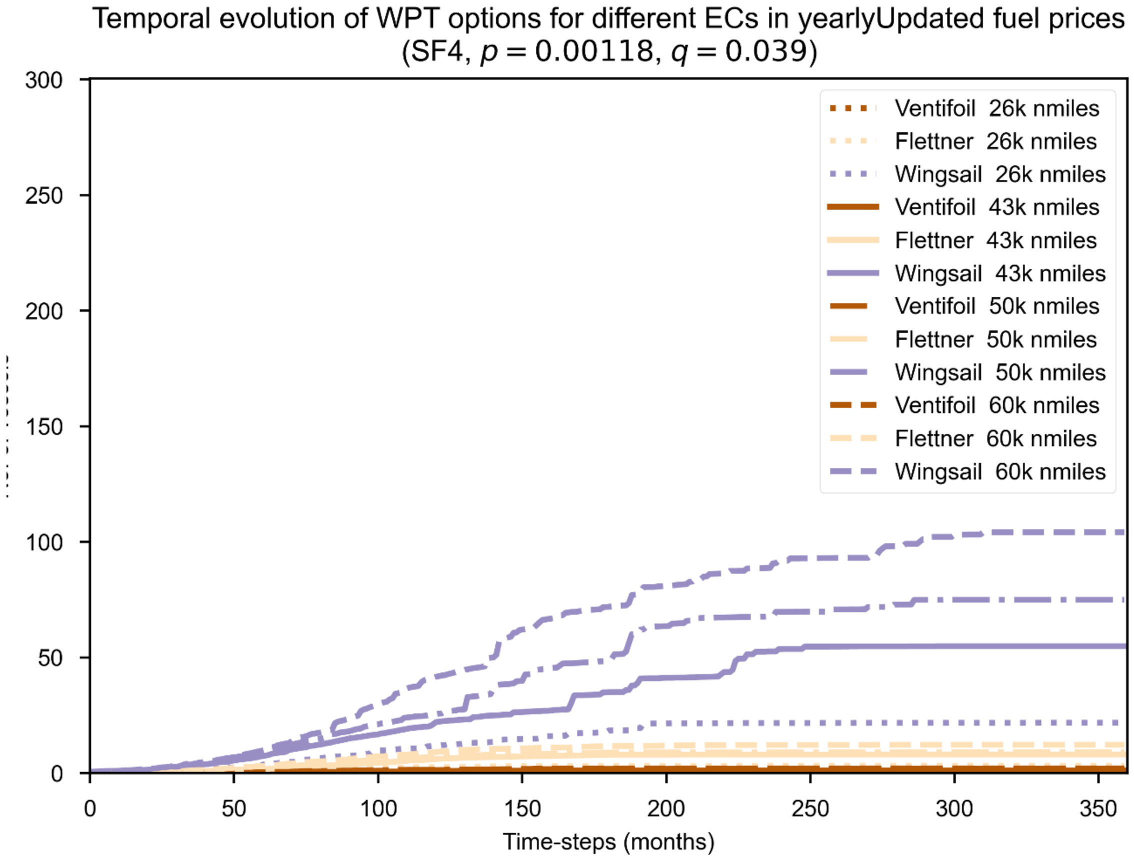


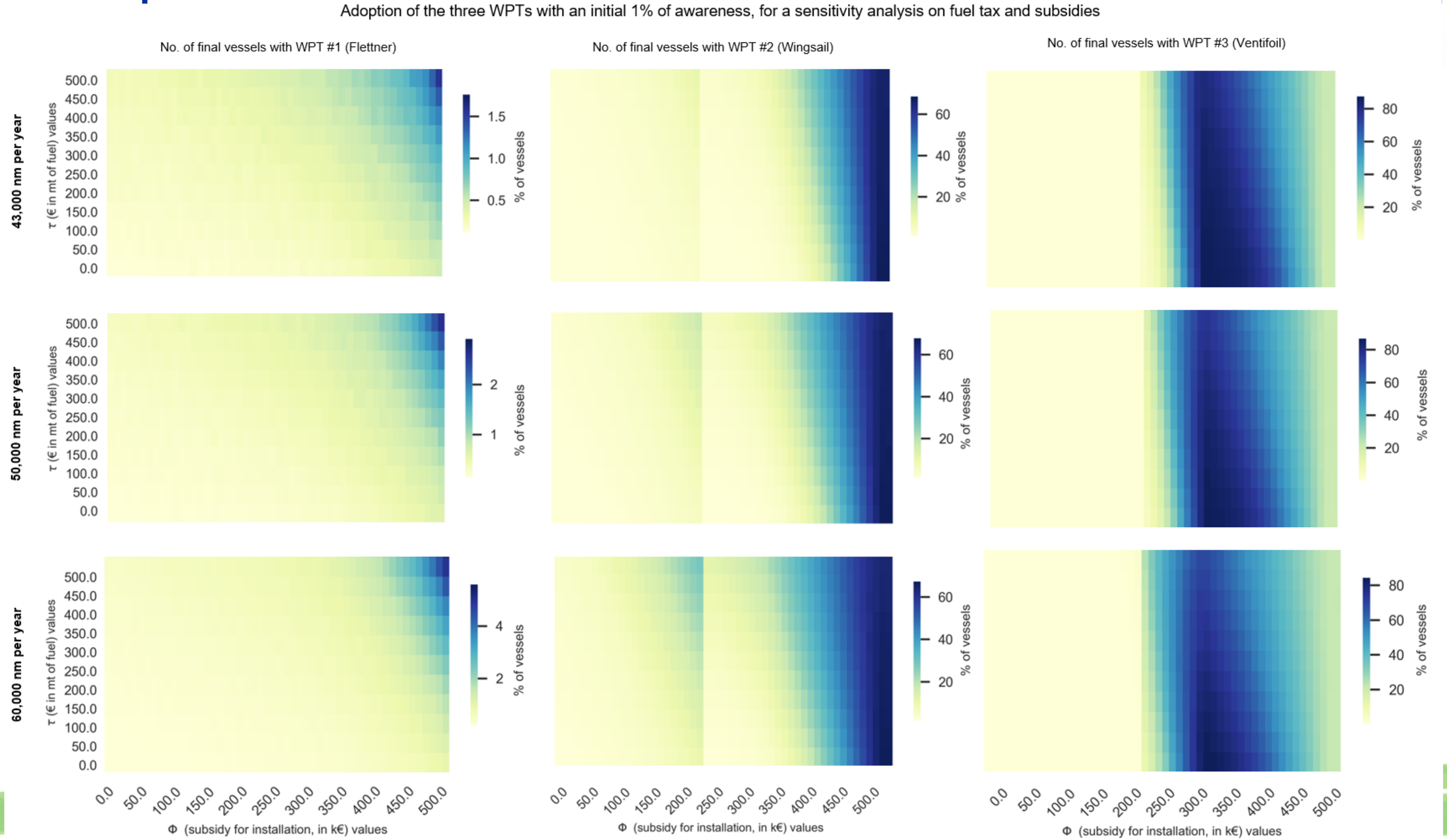
Figure 3: Evolution in the WPT awareness levels for different network densities and initial awareness of the WPT for the 30 years of simulation.

WPT adoption in baseline scenarios

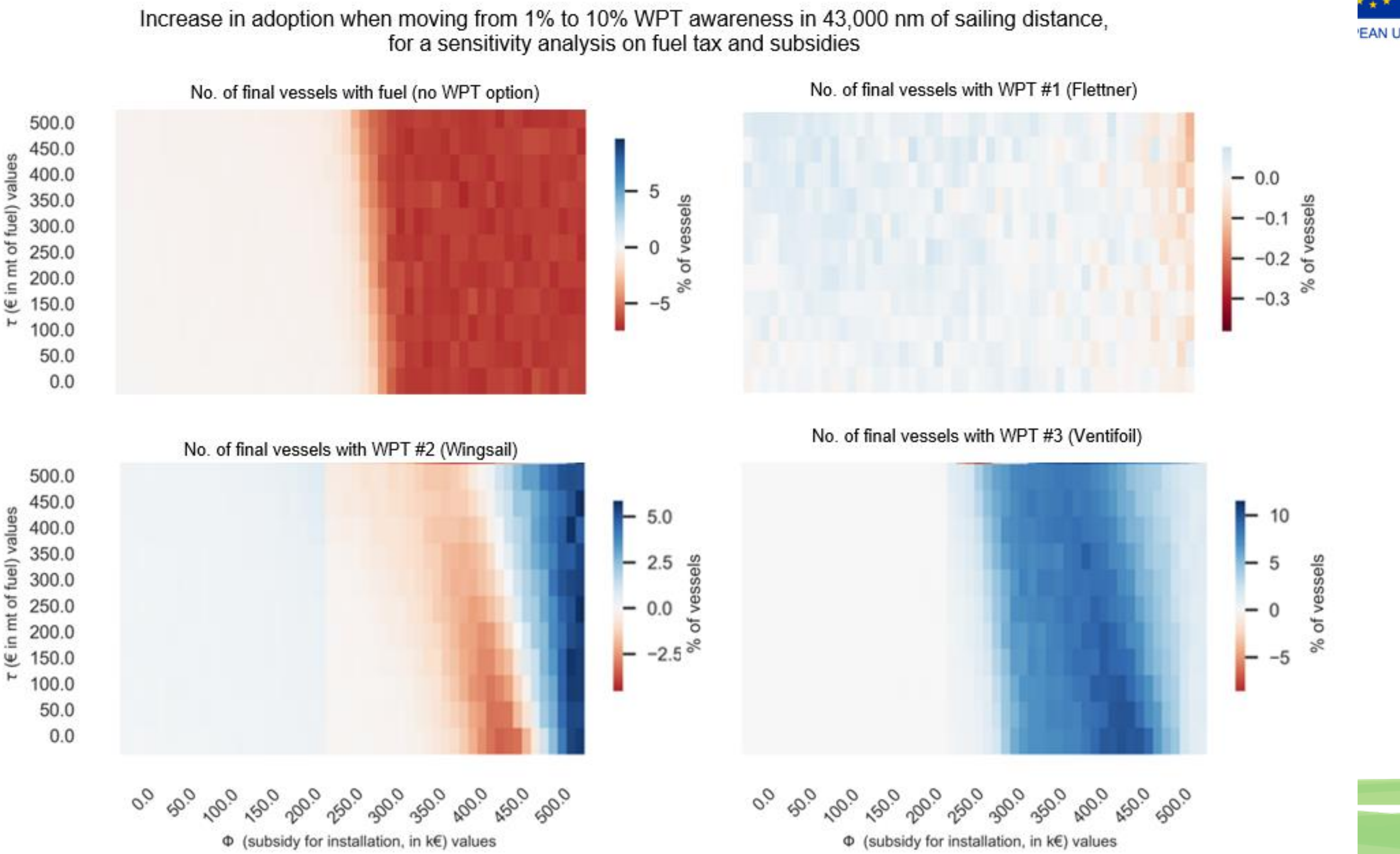




Incentivization policies of subsidizing installation costs and taxing fuel consumption



Combining networking for WPT awareness and policy interventions



Implications to practioners

- From a managerial point of view, the main insights we observed from the computational study are that, without interventions, the adoption of any of the three WPT options is very limited (i.e., under 5%).
- The best policies to promote adoption involve the use of subsidies to reduce the installation costs of the WPT for the retrofit vessels, with this being more effective in boosting WPT adoption than taxes on fuel.
- Hybrid policies to promote adoption should focus on networking effects and installation subsidies.
- Another managerial insight is how increasing the awareness of the technology through networking boosts and favors Ventifoil, lowest costs, at the expense of the Wingsail technology.