

## Supplementary Materials

### File S1. Input parameters and calculation equations for the SD model.

- (01) Annual CO<sub>2</sub> emissions=Emission from HFO+Emission from LNG + Emission from MDO
- (02) Carbon tax=Total carbon dioxide emission\*Carbon tax rate\*10<sup>-4</sup>
- (03) Carbon tax rate=40
- (04) Design power of auxiliary engine=4500
- (05) Design power of main engine=23000
- (06) Design speed=24
- (07) Emission from HFO=HFO consumption\*HFO emission factor
- (08) Emission from LNG=LNG consumption\*LNG emission factor
- (09) Emission from MDO=MDO consumption\*MDO emission factor
- (10) Energy consumption in shipping each voyage=Operational power\*Sailing time\*Number of vessels\*0.45
- (11) FINAL TIME = 2030, The final time for the simulation.
- (12) Growth rate of voyage= (Total revenue of shipping companies-DELAY1(Total revenue of shipping companies, 1))/DELAY1(Total revenue of shipping companies, 1)
- (13) HFO consumption=Usage rate of HFO\*Specific fuel consumption of HFO\*Total energy consumption
- (14) HFO emission factor=3.144\*10<sup>-3</sup>
- (15) INITIAL TIME = 2008, The initial time for the simulation.
- (16) LNG consumption=Usage rate of LNG\*Specific fuel consumption of LNG\*Total energy consumption
- (17) LNG emission factor=2.75\*10<sup>-3</sup>
- (18) Load factor= 0.8
- (19) MDO consumption=Usage rate of MDO\*Specific fuel consumption of MGO\*Total energy consumption
- (20) MDO emission factor=3.206\*10<sup>-3</sup>

(21) Number of vessels = WITH LOOKUP (Time, ([ (2008,0) -(2030,4000)], (2008,382), (2009,389), (2010,511), (2011,454), (2012 ,648), (2013,747), (2013.99,644), (2014.86,845), (2015.87,1808), (2017,1640), (2018 ,1735), (2019.03,1636), (2020,2044), (2021,2001), (2022,2008), (2023,2354), (2024,2500), (2025,2646), (2026,2792), (2027,2938), (2028,3085), (2029,3230), (2030,3377) ))

(22) Number of voyages on route= INTEG (Growth rate of voyage,260)

(23) Operational power=Design power of main engine\*(Speed/Design speed) ^3+Design power of auxiliary engine\*Load factor

(24) Pollution loss=Total carbon dioxide emission\*Pollution loss factor

(25) Pollution loss factor= $1.905 \times 10^{-5}$

(26) Revenue decrease=Ship energy consumption costs + Carbon tax + Pollution loss

(27) Revenue increase=Shipping income + Shipping Subsidy

(28) Sailing distance=6000

(29) Sailing time=Sailing distance\*0.9/Speed

(30) SAVEPER = TIME STEP, the frequency with which output is stored.

Ship energy consumption costs=HFO consumption\* $3.14 \times 10^{-6}$  + MDO consumption \*  $6.125 \times 10^{-6}$ +LNG consumption \* $10^{-6}$ )\*7

(32) Shipping income=Number of voyages on route\* $5.1231 \times 10^{-4}$  \*5000

(33) Shipping Subsidy=Carbon tax\*Subsidy factor

(34) Specific fuel consumption of HFO= $175 \times 10^{-10}$

(35) Specific fuel consumption of LNG= $150 \times 10^{-10}$

(36) Specific fuel consumption of MGO= $170 \times 10^{-10}$

(37) Speed=15

(38) Subsidy factor=0

(39) TIME STEP = 1, The time step for the simulation

(40) Total carbon dioxide emission= INTEG (Annual CO<sub>2</sub> emissions,0.277)

(41) Total energy consumption=Energy consumption in shipping each voyage\*Number of voyages on route

(42) Total revenue of shipping companies= INTEG (Revenue Increase-Revenue decrease,3.55\*0.37)

(43) Usage rate of HFO=0.8

(44) Usage rate of LNG=0

(45) Usage rate of MDO=0.2

**File S2. Basic variables and values for the SD model.**

**Table S1. Values for different variables in the SD model**

| Variables                           | Unit               | Value                     | Data resource  |
|-------------------------------------|--------------------|---------------------------|--|
| Carbon tax rate                     | yuan/ton           | 40                        | Gao ta al.2023   |
| Design power of auxiliary engine    | kw                 | 4500                      | Lloyd's List Intelligence                              |
| Design power of main engine         | kw                 | 23000                     |  |
| Design speed                        | knot               | 24                        |  |
| Number of vessels                   | /                  | [(2008,382) -(2030,3377)] |  |
| HFO emission factor                 | /                  | 3.144                     | Jing et al.2021  |
| MDO emission factor                 | /                  | 3.206                     |  |
| LNG emission factor                 | /                  | 2.75                      |  |
| Load factor                         | /                  | 0.8                       |  |
| Pollution loss factor               | /                  | $1.905 \times 10^{-5}$    | Chen 2015  |
| Sailing distance                    | mile               | 6000                      | shipxy.com   |
| Specific fuel consumption of HFO    | million tonnes/kwh | $175 \times 10^{-10}$     | Jing et al.2021  |
| Specific fuel consumption of LNG    | million tonnes/kwh | $150 \times 10^{-10}$     |  |
| Specific fuel consumption of MGO    | million tonnes/kwh | $170 \times 10^{-10}$     |  |
| Subsidy factor                      | /                  | 0/0/2/0/3                 |  |
| Total revenue of shipping companies |                    | $3.55 \times 0.37$        | Liu et al.2019<br>Estimated from the Clarkson database |

**Table S2. Basic information of container ships used in the SD model.**

| Ship type              | Feedermax  | Panamax      | Post Panamax | Neo-Panamax      | VLCS            | ULCS      |
|------------------------|------------|--------------|--------------|------------------|-----------------|-----------|
| Capacity (TEU)         | 2510       | 4250         | 5551         | 90757            | 14000           | 19226     |
| Name                   | Progress C | Maersk Cairo | YM Wealth    | Xin Da Yang Zhou | CMA CGM Dignity | MSC Ditte |
| IMO number             | 9280809    | 9525479      | 9278088      | 9337949          | 9897779         | 9754953   |
| Main engine power (KW) | 36450      | 23000        | 54900        | 68520            | 75275           | 62380     |

|                                   |      |      |      |      |      |      |
|-----------------------------------|------|------|------|------|------|------|
| Auxiliary<br>engine power<br>(KW) | 1995 | 4500 | 7600 | 2760 | 4000 | 4300 |
| Design speed<br>(knt)             | 24   | 25   | 25.9 | 25   | 24.1 | 19   |
| Maximum<br>speed (knt)            | 18.9 | 22.1 | 20.4 | 20.4 | 20.6 | 19   |
| Minimum<br>speed(knt)             | 0    | 0    | 0    | 0    | 0    | 0    |
| Average<br>speed(knt)             | 1.19 | 14   | 14   | 16   | 15.6 | 13.5 |