Second Module: Emissions

- **Different module for each ship type (bulk carriers, tankers, containerships, etc.)**
- **Present development: Bulk carriers**
- **Two approaches (*regression analysis*), corresponding to different user input data sets**

Inputs for 1st approach:

(a) Displacement (D - tn)
(b) Operational speed (V - kn)
(c) Operational Break Power (P – kW)
(d) Draft at loading condition (T – m)
(e) Temperature of air inlet (Θ - °C)
(f) Temperature of cooling water inlet (Θ - °C)
(g) Fuel Type

Inputs for 2nd approach:

(a) Displacement (D - tn)
(b) Operational speed (V - kn)
(c) Operational Break Power (P – kW)
(d) Draft at loading condition (T – m)
(e) Temperature of air inlet (Θ - °C)
(f) Temperature of cooling water inlet (Θ - °C)
(g) Fuel Type
(h) Engine number of cylinders (z - #)
(i) Piston stroke (s - m)
(j) Cylinder bore (b - m)

→ **Both approaches: input data of (a)-(c) correspond to associated draft (d) – one operation point**

→ **First approach: less input data needed Second approach: more accurate (SFOC calculation)**

→ **Calculation: Specific Fuel Oil Consumption (SFOC) *for ISO conditions* (using digitized engine envelope and propeller curve) →*Pre-processing step* for present module (pg. 2) →*Regression* (pg. 3)**

→ **Correction (present module): Modified SFOC, accounting for *fuel type* and *air-water temperature***

→ **Emissions: CO_2, NO_x and SO_x**

Second Module: Emissions - Development

- Data: using previous NTUA work, collected from SeaWeb database *for 10,350 Bulkcarriers* of global fleet, including all subclasses: Handysize, Handymax, Panamax, Capesize, VLBC
- Building dates: after 2005
- Ship data considered/generated: (i) geometry (L, B, D), (ii) DWT, (iii) hull form coefficients (C_b, C_p, C_m, C_w), (iv) number of propeller blades, (v) (P, n) at engine MCR, etc.
- Database generated: includes *24,000 operating points* of different ship loading conditions: (i) full load condition - 70%, (ii) ballast condition - 20%, (iii) random condition - 10%
- Consideration of hull fouling: between 0% (clean hull) and 25% (drydock condition)
- Slow steaming: *not considered* in present release
- Sequence of calculations (NTUA development):
  1. Specific input: DWT
  2. Calculation of geometry/hydrodynamic parameters and Lightship: use of empirical relations (Papanikolaou 2009, Molland 2012, Carlton 2012, MAN technical papers 2013-2019)
  3. Calculation of engine brake power – speed (P, n) at MCR → automatic selection of two-stroke Diesel engine
  4. For every case of the database (24,000 operating points): Calculation of the “real” SFOC, for "standard reference conditions" (ISO 3046: fuel type, engine intake air temperature, cooling water inlet temperature)

Second Module: Emissions - Development

- **Regression analysis (24,000 points): Two new correlations extracted for SFOC**

$$1)\ calculated\ SFOC_1^{*} = c_o \cdot D^{b_1} \cdot V^{b_2} \cdot P^{(b_3-1)} \cdot T^{b_4}$$

$$2)\ calculated\ SFOC_2^{*} = c_o \cdot D^{b_1} \cdot V^{b_2} \cdot P^{(b_3-1)} \cdot T^{b_4} \cdot (1+z)^{b_5} \cdot \left(\frac{b}{s}\right)^{b_6}$$

*not to be confused with engine SFOC values provided by the engine manufacturer ("real" SFOC)

- **Regression analysis: Calculated coefficient values**

***First approach*:**

c_0	b_1	b_2	b_3	b_4
230.056	-0.026	-0.166	1.045	-0.011

***Second approach*:**

c_0	b_1	b_2	b_3	b_4	b_5	b_6
223.577	-0.030	-0.201	1.058	-0.009	0.004	-0.028

- **Error quantification:**

$$\left| \frac{"real"\ \ SFOC - calculated\ SFOC}{"real"\ \ SFOC} \right| \cdot 100\%$$

Error of 1st approach	Error of 2nd approach
1.25%	1.20%

Second Module: Emissions - Development

- **Corrections in calculated SFOC: account for (a) *fuel type*, (b) *air intake temperature*, (c) *sea cooling water inlet temperature* (following MAN guidelines)**

- **Fuel options:**

(i) Heavy Fuel Oil (HFO)
(ii) Low Sulfur Heavy Fuel Oil (LSHFO)
(iii) Marine Diesel Oil (MDO)

- **Emission factors (*EF*) for calculating CO_2, NO_x and SO_x:**

CO_2	3.114 (tn CO_2 /tn fuel)	Iosifidi (2020)
NO_x	0.092 (tn NO_x /tn fuel)	Entec (2002)
SO_x	2.023 x S by mass (tn SO_x /tn S in fuel)	Iosifidi (2020)

- **Emissions calculation:**

$$Emissions\left(\frac{gr}{hr}\right) = P(kW) \cdot SFOC\left(\frac{gr}{kWhr}\right) \cdot EF$$

Second Module: Emissions

➢ Emission Calculation Examples:

- **Different bulk carrier types (*all subclasses were considered*): *minimum*, *average* and *maximum* values of all input data parameters**
- **Two different computational approaches (regression analyses)**
- **Calculation of SFOC → modified SFOC → CO_2, NO_X and SO_X emissions**

➢ Range of input variables:

	Displacement (tn)		Speed (kn)		Draft (m)		Power (kW)		Air Inlet Temperature (°C)		Cooling Water Temperature (°C)	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*
Handysize	25417	42921	11.0	14.0	5.0	10.71	2208	6734	20	50	5	35
Handymax	42931	65765	11.3	14.5	7.5	12.9	2965	9659				
Panamax	65833	93883	11.6	14.5	10	14.42	4437	11693				
Capesize	93898	225860	11.6	14.5	12	18.03	4646	21129				
VLBC	229150	445554	11.6	14.5	14	22.79	10308	36521				

Second Module: Emissions – First approach

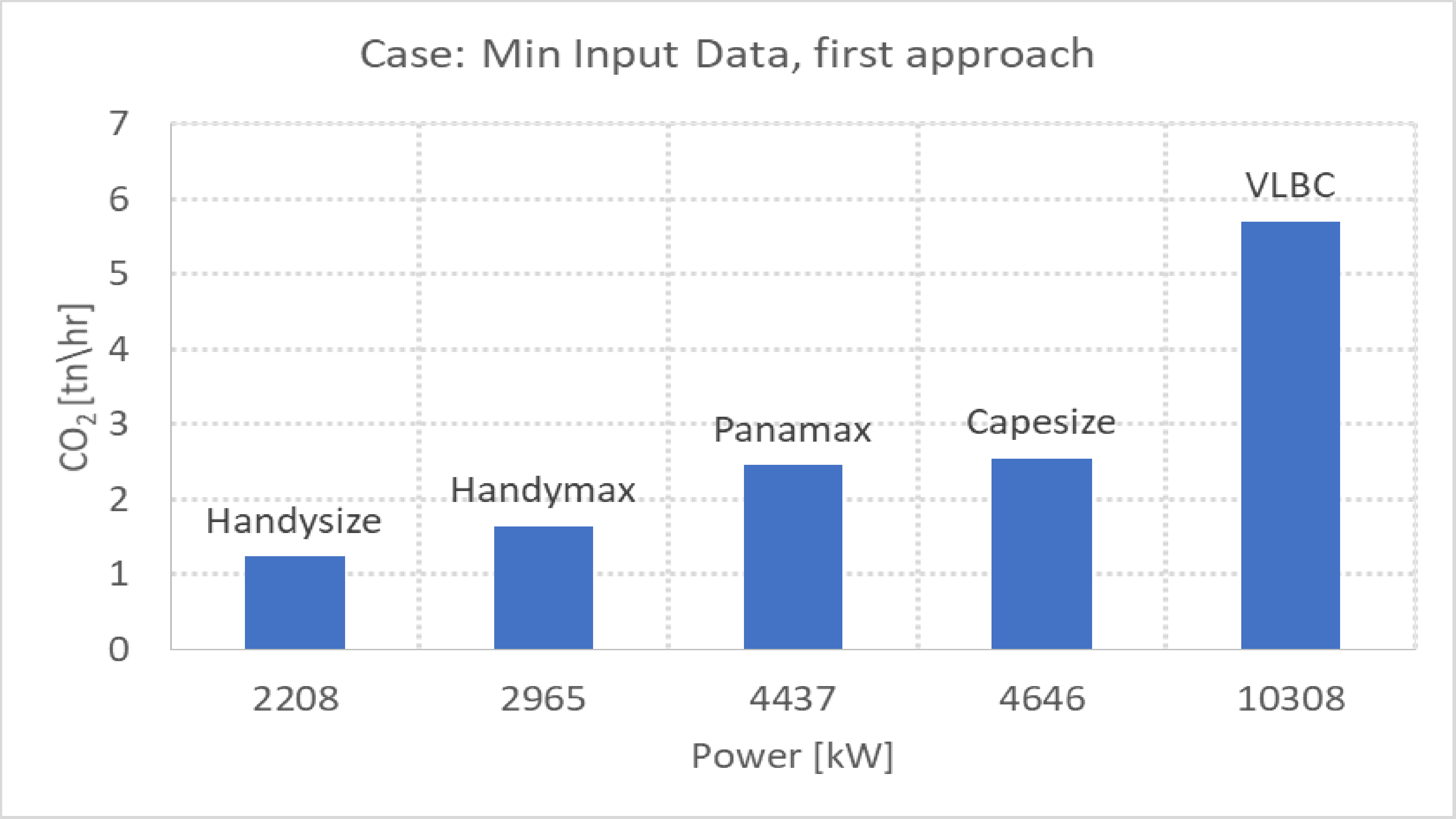
- **Fuel considered: Heavy Fuel Oil with Sulfur content 2.7% by mass**

- **Minimum values of input variables:**

	Displacement (tn)	Speed (kn)	Draft (m)	Power (kW)	Air Inlet Temperature (°C)	Cooling Water Temperature (°C)
Handysize	25417	11.0	5.0	2208	20	5
Handymax	42931	11.3	7.5	2965	20	5
Panamax	65833	11.6	10	4437	20	5
Capesize	93898	11.6	12	4664	20	5
VLBC	229150	11.6	14	10308	20	5

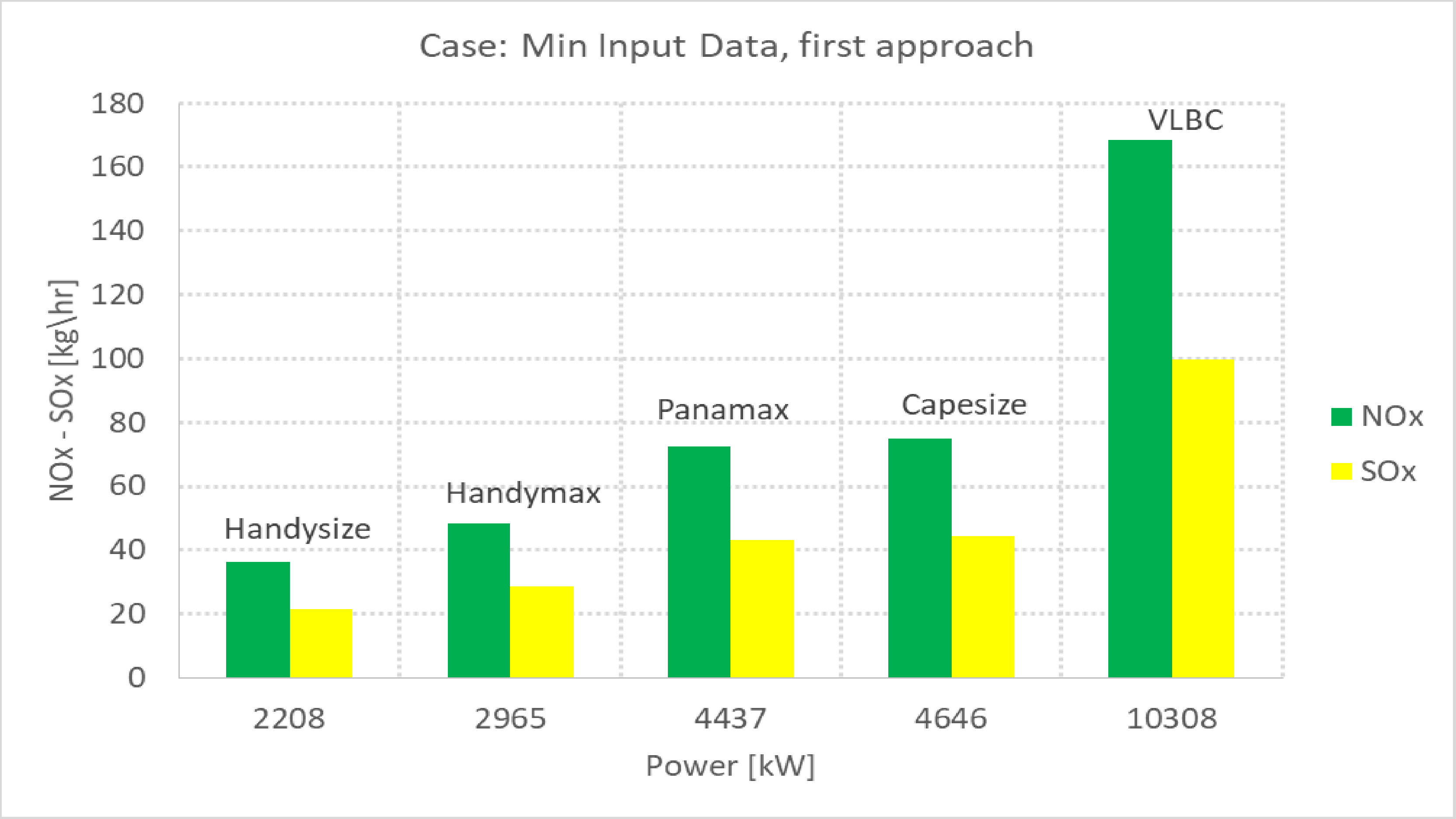
Second Module: Emissions – First approach

➢ Results: CO_2



Second Module: Emissions – First approach

➢ **Results: NO_x - SO_x**



Second Module: Emissions – First approach

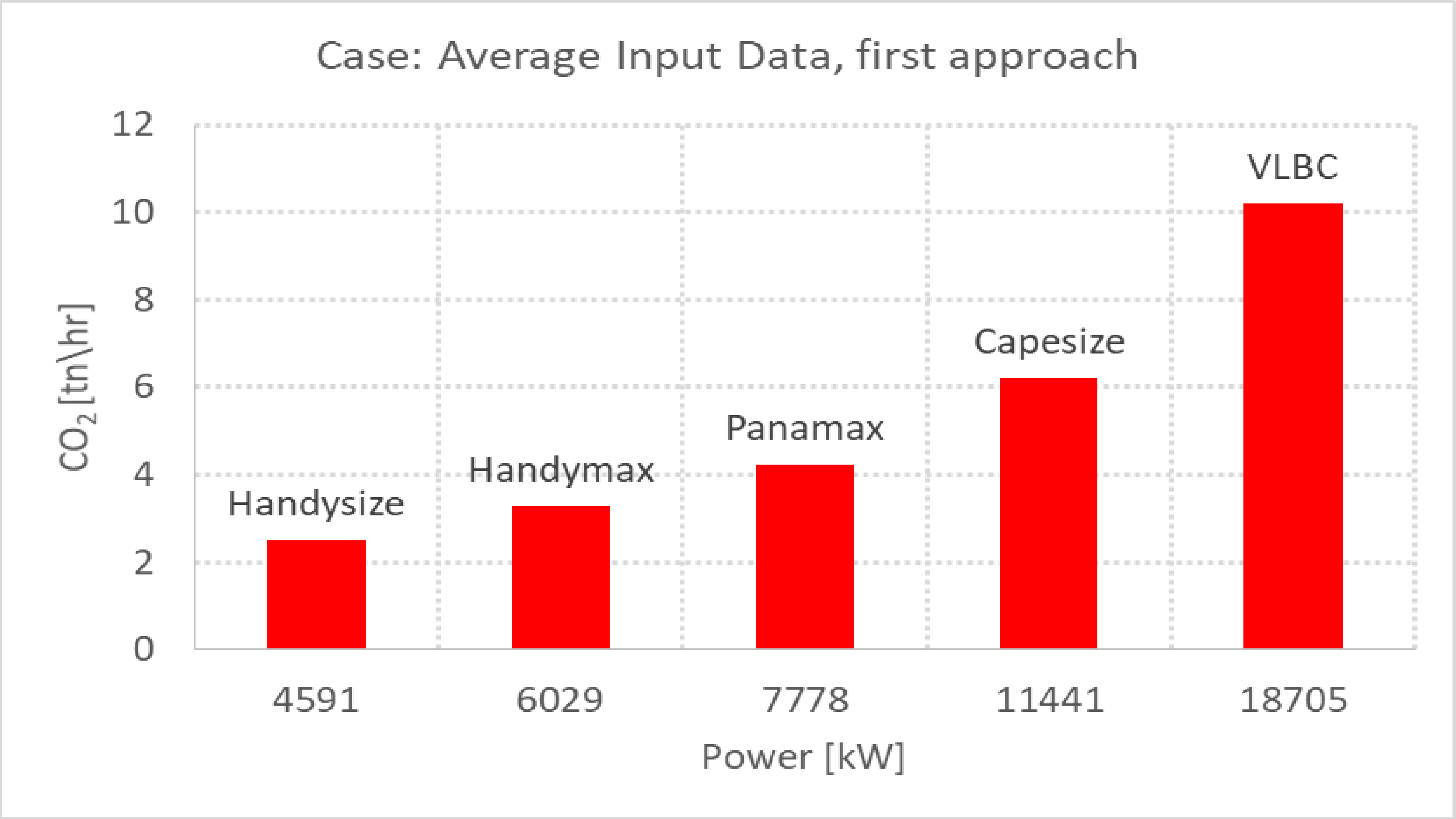
- **Fuel considered: Heavy Fuel Oil with Sulfur content 2.7% by mass**

- **Average values of input variables:**

	Displacement (tn)	Speed (kn)	Draft (m)	Power (kW)	Air Inlet Temperature (°C)	Cooling Water Temperature (°C)
Handysize	37837	13.7	8.74	4591	35	20
Handymax	52138	14.1	9.67	6029	35	20
Panamax	74879	14.4	11.37	7778	35	20
Capesize	141025	14.4	13.52	11441	35	20
VLBC	275495	14.4	16.28	18705	35	20

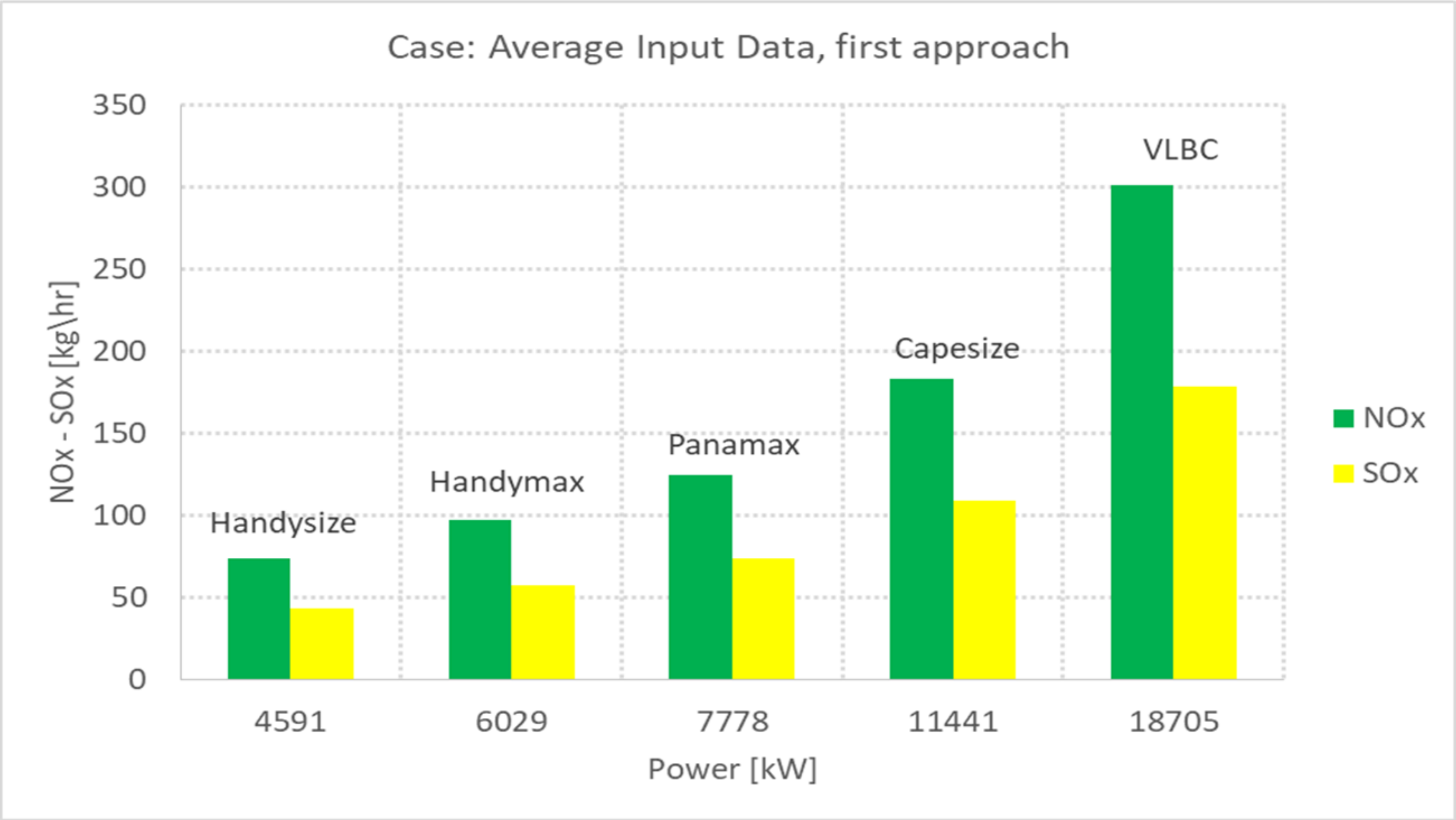
Second Module: Emissions – First approach

➢ **Results: CO_2**



Second Module: Emissions – First approach

➢ **Results: NO_x - SO_x**



Second Module: Emissions – First approach

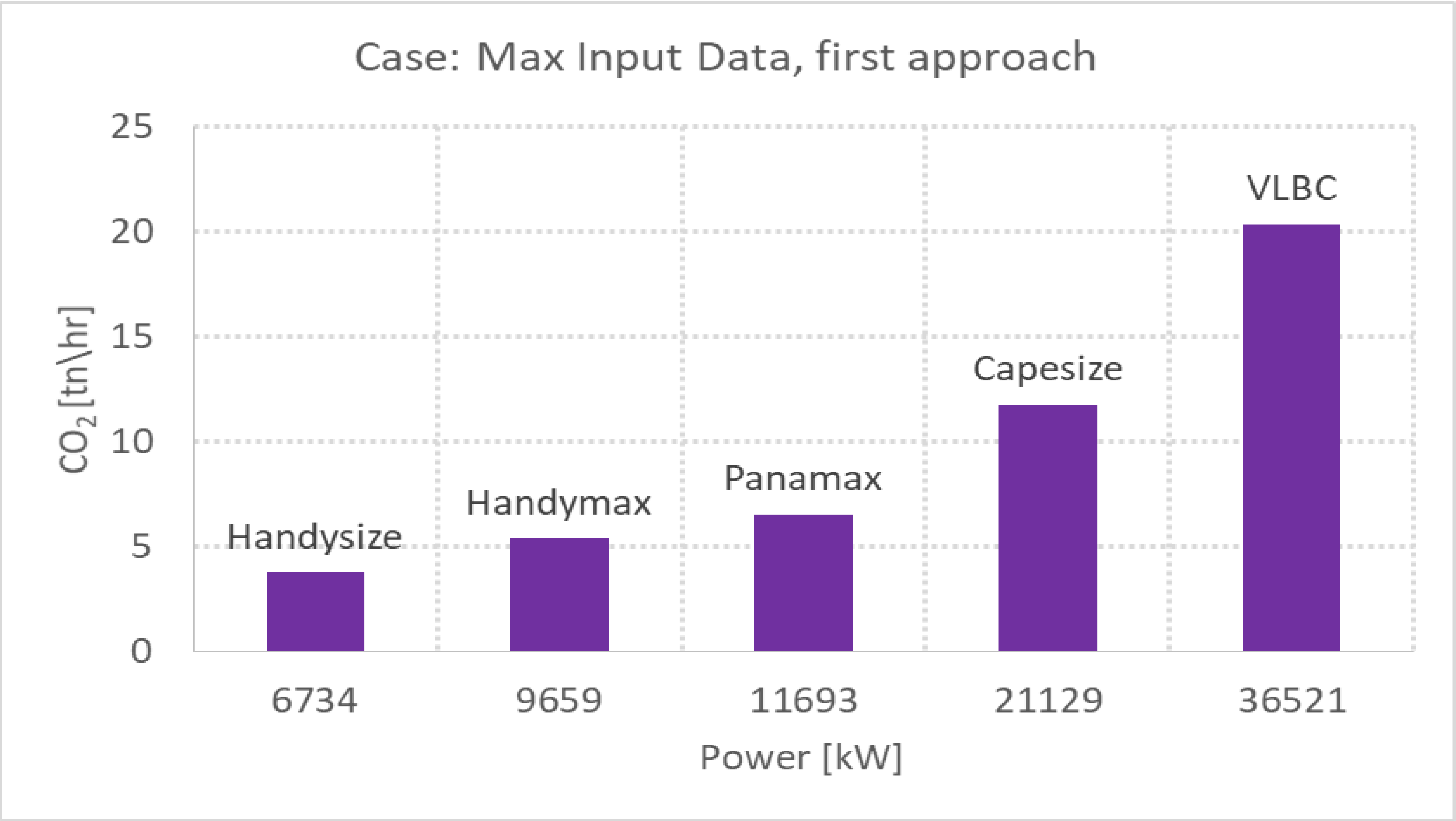
- **Fuel considered**: Heavy Fuel Oil with Sulfur content 2.7% by mass

- **Maximum values of input variables:**

	Displacement (tn)	Speed (kn)	Draft (m)	Power (kW)	Air Inlet Temperature (°C)	Cooling Water Temperature (°C)
Handysize	42921	14.0	10.71	6734	50	35
Handymax	65765	14.5	12.90	9659	50	35
Panamax	93883	14.5	14.42	11693	50	35
Capesize	225860	14.5	18.03	21129	50	35
VLBC	445554	14.5	22.79	36521	50	35

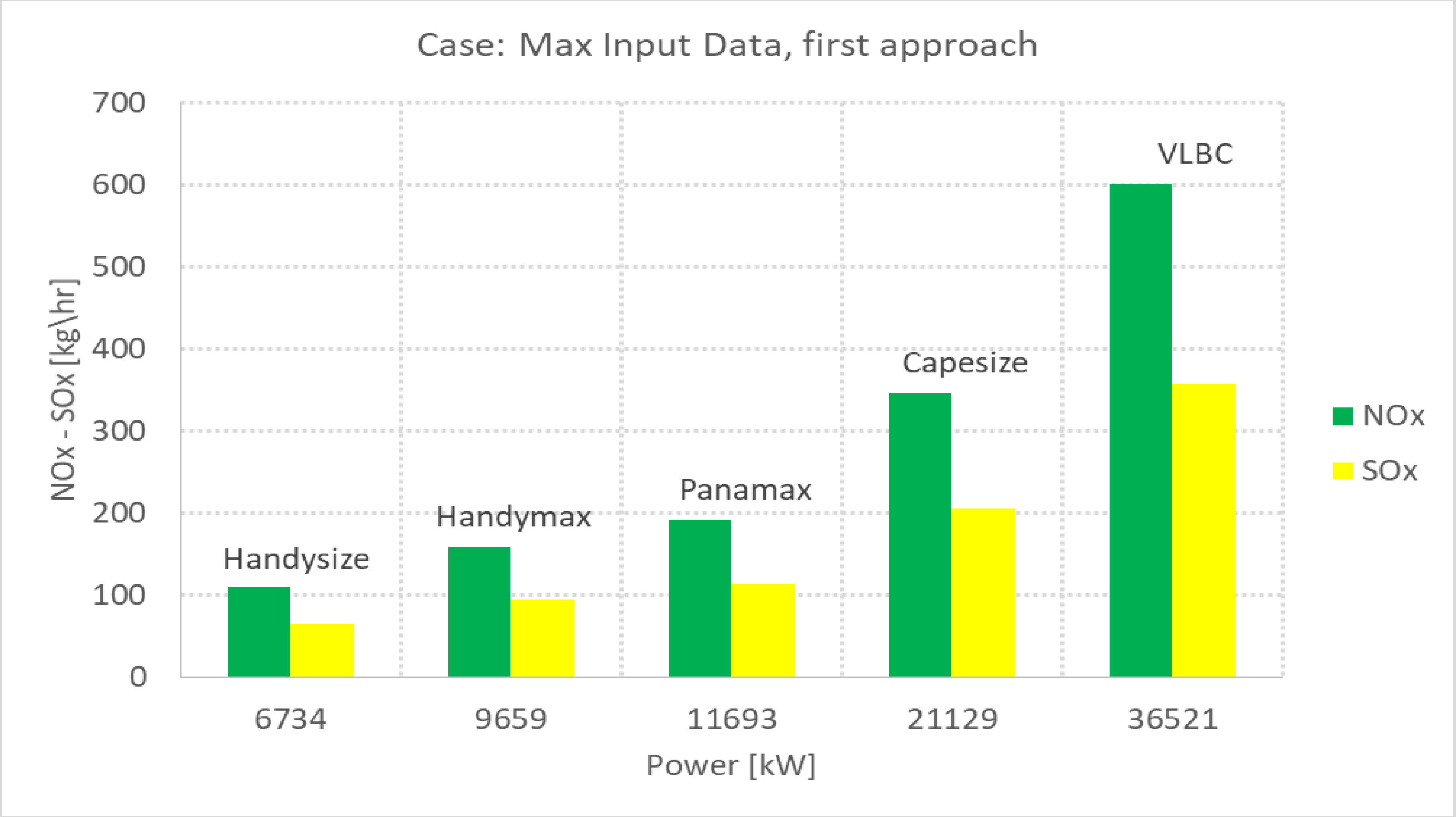
Second Module: Emissions – First approach

➢ **Results**: CO_2



Second Module: Emissions – First approach

➢ **Results: NO_x - SO_x**



Second Module: Emissions – Second approach

- **Fuel considered: Heavy Fuel Oil with S content 2.7% by mass**

- **Minimum values of input variables (same as for first approach):**

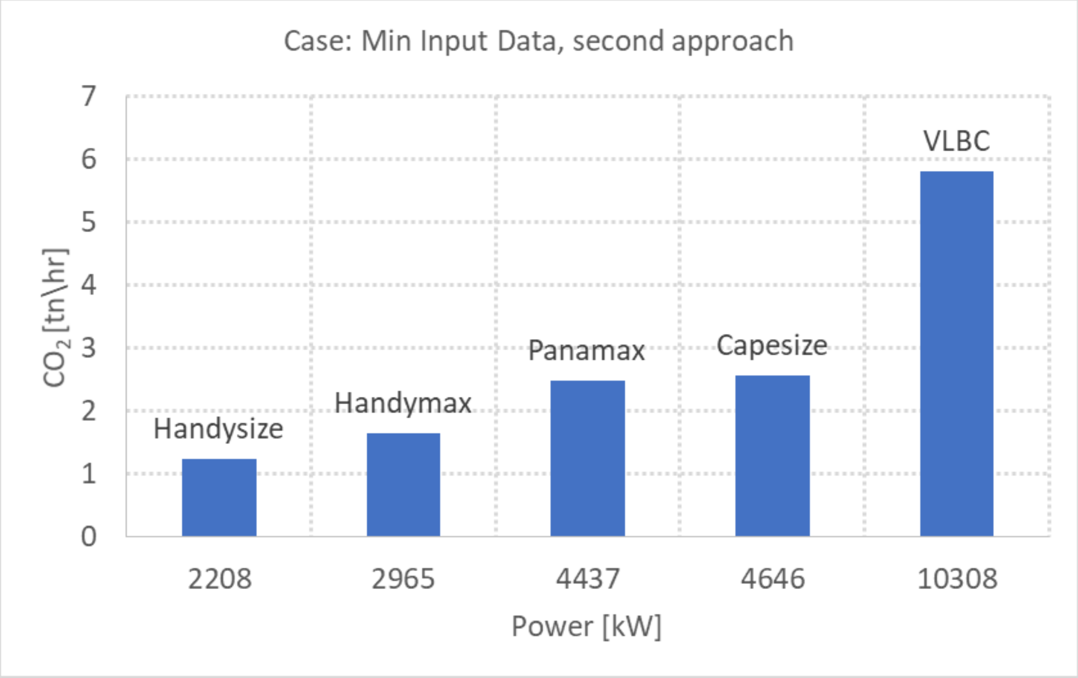
	Displacement (tn)	Speed (kn)	Draft (m)	Power (kW)	Air Inlet Temperature (°C)	Cooling Water Temperature (°C)
Handysize	25417	11.0	5.0	2208	20	5
Handymax	42931	11.3	7.5	2965	20	5
Panamax	65833	11.6	10	4437	20	5
Capesize	93898	11.6	12	4664	20	5
VLBC	229150	11.6	14	10308	20	5

Second Module: Emissions – Second approach

➢ Supplementary input variables: minimum values

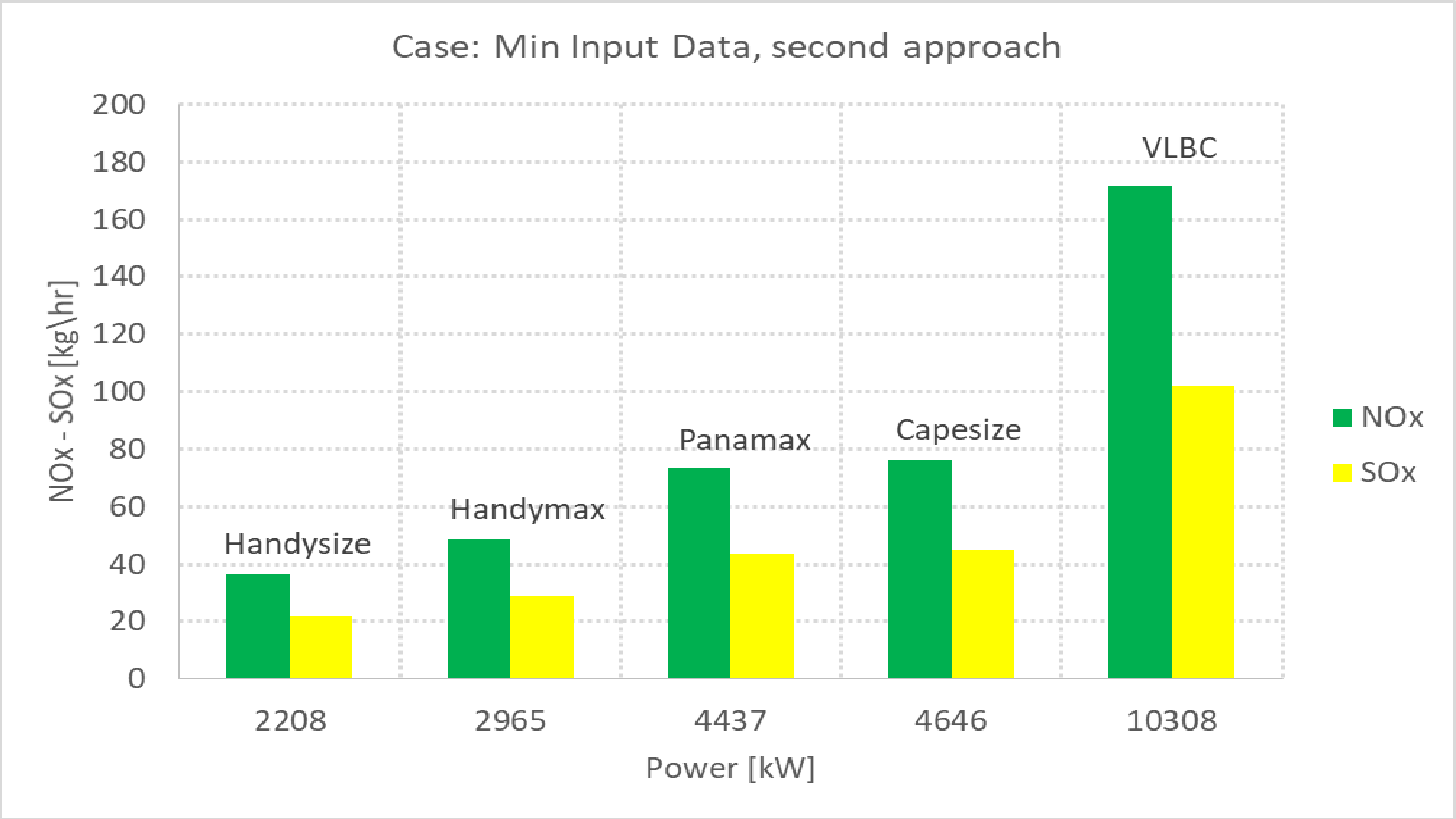
	Cylinders	Stroke(m)	bore (m)
Handysize	5	1.77	0.40
Handymax	5	2.00	0.45
Panamax	5	2.40	0.50
Capesize	5	2.40	0.50
VLBC	5	2.21	0.50

➢ Results: CO_2



Second Module: Emissions – Second approach

➢ Results: NO_x - SO_x



Second Module: Emissions – Second approach

- **Average values of input variables (same as for first approach):**

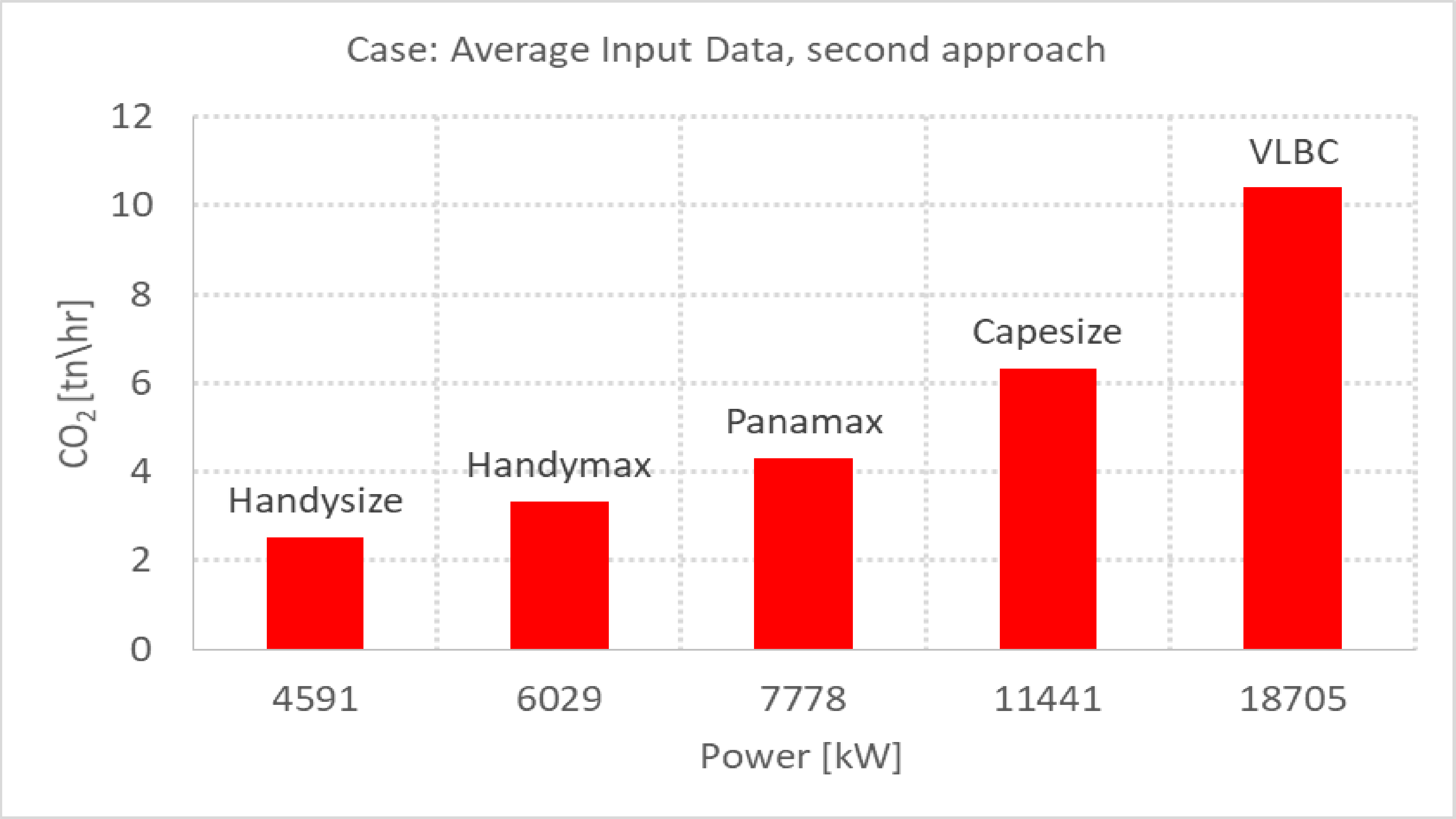
	Displacement (tn)	Speed (kn)	Draft (m)	Power (kW)	Air Inlet Temperature (°C)	Cooling Water Temperature (°C)
Handysize	37837	13.7	8.74	4591	35	20
Handymax	52138	14.1	9.67	6029	35	20
Panamax	74879	14.4	11.37	7778	35	20
Capesize	141025	14.4	13.52	11441	35	20
VLBC	275495	14.4	16.28	18705	35	20

- **Supplementary input variables: average values**

	Cylinders	Stroke (m)	bore (m)
Handysize	6	2.00	0.44
Handymax	6	2.15	0.49
Panamax	6	2.48	0.52
Capesize	7	2.82	0.59
VLBC	7	3.25	0.74

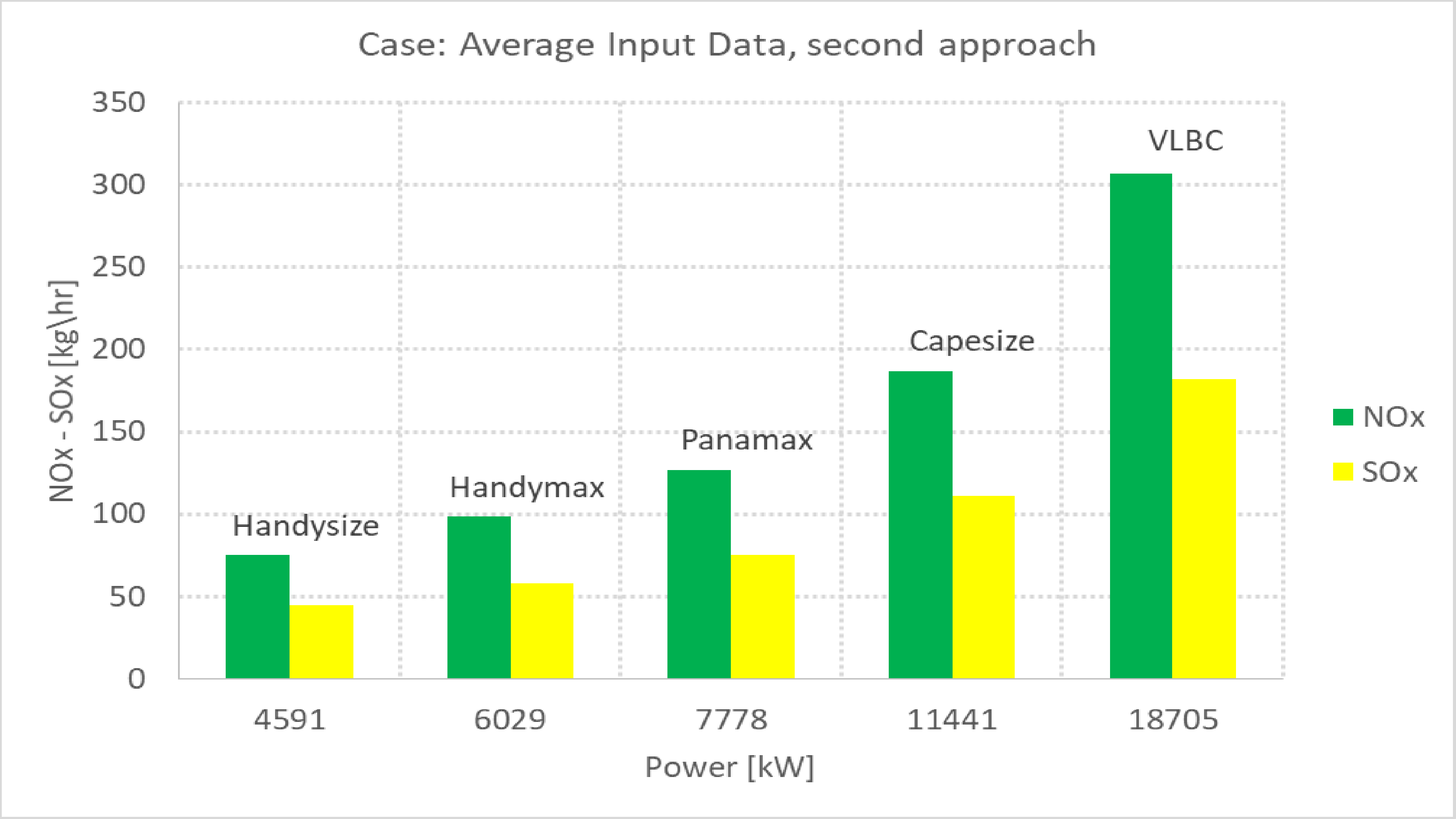
Second Module: Emissions – Second approach

➢ **Results: CO_2**



Second Module: Emissions – Second approach

➢ **Results: NO_x - SO_x**



Second Module: Emissions – Second approach

- **Maximum values of input variables (same as for the first approach):**

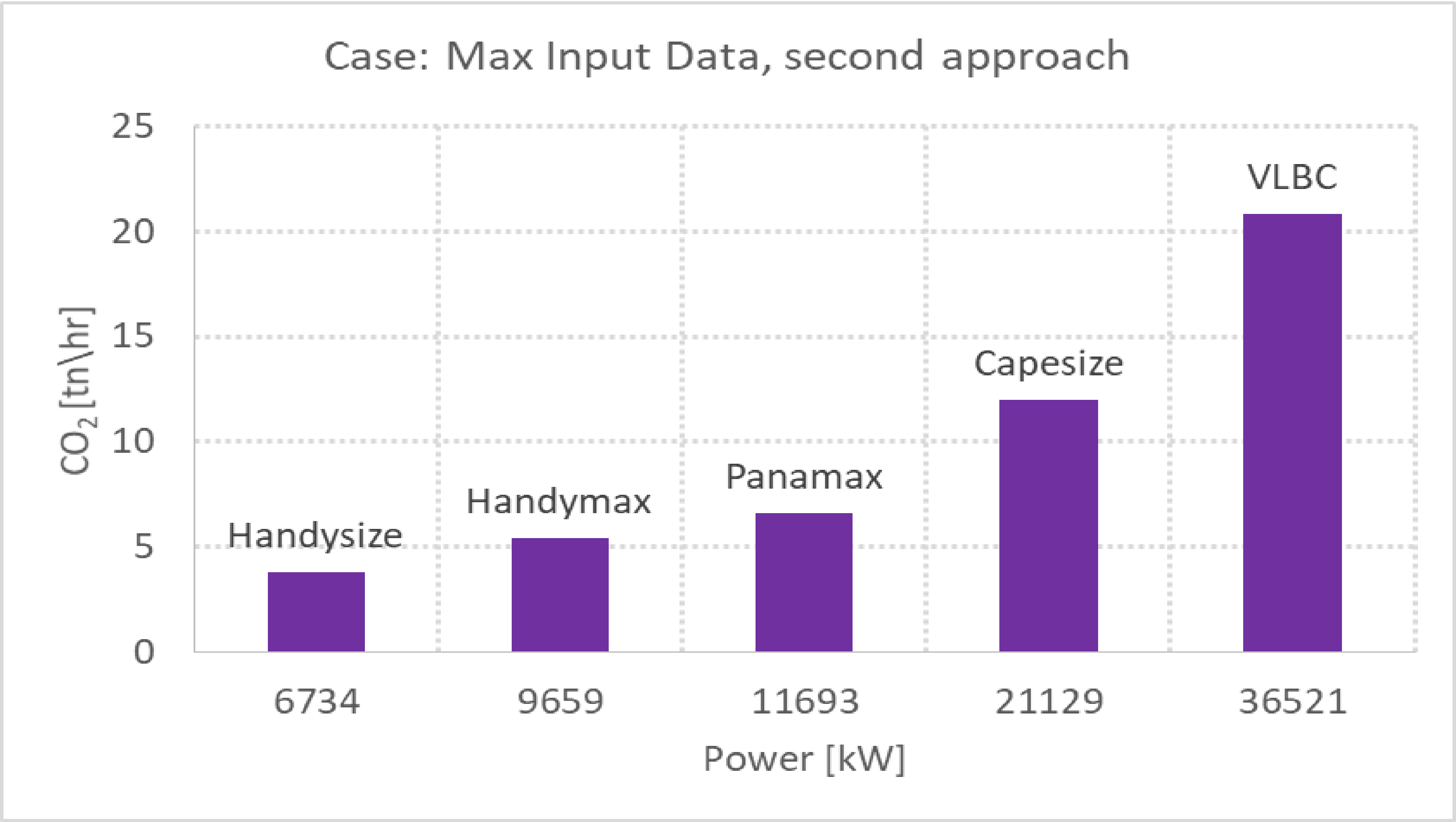
	Displacement (tn)	Speed (kn)	Draft (m)	Power (kW)	Air Inlet Temperature (°C)	Cooling Water Temperature (°C)
Handysize	42921	14.0	10.71	6734	50	35
Handymax	65765	14.5	12.90	9659	50	35
Panamax	93883	14.5	14.42	11693	50	35
Capesize	225860	14.5	18.03	21129	50	35
VLBC	445554	14.5	22.79	36521	50	35

- **Supplementary input variables: maximum values**

	Cylinders	Stroke (m)	bore (m)
Handysize	8	2.25	0.50
Handymax	7	2.50	0.60
Panamax	8	2.50	0.60
Capesize	8	3.26	0.70
VLBC	8	3.72	0.95

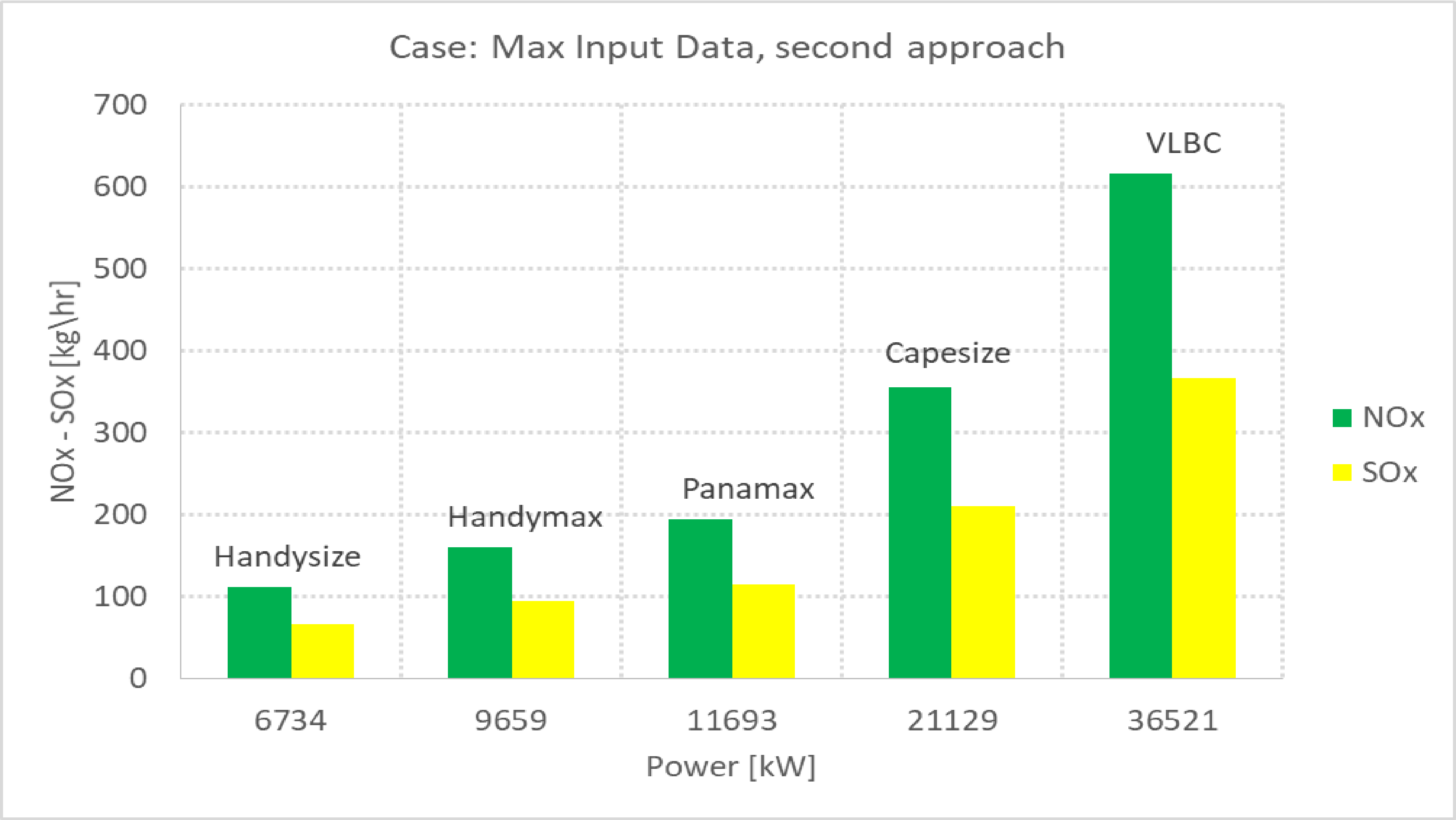
Second Module: Emissions – Second approach

- **Results: CO_2**



Second Module: Emissions – Second approach

➢ **Results: NO_x - SO_x**



Questions?