Data-Driven Explainable Artificial Intelligence for Energy Efficiency in Short-Sea Shipping

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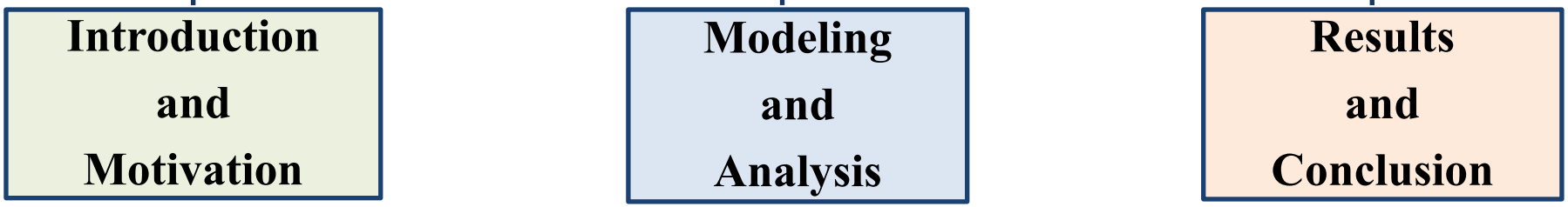
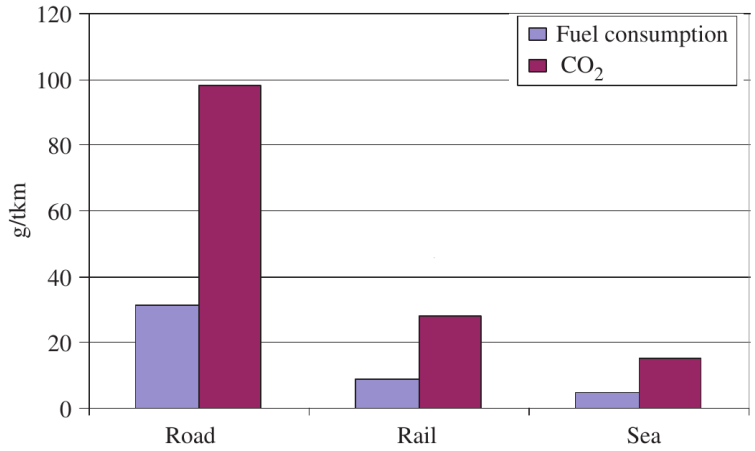
Data-Driven Explainable Artificial Intelligence (XAI) for Energy Efficiency in Short-Sea Shipping (SSS)



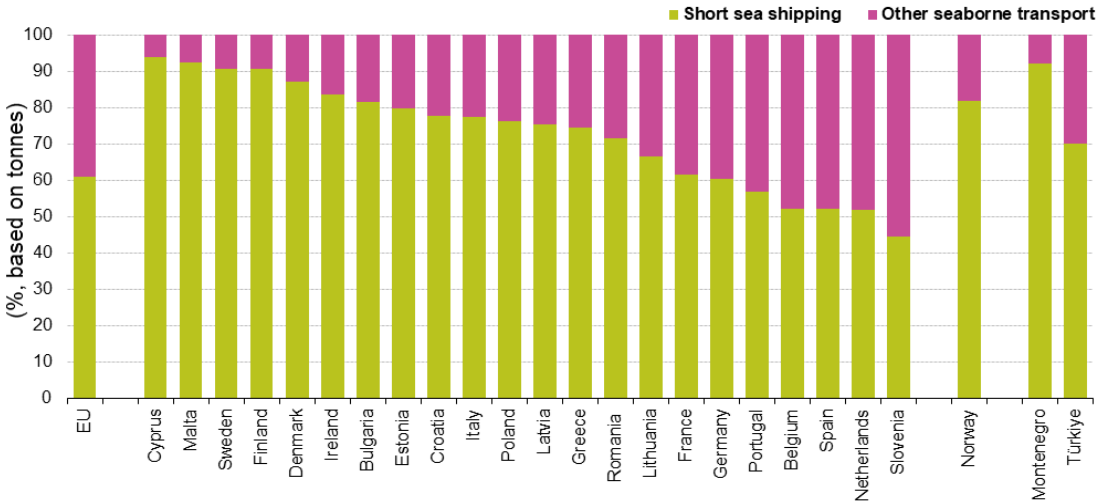
Introduction

Short Sea Shipping (SSS) is the maritime transport of goods over relatively short distances, as opposed to the intercontinental cross-ocean/deep-sea shipping.

International Maritime Organization (IMO) set up regulations to cut CO_2 to **40%** by **2030** and cut **50%** of **all GHGs** by **2050**, based on the emissions in 2008.
[1] Source Link

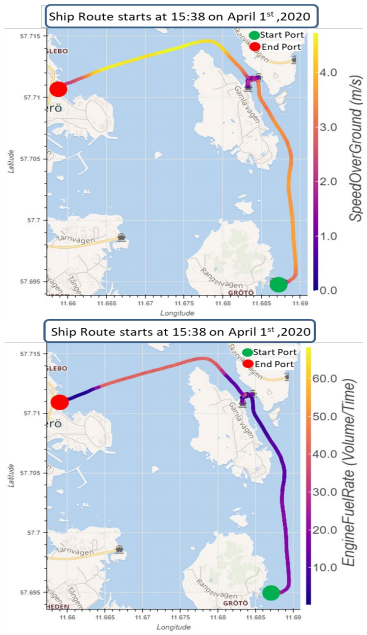


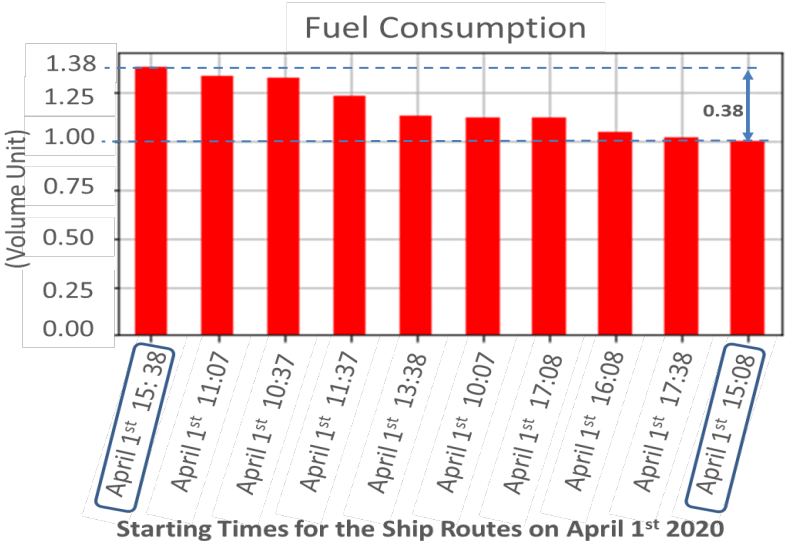
Average environmental impact of different transportation modes per tonne-kilometer (in terms of fuel consumption and CO_2 emission)
[2] Source Link

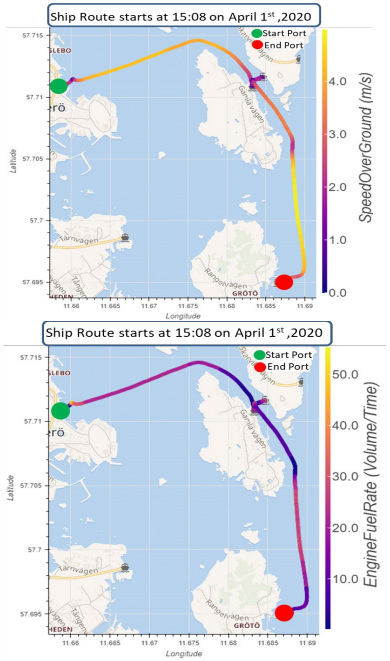


European short-sea shipping of freight versus total sea transport, in 2021
[3] https://ec.europa.eu/eurostat

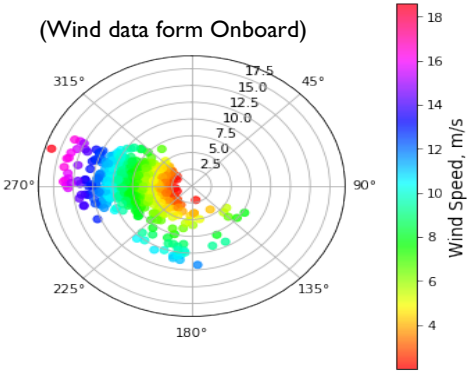
What is the most suitable approach for analyzing and capturing the critical factors influencing the vessel's fuel consumption in SSS?

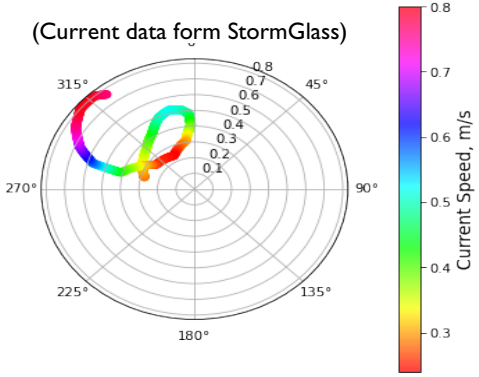


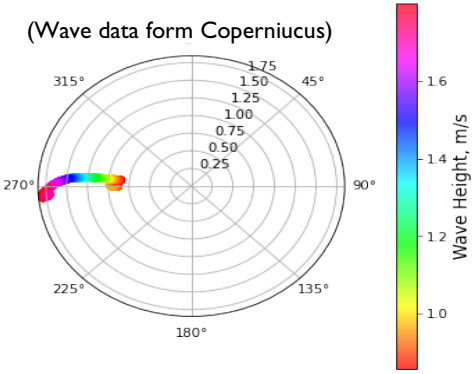




Wind, Current, and Wave, 1min-Avg., April 1st 2020

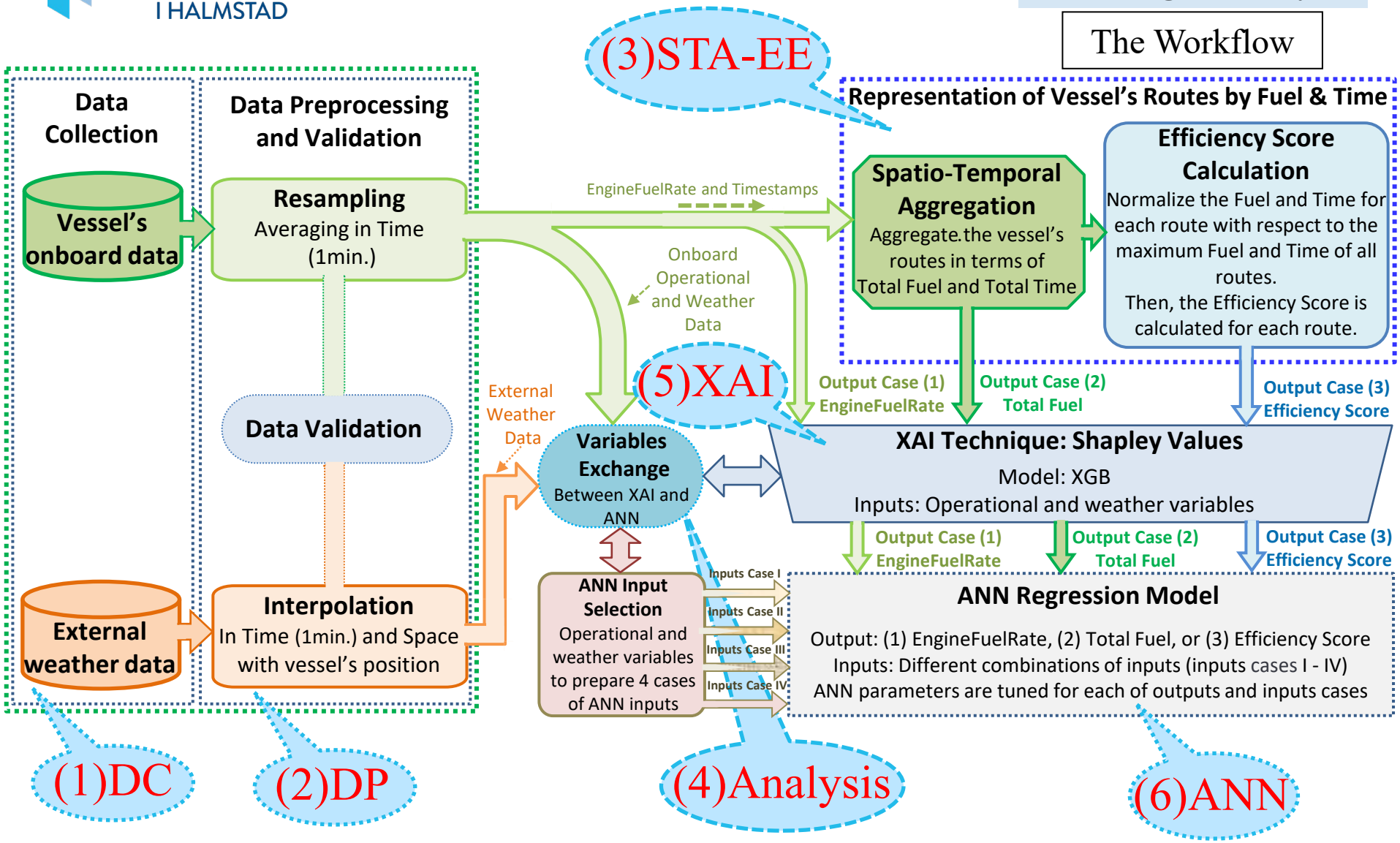






Modeling & Analysis

The Workflow

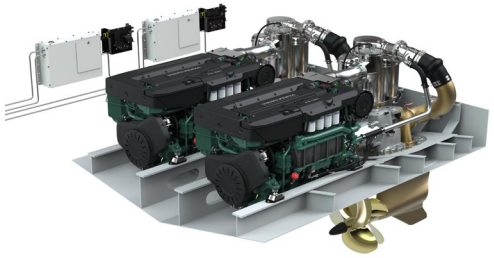


The Workflow of the Methodology

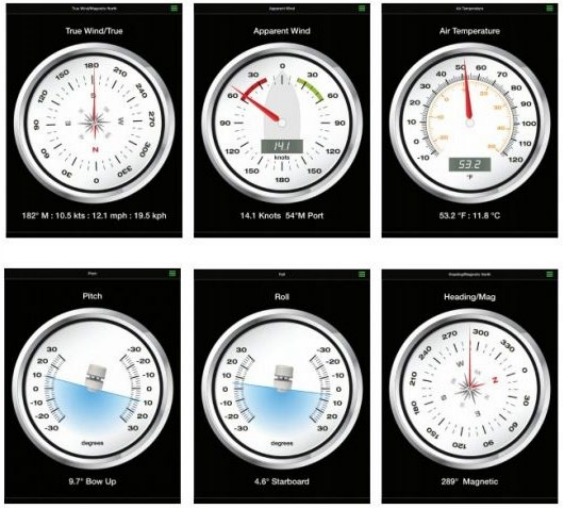
The vessel's onboard data have been received from our industry partner CetaSol AB in Gothenburg [4]. It has been gathered from January 2020 to March 2021.
It has a 3Hz frequency and records about the ship's position, course direction, and speed. It is also including some of operational and meteorological data.

Vessel name: Buro; Type: A passenger ship,
Size:(Length by Breadth) 19m * 6.41m; Average speed is 8.2 knots(4.2 m/s)

The Vessel, is named Buro [5]



Engine Volvo Penta [6]



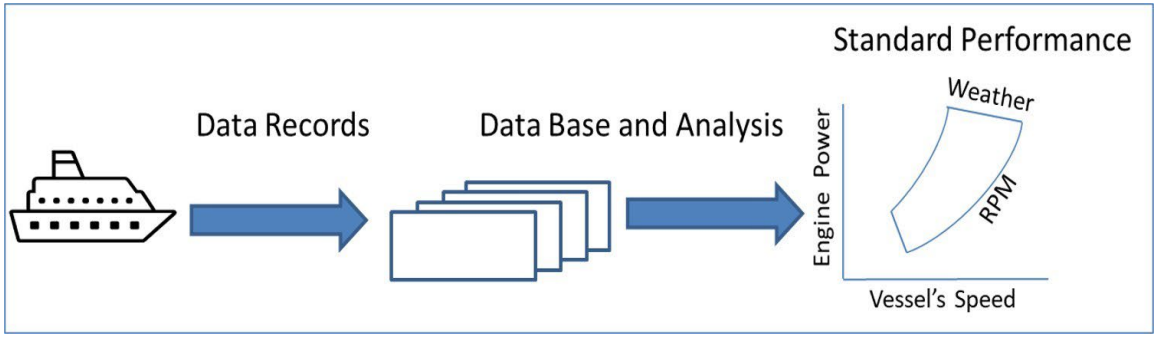
Some of Vessel's Motion and Environmental Data are Collected from an Instrument, which has been installed on the Vessel [7].

[4] CetaSol AB ." [Online]. Available: https://cetasol.com/
[5] https://www.marinetraffic.com/
[6] Engine Volvo Penta tier13 A2022 8398." [Online]. Available: Source Link
[7] https://www.boatsnews.com/story/18720/the-weather-station-in-airmar-a-real-swiss-army-knife

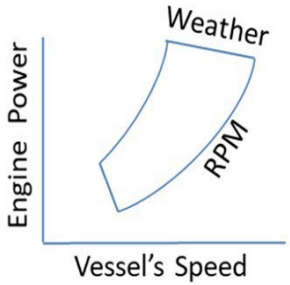
(2)DP

Modeling & Analysis

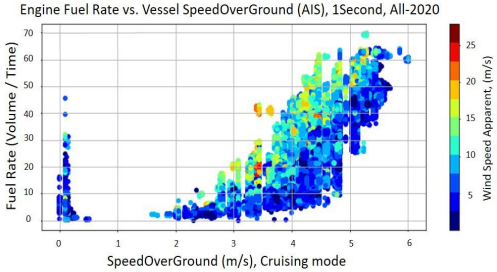
Data Processing



The vessel's data analytics

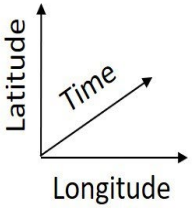


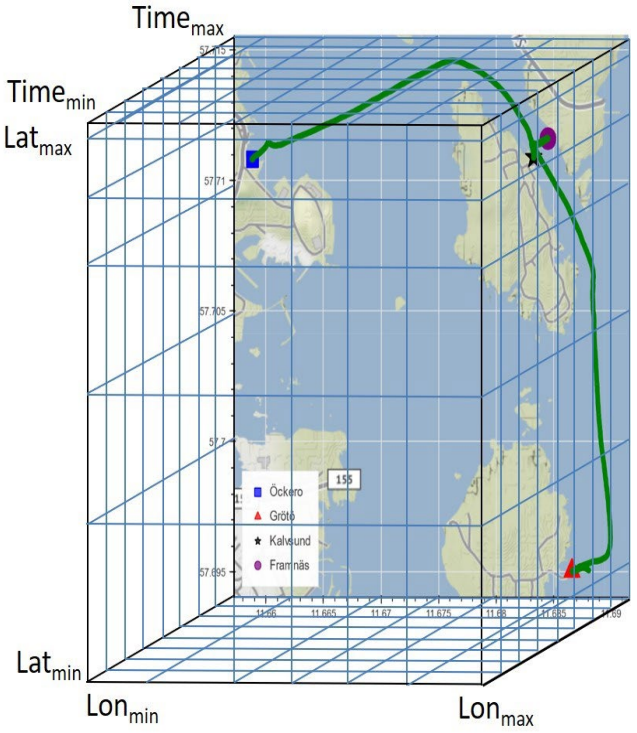
(a) Ship standard performance [8].



(b) Vessel Buro's Standard Performance Graph.

Data: Averaged values of available features of Onboard and Weather data from External Sources. [9, 10]





Trilinear Interpolation

[8] J. Carlton, Marine propellers and propulsion. Butterworth-Heinemann, 2018.
[9] Copernicus Marine Service. [Online]. Available: https://marine.copernicus.eu/
[10] Stormglass API . [Online]. Available: https://stormglass.io/

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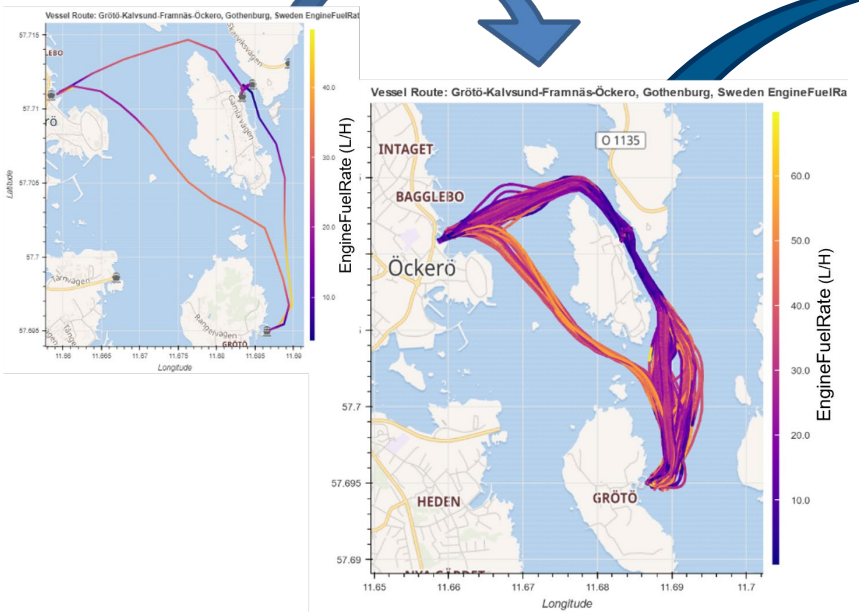
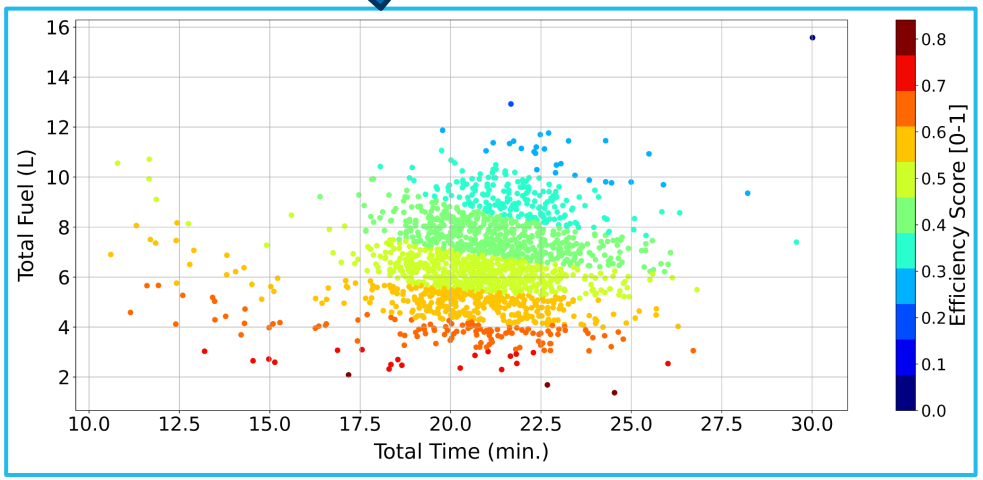
Modeling & Analysis

Spatio-temporal Aggregation & Energy Efficiency Modeling



The vessel routes are mapped by latitude and longitude.



The vessel's routes are projected by aggregated Efficiency Score in dimensions of fuel and time.

$$Eff_{socre} = 1 - \frac{2*(Fuel\ Total_{norm} * Time\ Total_{norm})}{(Fuel\ Total_{norm} + Time\ Total_{norm})}$$

(4)Analysis

Modeling & Analysis

Multiple Cases of Inputs and Outputs

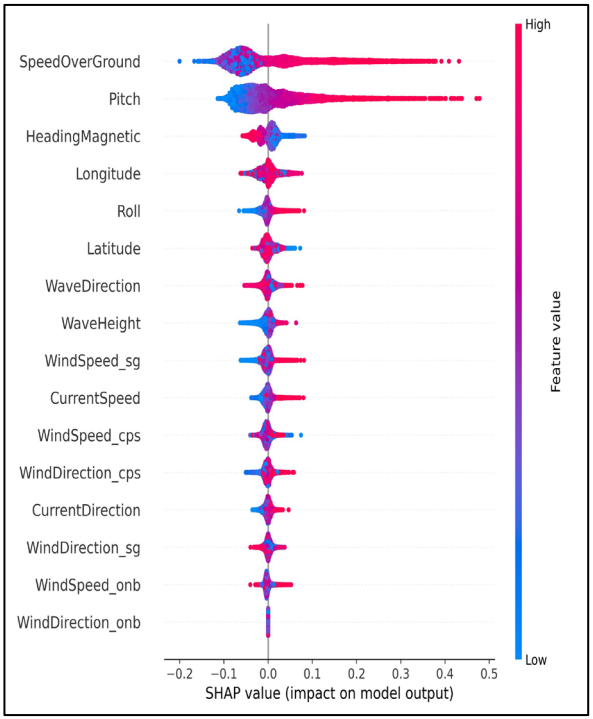
Inputs Description

Inputs Case	Inputs	No.# of Inputs	Inputs of ANN
I	Navigation and Weather (Weather=wind speed and direction from onboard data)	6	[latitude, longitude , speedOverGround , headingMagnetic , windSpeed_onboard , windDirection_onboard]
II	Navigation and Weather (wind, wave, current, all from external sources)	12	[latitude , longitude , speedOverGround , headingMagnetic , waveheight , wavedirect , windSpeed_cds , windSpeed_sg , windDirection_cds , windDirection_sg , currentSpeed , currentDirection]
III	Navigation and Weather (wind onboard, wave & current from external sources)	10	[latitude , longitude , speedOverGround , headingMagnetic , windSpeed_onboard , windDirection_onboard , waveheight , wavedirect , currentSpeed , currentDirection]
IV	Navigation and Weather (wind, wave, current) (onboard & external sources)	14	[latitude , longitude , speedOverGround , headingMagnetic , windSpeed_onboard , windDirection_onboard , windSpeed_cds , windSpeed_sg , windDirection_cds , windDirection_sg , waveheight , wavedirect , currentSpeed , currentDirection]

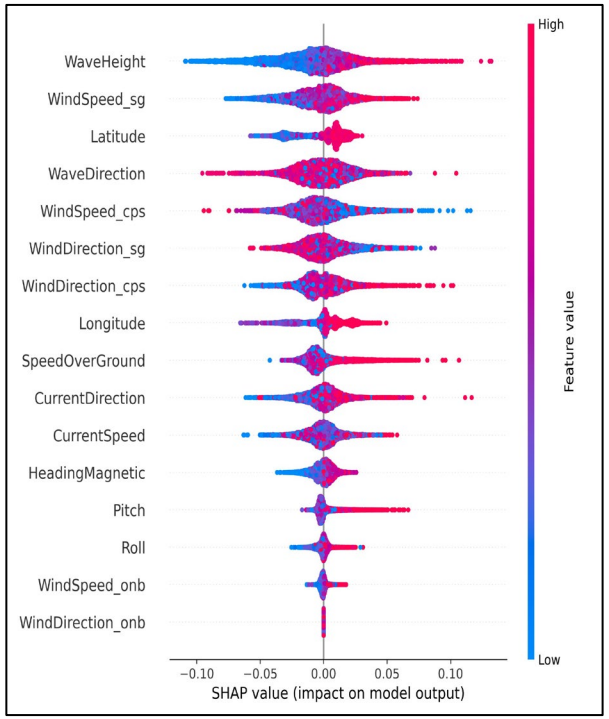
1) ANN output is **EngineFuelRate**

2) ANN output is **Total Fuel**

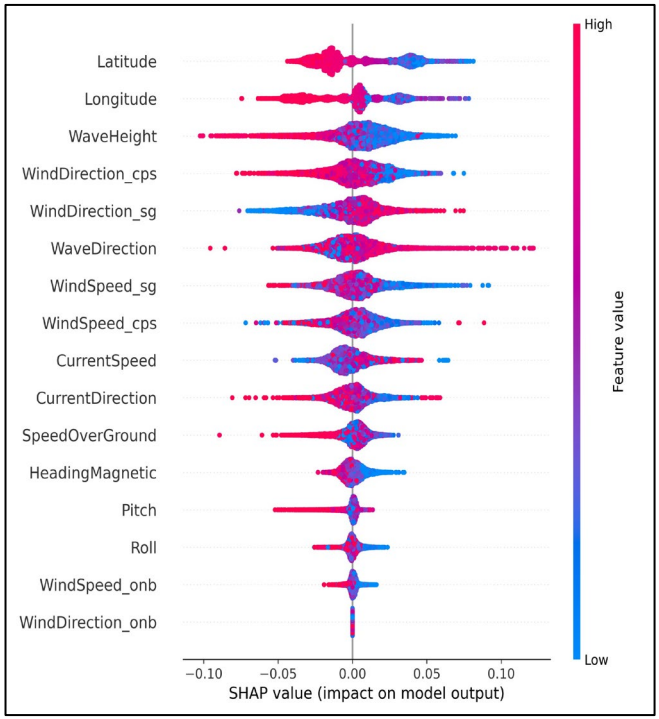
3) ANN output is **Efficiency Score**



(a)Model's output is EngineFuelRate, (b)(R2=0.7615)



(b) Model's output is Total Fuel, (R^2=0.8400)



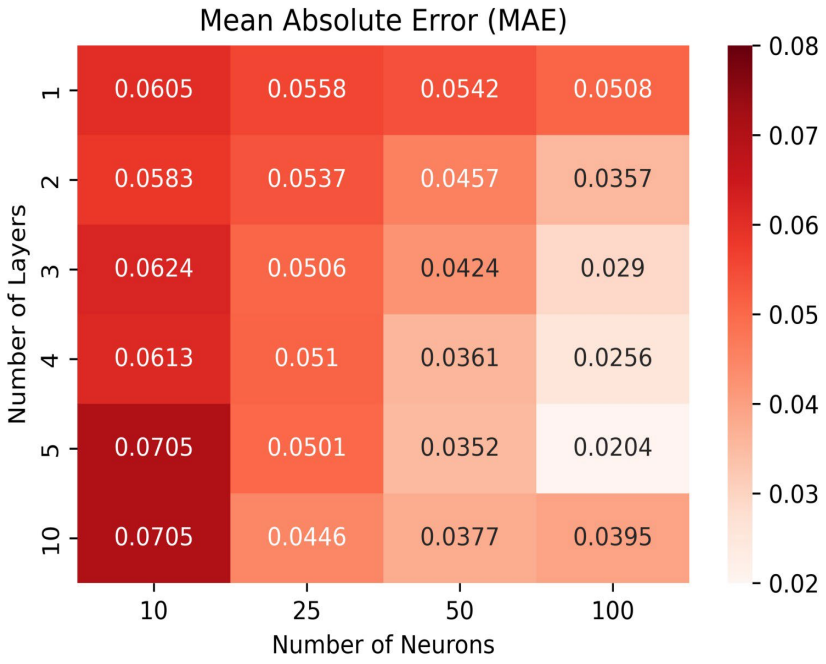
(c) Model's output is Efficiency Score, (R^2=0.8324)

Beeswarm plots of SHAP values for the regression model with different outputs

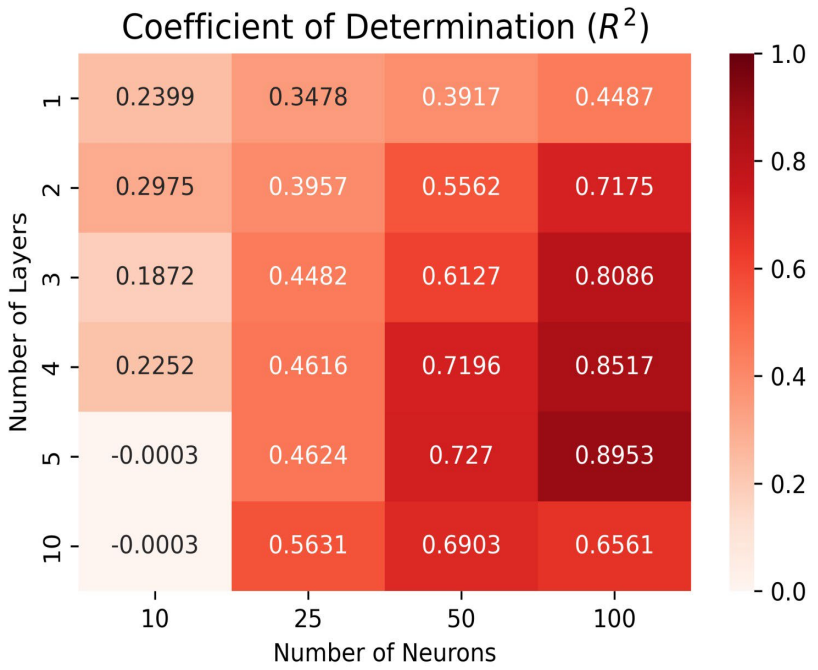
Shapley additive explanations (SHAP) [11], a technique is employing the SHAP package, which is publicly available in Python [12].

[11] Lundberg, S.M., Lee, S.I.: A unified approach to interpreting model predictions. Advances in neural information processing systems 30 (2017)

12. Shap package. [Online]. Available: https://github.com/slundberg/shap



(a) Results in MAE for ANN Structure Search



(b) Results in R^2 for ANN Structure Search

Grid search results for the best ANN structure,
with Efficiency Score output.

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Results

Multiple Cases of Inputs and Outputs

Inputs Description

Inputs Case	Inputs	No.# of Inputs	Inputs of ANN
I	Navigation and Weather (Weather=wind speed and direction from onboard data)	6	[latitude, longitude , speedOverGround , headingMagnetic , windSpeed_onboard , windDirection_onboard]
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ANN Regression

1) ANN output is **EngineFuelRate**

2) ANN output is **Total Fuel**

3) ANN output is **Efficiency Score**

Inputs Case	No.# ANN Inputs	ANN Layers #	ANN Neurons #	RMSE	R2	MAE
I	6					
II	12					
III	10					
IV	14					

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Results

ANN Regression

1) ANN output is **EngineFuelRate**

Inputs Case	No.# ANN Inputs	ANN Layers #	ANN Neurons #	RMSE	R2	MAE
I	6	10	100	0.0852	0.7153	0.0631
II	12	4	100	0.0730	0.7909	0.0544
III	10	5	100	0.0714	0.8001	0.0531
IV	14	4	100	**0.0698**	**0.8088**	**0.0516**

2) ANN output is **Total Fuel**

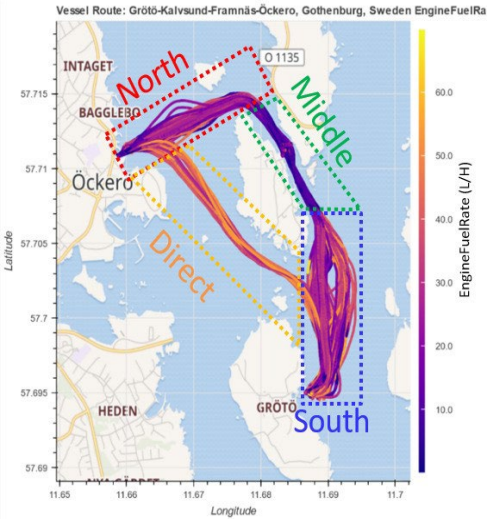
Inputs Case	No.# ANN Inputs	ANN Layers #	ANN Neurons #	RMSE	R2	MAE
I	6	4	100	0.0980	0.2074	0.0776
II	12	5	100	**0.0317**	**0.9170**	**0.0221**
III	10	5	100	0.0562	0.7398	0.0409
IV	14	5	100	0.0351	0.8986	0.0249

3) ANN output is **Efficiency Score**

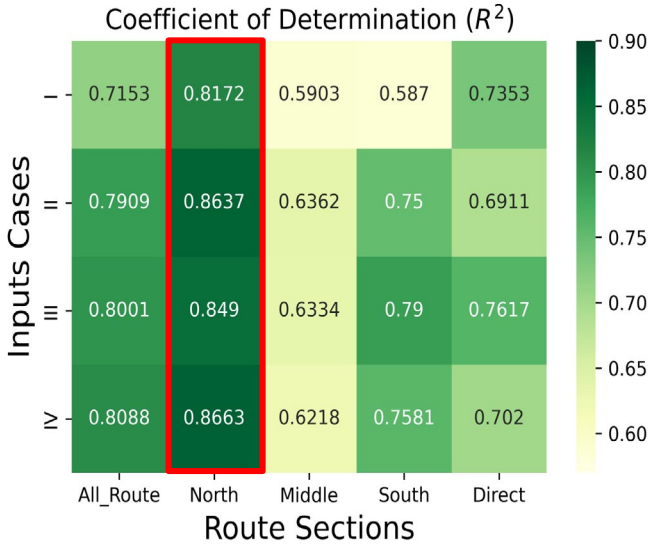
Inputs Case	No.# ANN Inputs	ANN Layers #	ANN Neurons #	RMSE	R2	MAE
I	6	3	50	0.0807	0.1886	0.0634
II	12	5	100	**0.0290**	**0.8953**	**0.0204**
III	10	4	100	0.0564	0.6037	0.0431
IV	14	5	100	0.0363	0.8361	0.0267

Results

Spatial Analysis



The vessel routes are mapped by latitude and longitude, and distributed in different sections of geographical directions



(a) EngineFuelRate

(b) Efficiency Score

Results (R^2) for ANN regression

With EngineFuelRate and Efficiency Score as outputs across different input cases in relation to varying vessel's route sections.

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Conclusion

- ✓ This study showcases how XAI with ML techniques can facilitate decision-making.
- ✓ The resulting model is based on a more comprehensive understanding of the critical factors that impact fuel efficiency, both temporally and spatially.

- ✓ ***Moving forward***, the developed model will be integrated with the vessel's energy optimization framework to provide decision support to captains on suitable speed profiles based on current and forecasted weather conditions, thereby enhancing energy efficiency.

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Thanks for your listening
Any Qs?

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