



Craft-specific Assessment of Resource Use Efficiency of Marine Fisheries in Balasore District of Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study examined the economics and Resource use efficiency of marine fishing operations during the financial year 2023-24 in the Balasore district of Odisha, India, with a focus on mechanised, motorised, and non-motorised fishing units. Using primary data from 120 respondents across six villages, namely Chandipur, Bahabalpur, Kasafal, Saudi, Budhirani and Chaumukh, the research employed cost-return analysis to evaluate input-output relationships and the Cobb-Douglas production function to find out resource efficiency. Results revealed that mechanised units,

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despite generating the highest gross returns(72.23lakhs), suffered from high operational costs and exhibited decreasing returns to a scale of 0.822. Mechanised sector exhibited MVP/MFC ratio such as food(14.62), ice(4.96) and repair and maintenance(3.79) implicating scope for increase in these input for improving production. Motorised units demonstrated increasing returns to scale of 1.353 and efficient responsiveness to key inputs depicted by efficiency ratio(MVP/MFC) such as diesel(2.91), labour(5.91), and fishing days(1.10), indicating strong potential for scaled-up productivity. Non-motorised units, though limited in scale and technology, achieved the highest input-output ratio of 1.58, reflecting superior cost efficiency. Resource efficiency analysis highlighted the underutilisation of inputs, such as labour, nets, and operational days in non-motorised sector thus reflecting addition of these resource for increased productivity. The results highlighted the importance of targeted policy measures, such as fuel-efficient technologies, skill development, and the modernisation of artisanal crafts, to improve sustainability and profitability in Odisha's marine fisheries.

Keywords: Resource efficiency; fishing operations; mechanised fishing units; sustainability.

1. INTRODUCTION

The marine ecosystem is an indispensable source of economic resources, offering an assorted range of produce that plays a vital role in global economies. India has abundant marine fishery resources endowed with an extensive coastline of 8,118 kilometres and 2.02 million square kilometres of EEZ (DOF, 2024). As the world's sixth-largest producer of marine capture fish, India accounts for 4.5% of global marine fish production (FAO, 2024).

In India, throughout the initial phase (1950–66), fishing was primarily conducted using traditional, non-mechanised vessels and equipment, with production remaining below one million tons (Sathianandan et al., 2011). The mechanisation of fishing crafts and advancements in fishing equipment have resulted in substantial marine production, reaching an impressive total of 4.495 million tonnes in the fiscal year 2023-24 (DOF, 2024). Fishermen utilise various fishing methods, including multi-day or voyage fishing, which typically lasts between 5 to 12 days, in an effort to augment their income. This practice, however, frequently leads to indiscriminate exploitation of marine resources (Narayanakumar and Sathiadhas, 2005). Thus, the Food and Agriculture Organization (FAO) initiated efforts to enhance national capacities against illegal fishing, develop participatory National Plans of Action for Small-Scale Fisheries, and integrate them into broader agrifood policies and sustainable development (FAO, 2024). According to the marine fishery census, there are currently 166,333 fishing crafts operating within the marine fisheries sector. Of this total, 42,985 (25.8%) are classified as mechanised, 97,659 (58.7%) as

motorised, and 25,689 (15.4%) as non-motorised (CMFRI-FSI-DoF, 2020).

Odisha, a coastal state, has a 480-kilometre coastline along the Bay of Bengal, accounting for 8% of India's total coastline. It comprises six maritime districts: Balasore, Bhadrak, Kendrapara, Jagatsinghpur, Puri, and Ganjam (FARD, 2024). The coastal and offshore waters of Odisha constitute a rich habitat for a wide range of high-quality pelagic and demersal resources (Sivakami and Kuriakose, 2009). The Balasore district reported the greatest fish landings at 0.52 lakh tonnes (CMFRI, 2024). According to the Office of the Additional Fisheries Officer (Marine) Balasore, the district of Balasore has 15 landing centres and a total of 1916 fishing crafts, out of which 722 are mechanised, 796 are motorised, and 398 are non-motorised. The depletion of resources targeted by mechanised fishing units, combined with rising fuel prices, presents a significant threat to the economic viability of many of these units (Aswathy et al., 2011). Furthermore, the current challenges posed by global warming and climate change have increasingly impacted the fishing sector (Kumar and Shivani, 2014).

The decline in catch per unit effort, coupled with rising operational costs, has led to the unsustainable operation of the fishing fleet, forcing some fishers to exit the business entirely (Narayanakumar et al., 2009). One key objective of fisheries management is to maximise the long-term benefits derived from marine fishery resources (Sathianandan & Jayasankar, 2009). Achieving this goal necessitates a comprehensive study of the efficient utilisation of inputs by various types of vessels and their respective production functions. To extend the

operational lifespan of vessels, fishers are investing in the installation of new, more fuel-efficient engines, modernising fishing gear systems, and adhering to effective maintenance and repair practices (Carvalho et al., 2020). This paper analyses the economics of marine fishing operations and examines production functions for efficient input allocation, aiming for sustainable use of marine resources and increased productivity per craft.

1.1 Objectives

- i. To study cost and return analysis of marine fishing operations.
- ii. To analyse the production function and evaluate the resource use efficiency of marine fishing operations.

2. MATERIALS AND METHODS

2.1 Sampling Design

Stratified multistage purposive and random sampling techniques were employed to select respondents in the Balasore district, Odisha, which was recognised for its high marine production. Two blocks, Balasore Sadar and Baliapal, were randomly selected from the district's twelve blocks. Within each block, three villages were randomly selected, and 20 respondents were chosen from each village, resulting in a total sample size of 120 respondents. The stratification was based on the different types of crafts: mechanised, motorised, and non-motorised.

2.2 Analytical Procedure

The primary data were gathered regarding the operating expenses incurred per trip, which encompassed fuel costs, labour fees, food expenditures, repair and maintenance costs, as well as various daily expenses associated with conducting fishing operations (Raju et al., 2022). Depreciation cost was worked out for investment made in establishing fishing crafts and gears and capital assets and included in the total costs.

Returns:

Gross return = Total production(in kg.) × Average price per kg.

Net return (Rs.) = Gross return – Total cost

Cost-return ratios were utilised to evaluate the overall efficiency of inputs and outputs in terms of their value. (Raju et al., 2022; Roul et al., 2023).

Operating ratio = Operating cost / Gross return

Fixed ratio = Fixed cost / Gross return

Input-Output ratio = Gross return / Total cost (Variable cost + Fixed cost)

Net cash flow (NCF) = Gross return - Operational cost

In examining the efficiency of resource use in marine production, the Cobb-Douglas production function was employed due to its parameters offering clear economic interpretations, including output elasticities and returns to scale. This characteristic facilitates a better understanding of the relationships between inputs, outputs, and various economic variables.

The mathematical form of the Cobb-Douglas production function is given by-

$$Y = aX_1^{b_1}X_2^{b_2}X_3^{b_3}X_4^{b_4}X_5^{b_5}X_6^{b_6}X_7^{b_7}e^{U_i}$$

Logarithmic form of Cobb-Douglas production function-

$$\ln Y = \ln a + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + b_7 \ln X_7 + U_i$$

where, Y = Total output (quintals/year), a = Constant or intercept value, X₁ = Diesel (litres/year), X₂ = Food/M meal (Rs./year), X₃ = Labour (Mandays/year), X₄ = Ice (Pieces/year), X₅ = Net/Gears (Kg./year), X₆ = Repair and maintenance cost (Rs./year), X₇ = Number of fishing days (Fishing days/year), b_i = Elasticity coefficient of the respective input variables (b_i = b₁, b₂, b₃, ..., b₇), U_i = Error term

The marginal value product (MVP) of a specific input refers to the increase in gross returns resulting from the addition of one more unit of that input, while keeping all other inputs constant (Panikkar and Srinath, 1991). The MVP of each Resource is calculated as-

$$MVP = MPP_{xi} \times P_y \dots\dots\dots(\text{Aswathy and Joseph, 2019})$$

where, MPP_{xi} = Marginal physical product of the ith input, P_y = Price per unit of output

$$MPP_{xi} = b_i \times \frac{\bar{Y}}{\bar{X}}$$

where, b_i = Coefficient of respective inputs, \bar{Y} = Geometric mean of Output, \bar{X} = Geometric mean of i^{th} input

The price of one unit of input is called marginal factor cost (MFC)(Akter et al., 2015). The ratio of the MVP to MFC was used to determine the resource use efficiency as shown below-

$$r = \frac{MVP}{MFC}$$

If MVP/MFC equals unity, resources are optimally used. Values less than unity indicate overuse, while values greater than unity indicate underuse (Aswathy et al., 2019).

3. RESULTS AND DISCUSSION

3.1 Cost and Return Analysis of Different Fishing Sectors

As depicted in Table 1., the cost structure of various types of fishing vessels—mechanised, motorised, and non-motorised—revealed significant differences in both the scale and composition of expenditures. Mechanised boats incurred the highest annual costs at ₹63.53 lakhs, primarily due to fuel expenses of ₹34.71 lakhs (54.63% of total costs). Motorised boats followed at ₹13.29 lakhs, with fuel costs of ₹4.67 lakhs (35.15%), while non-motorised boats had the lowest costs at ₹4.70 lakhs, relying on manual labour instead of fuel. Labour costs increase as vessel size decreases, with mechanised boats spending 15.34% on labour, motorised boats 17.58%, and non-motorised boats 43.85%. Non-motorised boats also had higher food expenses (19.11%) compared to mechanised boats (4.40%). Furthermore, smaller vessels faced rising costs for supplies due to their frequent small-scale trips.

The fixed cost proportion increased as we move from mechanised to non-motorised boats—8.49% for mechanised, 11.48% for motorised, and 12.60% for non-motorised vessels. While the absolute fixed costs were lowest for non-motorised boats, their share was higher due to the smaller base cost. Depreciation and interest on fixed capital constituted the major components here. Interestingly, motorised boats depicted a higher percentage of interest on fixed

capital (6.69%) than mechanised boats (2.20%), possibly due to higher loan dependency in mid-scale operations, as shown in Table 1. These variations highlight the need for differentiated policy support, where fuel subsidies might benefit mechanised operations, while wage support and capital subsidies could be more impactful for small-scale and artisanal fishers.

The study analysed gross returns based on average catch value and modal price as shown in Table 2. Mechanised crafts generated the highest gross returns (₹72.23 lakhs) but had lower net returns (₹8.70 lakhs) due to high operational costs. In contrast, motorised and non-motorised crafts, despite lower gross earnings, achieved significant net returns of ₹7.38 lakhs and ₹2.73 lakhs, respectively, indicating better profit retention. Despite the costs, mechanised crafts still exhibited significant cash flow.

The maximum operational cost was associated with mechanised crafts, which can be seen from the operating ratio of 0.80, which can be a result of extensive usage of inputs, mainly due to greater coverage of fishing grounds, longer voyage period, catch of demersal stock and extensive catch. The highest input-output ratio of 1.58 was seen for the non-motorised sector, which implies that for every 1 rupee investment, there is a 1.58 rupee return with 0.58 rupee profit. The lowest output return per unit of input utilised was seen in mechanised units, which was depicted by the input-output ratio of 1.13. This lower return can be attributed to increased operational expenses and potential overfishing.

3.2 Resource use Efficiency of Different Fishing Units

Cobb-Douglas production function has been used to work out the production elasticity values of respective inputs, which in turn have been used to calculate marginal value product(MVP) and efficiency ratios. Multiple linear regression method was used for the evaluation of Cobb-Douglas production function.

3.2.1 Resource use efficiency of mechanised fishing units

There were seven independent variables and total output as the dependent variable considered for the production function for mechanised fishing units, whose related statistics and ratios are depicted in Tables 3 and 4. Key

Table 1. Costs associated with marine fishing operations according to fishing crafts used

Sl. No.	Items	Types of fishing crafts					
		Mechanised craft		Motorised craft		Non-motorised craft	
		Cost(in Rs./year)	Percentage	Cost(in Rs./year)	Percentage	Cost(in Rs./year)	Percentage
Variable cost							
1.	Diesel/Kerosene	3471233.33	54.63	467200.00	35.15	984.50	0.21
2.	Food/Meal	279753.33	4.40	206914.67	15.57	89800.00	19.11
3.	Labour/Wages	974673.33	15.34	233653.33	17.58	206060.00	43.85
4.	Ice	162846.67	2.56	55326.67	4.16	37152.00	7.91
5.	Net	140398.00	2.20	74783.33	5.62	43540.00	9.26
6.	Repair and maintenance	561080.00	8.83	93101.33	7.00	17428.00	3.71
7.	Interest on working capital@4% per annum	223599.39	3.51	45239.17	3.40	15798.58	3.36
A.	Sub total	5813584.05	91.50	1176218.51	88.51	410763.08	87.40
Fixed cost							
1.	Depreciation @ 5% per annum	399607.67	6.29	63573.33	4.78	34820.00	7.41
2.	Interest on fixed capital@7% per annum	139862.68	2.20	89002.67	6.69	24374.00	5.19
B.	Sub total	539470.35	8.49	152576.00	11.48	59194.00	12.60
C.	Total cost(A+B)	6353054.40	100	1328794.51	100	469957.08	100.00

Table 2. Returns from marine fishing operations based on types of fishing craft used

Sl. No.	Returns and ratios	Types of fishing units		
		Mechanised craft	Motorised craft	Non-motorised craft
1.	Gross return	7223465	2066640.00	743500
2.	Net return	870411	737845.49	273542.92
3.	Net cash flow(NCF)	1633480.34	935660.66	348805.5
4.	Operating ratio	0.80	0.56	0.47
5.	Fixed ratio	0.07	0.07	0.06
6.	Input-output ratio	1.13	1.55	1.58

inputs such as diesel (0.423) and food/meal (0.575) had statistically significant (at 1% level) and positive coefficients, suggesting that increases in these inputs were strongly associated with increased fish production. Notably, repair and maintenance also showed a positive and significant effect at 5% level of 0.296, indicating the importance of well-maintained vessels for efficient operations. However, labour depicted a negative and significant coefficient at 1% level of -0.620, which implied that an increase in labour would have a negative impact on output. This may be due to overemployment or inefficiencies arising from excessive labour input in mechanised operations rather than further mechanisation efforts.

Other variables like ice, net, and number of fishing days showed statistically insignificant effects, suggesting they do not substantially influence output in the mechanised sector under the current production conditions. The coefficient of determination (R^2) value was 0.94, as shown in Table 3, which was high, implying that the seven independent variables explained up to 94% of the total variation in output. The return to scale has been determined to be 0.822, which reflects

the sum of the input elasticities, indicating that the mechanised fishing units experience decreasing returns to scale. This meant that a simultaneous increase of one unit in each input would result in only a 0.822-unit increase in output.

According to Table 4, the efficiency ratio (MVP/MFC) for diesel was less than 1, indicating that fuel was overutilised. This suggests that more advanced and fuel-efficient engines could be used to improve production efficiency. Efficiency ratios of food, ice, net, and repair and maintenance were found to be greater than 1, which implies that resources were underutilised, and thus, there is scope for increasing these inputs to increase the output. The efficiency ratio of labour input was found to be -4.40, indicating that there is no potential for enhancing production levels through any increase in labour input. This inefficiency highlights a need for better labour allocation or skill improvement. From the above study, we can infer that more mechanised nets or gears can also be used. The number of fishing days has an efficiency ratio of nearly 1, which indicates optimal use of fishing days.

Table 3. Estimated value of coefficients and related statistics of Cobb-Douglas production for mechanised fishing operations

Variables	Coefficients	Standard error	t Stat
Intercept	-1.914	2.160	-0.886
Diesel	0.423*	0.105	4.027
Food/Meal	0.575*	0.111	5.180
Labour	-0.620*	0.186	-3.330
Ice	0.112	0.107	1.052
Net	0.012	0.105	0.118
Repair and maintenance	0.296**	0.107	2.750
No. of fishing days	0.022	0.200	0.109
R Square (R^2)	0.947		
Adjusted R Square	0.914		
Return to scale	0.822		

*Significant at 1% level

**Significant at 5% level

Table 4. Estimates of efficiency parameters in mechanised fishing operations

Variables	MPP	MVP	MFC	Efficiency ratio (MVP/MFC)
Diesel	0.005	80.33	93	0.86
Food/Meal	0.0009	14.62	1	14.62
Labour	-0.248	-3857.56	875	-4.40
Ice	0.064	993.16	200	4.96
Net	0.016	250.80	200	1.25
Repair and maintenance	0.0002	3.79	1	3.79
No. of fishing days	0.388	6014.01	6000	1.002

Table 5. Estimated value of coefficients and related statistics of Cobb-Douglas production for motorised fishing operations

Variables	Coefficients	Standard error	t Stat
Intercept	-6.734	1.447	-4.651
Diesel	0.662**	0.278	2.377
Food/Meal	-0.143	0.215	-0.663
Labour	0.668*	0.261	2.565
Ice	-0.670*	0.164	-4.070
Net	0.211	0.173	1.219
Repair and maintenance	0.073	0.052	1.390
No. of fishing days	0.552**	0.185	2.974
R Square(R ²)	0.841		
Adjusted R Square	0.773		
Return to scale	1.353		

*Significant at 1% level

**Significant at 5% level

Table 6. Estimates of efficiency parameters in motorised fishing operations

Variables	MPP	MVP	MFC	Efficiency ratio (MVP/MFC)
Diesel	0.0226	271.17	93	2.91
Food/Meal	-0.0001	-1.43	1	-1.43
Labour	0.4188	5026.13	850	5.91
Ice	-0.2976	-3571.72	200	-17.85
Net	0.1203	1443.46	200	7.21
Repair and maintenance	0.0001	1.66	1	1.66
No. of fishing days	0.4611	5533.75	5000	1.10

3.2.2 Resource use efficiency of motorised fishing units

The regression results, as depicted in Table 5, suggest that the Cobb-Douglas model explained a substantial portion of the variation in output for motorised fishing units, with an R² of 0.841 and adjusted R² of 0.773. This indicated that approximately 84% of the variability in output was explained by the input variables included in the model. Among the variables, diesel (0.662), labour (0.668), and number of fishing days (0.552) had positive and statistically significant coefficients, implying these inputs significantly and positively affected fish production. These findings highlights that increased fuel use, adequate labour, and extended fishing days can enhance productivity in motorised crafts.

On the other hand, ice (-0.670) had a significant(at 1% significance) negative impact on output, suggesting either overuse or inefficient use, possibly due to excess costs or spoilage not matched by increased catch. Food/meal, net, and repair and maintenance were statistically insignificant, indicating a weaker or inconsistent relationship with output in this model. Notably, the return to scale was 1.353, provided in Table

5, indicating increasing returns to scale, i.e, if all inputs were increased proportionately, output would increase by a greater proportion. For a one-unit increase in every input, the production level would increase by 1.353 units. This suggests that motorised fishing units can benefit from scaling up operations and that resource investment in these crafts could lead to enhanced productivity and efficiency. Thus, motorisation of traditional craft is of utmost importance in order to increase the income of fishermen.

The input efficiency analysis for the motorised fishing sector highlights significant disparities in how effectively different inputs contribute to production. Inputs such as net (MVP/MFC = 7.21), labour (5.91), repair and maintenance(1.66) and diesel (2.91) were significantly underutilised, meaning their contribution to output was far greater than their cost. Increasing repair costs leads to improved craft quality and operational efficiency. Additionally, increased fuel usage enables greater area coverage for fishing. This suggests that expanding the use of these inputs could result in higher fish production and better economic returns. Additionally, fishing days

showed a near-optimal usage level (efficiency ratio = 1.10), as shown in Table 6, indicating that usage levels were close to economically efficient, with some room for further improvement. In contrast, several inputs were clearly overutilised or inefficiently managed. Ice, with a negative efficiency ratio (-17.85), reflected substantial wastage or ineffective use, possibly due to overuse or improper handling. Similarly, food/meal (-1.43) and repair and maintenance (0.001) revealed very poor efficiency, contributing little to output despite considerable costs. These findings imply the need for better cost management and technical practices in these areas.

3.2.3 Resource use efficiency of non-motorised fishing units

Since non-motorised crafts do not necessitate fuel during their operational processes, only six variables were considered for the evaluation of the Cobb-Douglas production function, as illustrated in Table 7. The analysis for non-motorised fishing units illustrated a strong model fit, with an R^2 of 0.913 and adjusted R^2 of 0.887, meaning nearly 91% of the variation in output was explained by the selected input variables.

Among these, labour (0.387) and number of fishing days (0.407) were statistically significant at 5% level, suggesting they were crucial drivers of production in this sector. This result is logical, given that non-motorised fishing relies heavily on human effort and time spent at sea due to the absence of engines or advanced equipment. Net usage (0.457), although not statistically significant here, had a positive coefficient and a t-stat of 2.039, indicating it was near significance and likely beneficial to the output.

Other inputs, such as food, ice, and repair and maintenance, had negative or statistically insignificant coefficients, indicating that they either had little impact or might be overutilised relative to their productivity in the non-motorised context. Most notably, the return to scale was 0.82, as shown in Table 7, indicating decreasing returns to scale, where a proportional increase in all inputs would result in a less-than-proportional increase in output. This could reflect limitations in resource efficiency or scale in the non-motorised sector, reinforcing the idea that simply adding more inputs is not the most effective way to boost productivity. Instead, improving labour productivity and motorisation of traditional crafts can lead to higher productivity.

Table 7. Estimated value of coefficients and related statistics of Cobb-Douglas production for non-motorised fishing operations

Variables	Coefficients	Standard error	t Stat
Intercept	-2.397	1.103	-2.172
Food/Meal	-0.150	0.142	-1.053
Labour	0.387**	0.163	2.364
Ice	-0.131	0.112	-1.160
Net	0.457	0.224	2.039
Repair and maintenance	-0.143	0.127	-1.123
No. of fishing days	0.407**	0.086	4.707
R Square(R^2)	0.913		
Adjusted R Square	0.887		
Return to scale	0.820		

*Significant at 1% level

**Significant at 5% level

Table 8. Estimates of efficiency parameters in non-motorised fishing operations

Variables	MPP	MVP	MFC	Efficiency ratio (MVP/MFC)
Food/Meal	-0.0001	-1.96	1	-1.96
Labour	0.132	1327.01	850	1.56
Ice	-0.083	-831.34	200	-4.15
Net	0.0203	203.85	200	1.01
Repair and maintenance	-0.001	-10.20	1	-10.20
No. of fishing days	0.324	3247.83	2500	1.29

The input efficiency analysis for the non-motorised fishing sector, given in Table 8, revealed that labour (1.56), net (1.01), and fishing days (1.29) were the most productive and efficiently used inputs, suggesting potential for improved returns through their increased use. In contrast, ice (-4.15), food/meal (-1.96), and repair and maintenance (-10.20) were highly inefficient, indicating overuse or poor contribution to output. Overall, the results highlight the need to optimise input use by focusing on labour and operational time while reducing ineffective expenditures. There is also scope for modernising and motorising these crafts to increase output.

4. CONCLUSION

This study assessed the economics and resource efficiency of marine fishing in the Balasore district, Odisha, with a focus on mechanised, motorised, and non-motorised sectors. Through cost-return analysis and Cobb-Douglas production function, the findings revealed distinct patterns of input use, profitability, and efficiency across these fishing units. Mechanised crafts, while achieving the highest gross returns, faced the burden of high operational costs and showed decreasing returns to scale, indicating inefficiencies, especially in labour utilisation. Motorised crafts demonstrated increasing returns to scale and strong output responsiveness to inputs like diesel, labour, and fishing days, suggesting a high potential for scaled-up, efficient operations. Non-motorised units, although yielding the lowest gross returns, achieved the highest input-output ratio, reflecting superior cost efficiency; however, they were limited by scale and technological input.

These results highlight the need for tailored policy interventions. For mechanised units, investing in fuel-efficient technologies and better labour management is crucial. Motorised units would benefit from scaling operations and improved input allocation, while non-motorised units require modernisation, including motorisation of crafts and skill enhancement. Overall, optimising input use and encouraging sustainable scaling through sector-specific strategies can significantly improve productivity and income in Odisha's marine fisheries sector while ensuring resource sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models,

etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

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CONSENT

In accordance with international and university standards, the written consent of all participants has been duly obtained and securely retained by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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