Sustainability of agricultural tractors usage in open field and in specialized crops, from the performance and environmental standpoints

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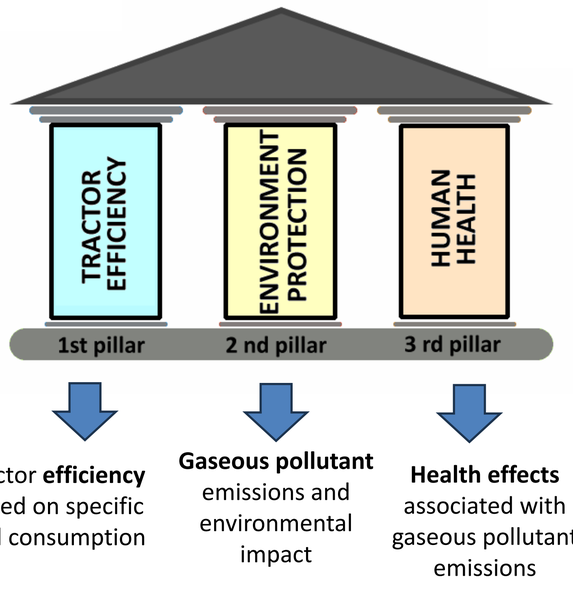
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1 Aim of the study

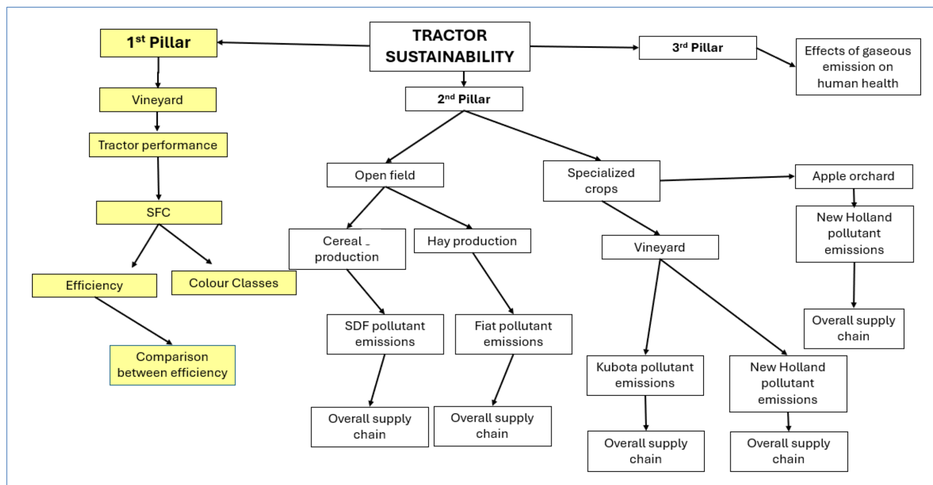
This study provides an integrated assessment of the sustainability of agricultural tractor use under representative operating conditions. The work was structured around three interconnected pillars:

- tractor performance and energy efficiency;
- exhaust emissions and their impact across agricultural production chains;
- potential health risks associated with operator exposure to diesel exhaust.



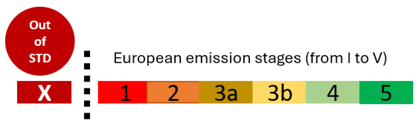
Together, these pillars connect machine efficiency, environmental sustainability and operator protection within a single assessment framework.

2 1st Pillar - Energy Efficiency



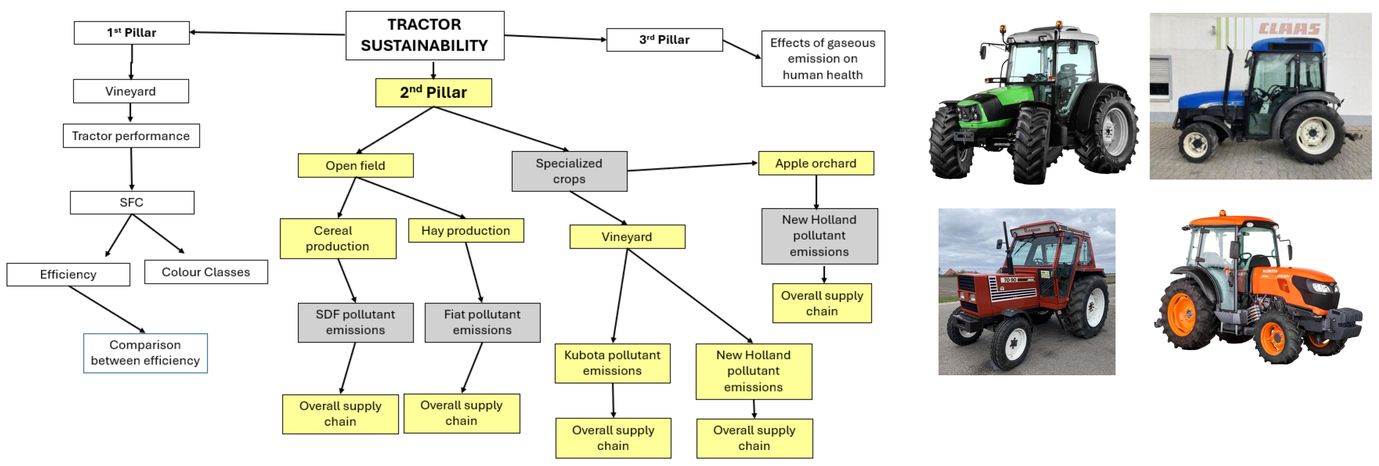


The first pillar assessed the energy efficiency of four narrow-track tractors during ten typical vineyard operations. Engine speed, torque and PTO power were measured using a dynamometer, while fuel consumption was monitored with a flow meter. These data were collected under representative working conditions to calculate specific fuel consumption (SFC). A color-coded classification system was then applied to compare tractor efficiency and identify the effects of engine characteristics, operating point and task-related power demand.



Field operation	SFC, g/kWh			
	Kubota M5091	Same Frutteto II 85	Same Argon 70	Goldoni E100
P. R. shredding	264.36	250.61	246.39	256.76
PPP spraying	269.03	290.19	237.72	238.91
Fertilising (M/O)	264.58	313.81	238.05	235.18
Pre-pruning	Out of scale	389.43	244.26	Out of scale
Grass shredding	278.58	302.54	242.66	240.12
(C/M) weeding	342.17	341.24	247.84	232.59
Sucking	Out of scale	389.43	244.26	Out of scale
Topping	342.17	341.24	247.84	232.59
Defoliation	269.13	266.68	244.49	233.17
G. harvesting	258.36	262.21	255.60	239.63
Weighted Avg.	267.91*	303.18	241.17	226.43*
Color class	**E**	**G**	**C**	**A**

3 2nd Pillar – Pollutant Emissions

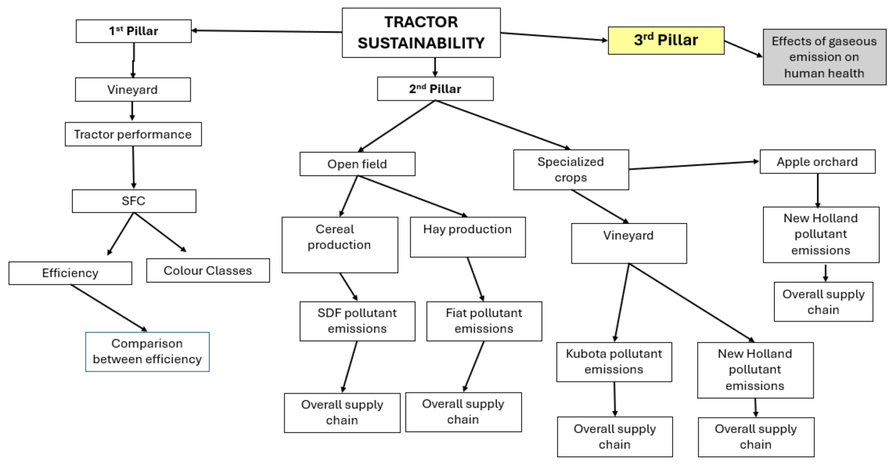


The second pillar quantified CO, HC, NO_x, and particulate matter emissions from tractors used in different agricultural production chains. Emissions were measured using a Testo 350 gas analyser and a Testo 338 soot meter, while a flow meter was employed to determine the exhaust-gas flow rate and express emissions in g/kWh. Representative operating conditions were reproduced through stationary tests, and the duration and annual frequency of each operation were considered to estimate seasonal emissions. This approach enabled comparison of the environmental impact associated with different tractors, crops, and mechanisation strategies.

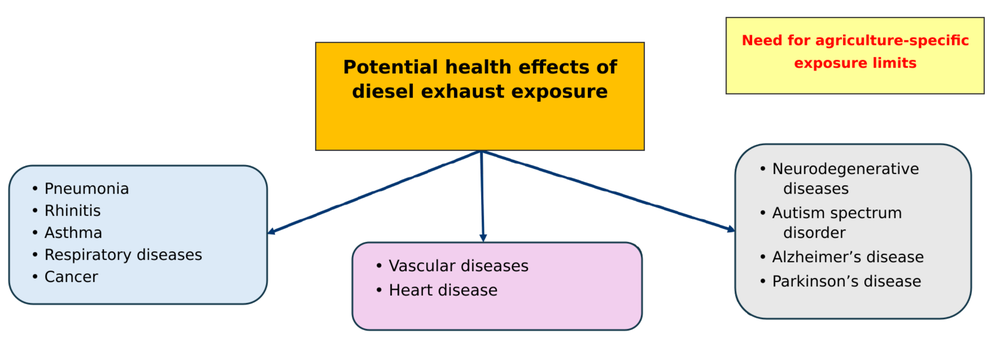
n.	Production chain	Annual use	CO	HC	NOx	PM
		h/year	*kg/year*			
1	Maize production	1196.2	106.7	459.8	475.7	8.0
2	Hay production	412.3	163.35	161.20	118.27	0.71
3	Vineyard (mechanical harvesting)	193.8	0.00	11.07	65.44	0.01
4	Vineyard (hand harvesting)	293.0	65.21	229.0	121.6	0.2
5	Apple orchard	852.5	69.71	330.7	352.60	9.02

n.	Production chain	Annual use	Area	CO	HC	NOx	PM
		h/year	ha	*Kg ha^{-1}year^{-1}*			
1	Maize production	1196.2	50	0.089	0.384	0.397	0.006
2	Hay production	412.3	20	0.396	0.390	0.287	0.001
3	Vineyard (mechanical harvesting)	193.8	10	0.000	0.003	0.337	0.000
4	Vineyard (hand harvesting)	293.0		0.222	0.781	0.415	0.000
5	Apple orchard	852.5		0.081	0.388	0.413	0.011

4 3rd Pillar – Operator Health



The third pillar was developed through a review of the scientific literature on the potential health effects of occupational exposure to diesel exhaust. Particular attention was paid to respiratory, cardiovascular and neurological disorders associated with acute or prolonged exposure. The available evidence highlights the need for field measurements in the operator's breathing zone and for exposure limits specifically designed to protect agricultural workers.



5 Final Remarks

Sustainable agricultural mechanisation requires the joint evaluation of machine efficiency, pollutant emissions and operator exposure. The results indicate that appropriate tractor selection, correct engine–implement matching and operation at efficient load levels can reduce both fuel consumption and exhaust emissions. The proposed methods may support farmers in selecting machinery suited to their operational needs and in assessing the benefits of fleet renewal. However, technological improvements should be complemented by emission monitoring throughout the tractor's service life and by field measurements in the operator's breathing zone. Combining these aspects provides a more comprehensive framework for developing agricultural machinery that is efficient, environmentally responsible and safer for operators.