Eco-Driving Effectiveness in Reducing Emissions and Crashes in Rural Areas

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Introduction

- Road transport is a major source of CO_2, NOx, and CO, worsening air quality, climate change, and public health.
- Studies show eco-driving cuts emissions by 5–40%, with benefits varying by road type, traffic, and driver compliance.
- Eco-driving also improves safety, reducing aggressive maneuvers, abrupt braking, and crash risk.
- Most research focuses on urban roads; evidence from rural and mountainous environments remains limited.

Experiment & Participants

- The study used the FOERST driving simulator to replicate rural and mountainous road environments.
- A total of 39 licensed drivers aged 18–30 participated, with balanced gender representation and an average of four years of driving experience.
- The experiment included two phases, with participants first driving normally and then repeating the scenarios after eco-driving training.
- Each driver completed a questionnaire of 31 items covering driving experience, behaviors, and eco-driving attitudes.

Scenarios & Data

- Drivers completed rural and mountainous routes with speed limits, sharp turns, and wildlife crossings.
- Each participant performed four drives in total, covering both environments before and after eco-driving training.
- The simulator recorded over 60 measurements per second, including speed, braking, time to collision, and headway.
- Additional indicators for emissions and fuel consumption were calculated using the Vehicle Specific Power method (Zhao et al., 2015).

Zhao, X., Wu, Y., Rong, J., & Zhang, Y. (2015). Development of a driving simulator based eco-driving support system. Transportation Research Part C: Emerging Technologies, 58, 631–641. https://doi.org/10.1016/j.trc.2015.03.030

Modeling Approach

- Linear regression models were applied to estimate CO_2, CO, NO_x emissions and fuel consumption.
- Binary logistic regression was used to calculate crash probability.
- Model performance was validated using p-values, R^2, and prediction accuracy.
- An elasticity analysis quantified the relative influence of each variable on outcomes.

Emissions

- Eco-driving reduced CO_2 emissions by 5.9%, CO emissions by 29.3%, and NO_x emissions by 34.7%, confirming its strong environmental benefits.
- Rural environments consistently produced lower emissions than mountainous roads, where frequent braking and acceleration increased pollutant levels.
- Erratic driving behaviors, such as abrupt braking and unstable maneuvers, led to higher emissions, while smoother driving reduced pollutant output.

Model of CO_2/km

Independent Variables	βi	Std. Error	t Value	p-Value	e	e*
(Constant)	309.057	7.533	41.028	0.000 ***		
Discrete variables						
Eco	-19.450	3.274	-5.940	0.000 ***	-0.059	9.55
Environment	-40.306	3.309	-12.181	0.000 ***	-0.121	19.80
RoutesPerDay	-2.036	0.970	-2.099	0.038 *	-0.006	1.00
Continuous variables						
AvgBrk	6.648	0.471	14.124	0.000 ***	0.0002	1.00
AvgDLeft	-19.485	7.370	-2.644	0.009 **	0.0006	2.93
StdAccLat	8.583	2.580	3.326	0.001 **	0.0003	1.29
R^2 = 0.836						
Adjusted R^2 = 0.830						

Model of CO/km

Independent Variables	βi	Std. Error	t Value	p-Value	e	e*
(Constant)	0.512	0.0615	8.331	0.000 ***		
Discrete variables						
Eco	-0.219	0.0225	-9.751	0.000 ***	-0.293	7.06
Environment	-0.064	0.023	-2.770	0.006 **	-0.086	2.06
MoneyPerMonth	-0.031	0.013	-2.309	0.023 *	-0.041	1.00
Continuous variables						
AvgTTL	0.00005	0.00002	2.689	0.008 **	0.00001	1.00
StdBrk	0.012	0.003	4.284	0.000 ***	0.0002	25.5
R^2 = 0.625						
Adjusted R^2 = 0.613						

Model of NO_x/km

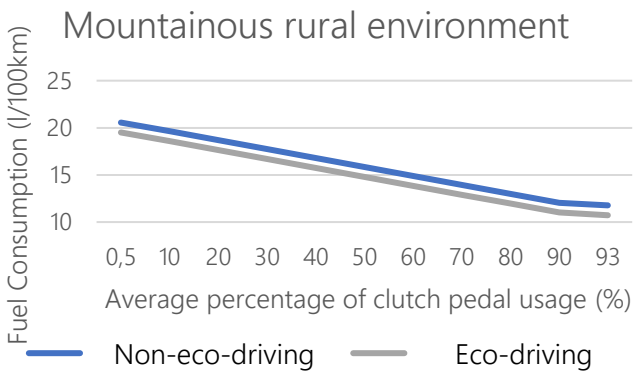
Independent Variables	βi	Std. Error	t Value	p-Value	e	e*
(Constant)	0.062	0.007	9.033	0.000 ***		
Discrete variables						
Eco	-0.020	0.002	-11.534	0.000 ***	-0.347	20.00
Environment	-0.004	0.002	-2.168	0.032 *	-0.069	4.00
RoutesPerDay	-0.001	0.001	-2.220	0.028 *	-0.017	1.00
Continuous variables						
AvgBrk	0.002	0.0003	6.002	0.000 ***	0.0003	1.00
Avgrspur	-0.009	0.004	-2.120	0.036 *	-0.002	-4.50
R^2 = 0.638						
Adjusted R^2 = 0.626						

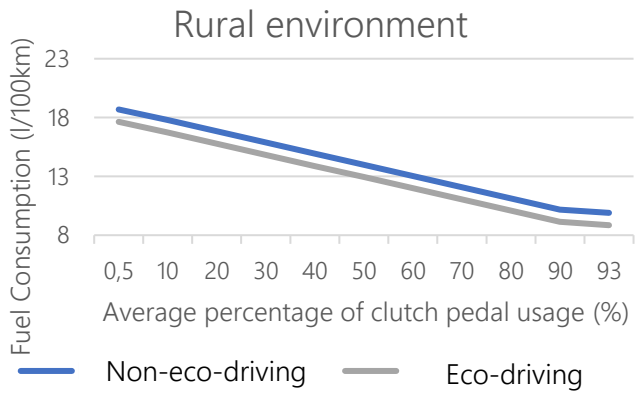
Fuel Consumption

- Eco-driving reduced fuel consumption by 7% (–1.05 l/100 km), demonstrating a direct economic and ecological benefit.
- Rural roads required less fuel compared to mountainous terrain, where steep inclines increased demand.
- Female drivers consumed slightly more fuel than males, likely due to different braking and acceleration patterns.
- Proper clutch management was identified as the most influential factor in reducing fuel use.

Independent Variables	βi	Std. Error	t Value	p-Value	e	e*
(Constant)	22.125	0.836	26.458	0.000 ***		
Discrete variables						
Eco	-1.050	0.155	-6.791	0.000 ***	-0.07	1.63
Environment	-1.870	0.160	-11.678	0.000 ***	-0.13	2.89
Gender	-0.646	0.152	4.262	0.000 ***	-0.04	1.00
Continuous variables						
Avgrspur	-0.874	0.368	-2.374	0.019 *	-0.0006	1.00
AvgClutch	-0.095	0.009	-10.987	0.000 ***	-0.00006	9.20

R^2 = 0.784
Adjusted R^2 = 0.777

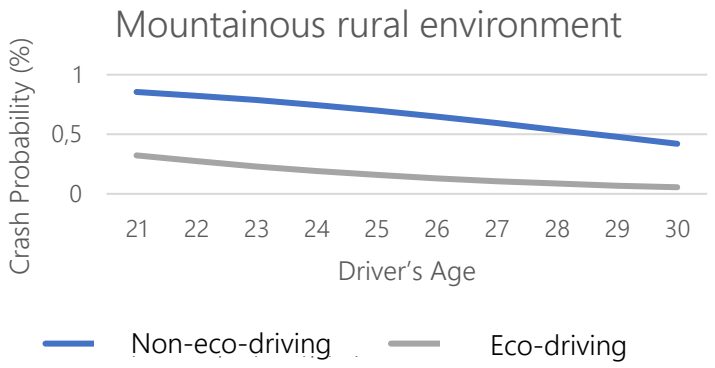


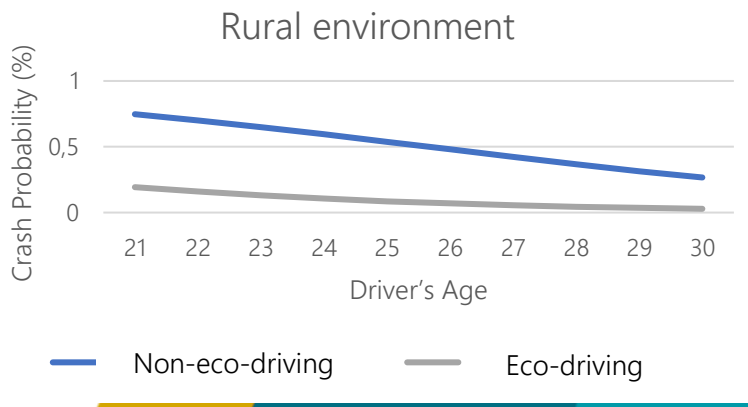


Crash Probability

- Eco-driving reduced crash probability by 66.2%, highlighting its role as a road safety intervention.
- Mountainous terrain significantly increased crash risk, whereas rural terrain was associated with safer outcomes.
- Compliance with speed limits strongly reduced crash probability, reinforcing the safety impact of eco-driving.
- Older drivers and those spending more on fuel per month showed lower crash risk, suggesting that driving experience and exposure support safer behavior.

Independent Variables	βi	Std. Error	z Value	p-Value	e	e*
(Constant)	9.248	2.613	3.540	0.000 ***		
Discrete variables						
Eco	-2.516	0.421	-5.977	0.000 ***	-0.662	1.82
Environment	0.689	0.398	1.731	0.083 *	14.365	-39.54
FuelMoney	-1.220	0.513	-2.378	0.017 **	-0.363	1.00
SpeedLimits	-0.410	0.184	-2.224	0.026 **	2.932	-8.07
Continuous variables						
Age	-0.233	0.094	-2.479	0.013 **	-0.072	-
Accuracy = 77.6%						





Discussion

- Eco-driving delivered **clear environmental and safety benefits**, reducing emissions, fuel use, and crashes.
- **Driving environment influenced results**, with rural terrains showing greater efficiency and safety gains than mountainous roads.
- **Driver behavior mattered** strongly, as abrupt braking and unstable maneuvers raised emissions and risks.
- The study confirms that **behavioral interventions** complement technological and infrastructural measures in sustainable transport.

Conclusions

- Eco-driving is a proven strategy for lowering emissions, saving fuel, and improving road safety.
- Training young drivers in eco-driving techniques offers measurable benefits across different road types.
- Simple and low-cost interventions can produce substantial ecological and economic advantages.
- Eco-driving should be considered a key component of future mobility policies and driver education programs.

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