Sustainable intensification and the land sparing mechanism

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July 2025

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Juillet 2025

Abstract.
The analysis of the malagasy "land rebound effect," conducted using an ordinary least squares (OLS) linear regression model and panel data of 27 countries on World Bank time series data from 1990 to 2022, quantitatively demonstrates the relationship between agricultural value added and the expansion of cultivated land areas. The findings suggest three priority interventions: contextual adaptation of technologies through participatory approaches, strengthening land tenure security via formal certification tools, and building the capacities of local producers including training, financing, and economic diversification. However, there are methodological limitations due to the lack of detailed data on land dynamics and institutional constraints within rural communities, calling for complementary field studies to ground the econometric analysis in territorial realities.

Keywords: agriculture, land sparing, land use, deforestation, OLS regression, panel data, Madagascar, sustainable intensification

1 Introduction

The expansion of agricultural land is currently one of the main drivers of deforestation, biodiversity loss, and greenhouse gas emissions [2, 9]. In the face of population pressure and nutritional transition, the challenge of producing more without expanding cultivated areas emerges as a central issue for sustainability [18, 21]. Agricultural intensification, and in particular the *land sparing* paradigm, proposes increasing yields in order to spare land, thereby reducing land pressure [3, 22]. However, this mechanism is controversial: in many cases, productivity gains induce a rebound effect, or even a *backfire effect*, by stimulating agricultural expansion rather than contraction [19, 4]. This phenomenon is exacerbated in developing countries, where regulations are often insufficient and economic incentives strong [8, 12]. The case of Madagascar illustrates this complexity: low yields, strong household dependence on agriculture, fragile institutions, and ecological vulnerability make a rebound effect more likely than actual land sparing [7, 17]. Thus, despite intensification efforts, land expansion continues, raising the question of the link between productivity and land pressure [1, 10]. This article explores the validity of the *land sparing* approach in Madagascar, formulating the hypothesis that, in a context of weak institutions, productivity gains enhance the economic attractiveness of agriculture, leading to an expansion of cultivated areas in the absence of appropriate public policies.

2 Literature review

The expansion of agricultural land is currently one of the main drivers of biodiversity loss and greenhouse gas emissions on a global scale [9]. In a context where the global population continues to grow and become wealthier, it is becoming crucial to slow down, or even halt, the increase in agricultural land area. To achieve this, relying solely on reduced consumption in wealthy countries is no longer sufficient; a more fundamental solution lies in what is known as sustainable intensification. This approach suggests that increasing agricultural productivity could help meet both food security and environmental conservation goals, by using less land to produce more [22].

This mechanism, known as *land sparing*, is based on the hypothesis that an increase in agricultural yields would allow land to be spared by preventing its conversion into cultivated areas. However, some researchers challenge this logic. Ewers and colleagues [9] highlight that in many cases, increased productivity does not lead to reduced land use but, on the contrary, to an intensification of land exploitation—a phenomenon known as *backfire* or rebound effect, historically associated with the Jevons paradox.

According to Kremen and Merenlender [16], believing that simplified and more intensive production systems will automatically contribute to

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nature conservation is an illusion. *Land sparing*, they argue, only works under very specific conditions. However, other researchers claim that although *land sparing* is not systematic at the local level, it is observed in many situations and more importantly, that it is almost guaranteed at the global level [22]. This contrast stems from the fact that the rebound effect manifests differently depending on the scale of analysis.

The underlying mechanism relies on two dynamics: on the one hand, improved productivity means that less land is needed to produce the same quantity (increased efficiency), which promotes *land sparing*. On the other hand, this rise in productivity reduces production costs, which tends to lower prices, increase demand, and encourage producers to expand output potentially offsetting the initial gains in spared land [21]. The magnitude of the rebound effect depends notably on consumers' price sensitivity and the degree of market integration [22].

For staple crops with inelastic demand, such as cereals, the rebound effect is relatively limited. In contrast, for products that are heavily traded on international markets, such as palm oil or soy, the price drop resulting from improved yields can strongly stimulate global demand, leading to an increase in cultivated areas, including in ecologically sensitive zones [6].

Another complex factor is the interaction between producers. When one region improves its productivity, it increases supply and drives prices down. This reduces profitability in other regions, which may then produce less, partially offsetting the local rebound effect. Assessing the net impact on land use thus requires a global approach [22].

Several equilibrium models have been developed to measure these dynamics on a large scale. The work of Stevenson et al. [21], comparing scenarios with and without the Green Revolution, estimates that improved seeds helped spare between 18 and 27 million hectares. Similarly, Hertel et al. [12] estimate that 144 million hectares were globally spared nearly half the size of Western Europe. Using an econometric method based on data from 1991 to 2010, Villoria [22] estimates that in the absence of productivity improvements, an additional 173 million hectares would have been required, with significant land expansion effects in highly integrated countries such as Argentina, and land sparing effects in more isolated countries such as India or Nigeria.

However, this global finding does not guarantee that *land sparing* will occur in all future scenarios. For instance, if a new Green Revolution were to take place in sub-Saharan Africa, it could, at least initially, lead to land expansion if baseline yields are low and markets are highly integrated [12]. This phenomenon has been described as a "double-edged sword" by Carrasco et al. [6]: increased agricultural productivity may save forests at the global level while causing local habitat loss, particularly in tropical regions with high biodiversity.

Several instruments can be used to regulate agricultural expansion and protect ecosystems. Ecological zoning, for example, helps delineate areas of high conservation value, notably through the establishment of protected areas [18].

In addition to this are economic tools such as payments for ecosystem services and land taxes, which encourage actors to adopt more sustainable practices.

A third lever lies in the strategic deployment of technologies or infrastructure designed to slow the advance of the agricultural frontier.

Finally, the adoption of environmental standards and certifications such as the soybean moratorium in the Amazon or the Roundtable on Sustainable Palm Oil represents a complementary regulatory approach aimed at conditioning market access on responsible agricultural practices.

These mechanisms can strengthen the *land sparing* effect by regulating land use where productivity increases. However, their effectiveness depends on the institutional context. Poorly designed regulation can lead to a leakage effect, where reduced cultivation in one region drives other regions to intensify deforestation, thus offsetting environmental gains.

3 Application to developing countries and the case of Madagascar

The previous analyses highlight the context-dependent nature of the effects associated with *land sparing*. In countries like Madagascar, several factors converge to promote the emergence of a rebound effect, at the expense of genuine land sparing.

First, the initially low productivity of Malagasy agriculture corresponds to situations where yield improvements tend to enhance local competitiveness. This dynamic therefore encourages the expansion of cultivated areas rather than their stabilization or reduction [12]. Under such conditions, intensification acts more as an accelerator of land conversion than as a lever for limiting agricultural land use.

Second, the strong dependence of households on agricultural activity means that productivity gains represent an economic opportunity and an incentive to enlarge farms. In this socio-economic context marked by poverty and food insecurity, restricting expansion without compensation would disadvantage the most productive farmers. Such an approach is difficult to justify from both political and social standpoints [7].

Moreover, the absence of a structured regulatory framework including ecological zoning, land taxation, or conservation incentive mechanisms represents a major obstacle to the implementation of targeted *land sparing* policies. In the absence of regulatory or compensatory mechanisms, market dynamics based on increased value-added and the economic attractiveness of crops tend to prevail, thereby intensifying pressure on available land [17].

Under these conditions, although global studies tend to show that agricultural productivity gains have helped spare land at the global level [21, 22], there is no certainty that such outcomes can be replicated in local contexts like Madagascar. The idea that increasing agricultural value-added fuels the expansion of cultivated areas thus fits squarely within the analytical framework of the rebound effect at the regional level [6, 18].

4 Methodology

In this study, the objective is to investigate the relationship between land area and agricultural value added. Existing literature emphasizes that land sparing is effective at the international level, whereas evidence at the local level remains scarce. To address this, the analysis employs a panel data model at the international level and an OLS model for the specific case of Madagascar.

4.1 Data

The data analyzed come from the World Bank and cover the period from 1990 to 2022. The analysis is based on three main variables: total cultivated area (the dependent variable), and agricultural expansion (measured as a percentage of agricultural land) and total population, which serve as explanatory variables.

Variable	Source
Agricultural value added	(`www.worldbank.org`)
Cultivated area	(`www.worldbank.org`)
Total population	(`www.worldbank.org`)

Table 1: Variables and data sources

4.2 Equation

The objective of this section is to estimate the relationship between cultivated land area and agricultural value added. This analysis aims to better understand the influence of agricultural economic development on land use. To do so, a simple linear regression model (OLS) is applied to quantify the effect of agricultural value added on cultivated land. The model is expressed as follows:

$$\text{SURF\_CULT}_t = \alpha_0 + \beta_1 \cdot \text{VA\_AGRI}_t + \beta_2 \cdot \text{POP}_t + \varepsilon_t \quad (1)$$

where:

- $SURF\_CULT_t$: cultivated land area at time t;
- VA_AGRI_t: agricultural value added at time t;
- POP_t: total population at time t;
- α_0: constant term;
- β_1: regression coefficient measuring the effect of agricultural value added on cultivated land area;
- β_2: regression coefficient measuring the effect of population on cultivated land area;
- ε_t: error term.

4.3 Countries comparison

The study uses data from the World Development Indicators (WDI) database of the World Bank, covering the period 1995–2022 and a panel of 27 countries across five continents: in Africa (Madagascar, Nigeria, Ethiopia, Kenya, South Africa, Rwanda, Morocco, Tanzania, Burkina Faso, Egypt), in America (Brazil, United States, Colombia, Argentina, Mexico), in Asia (Indonesia, Vietnam, India, Bangladesh, China), in Europe (France, United Kingdom, Germany, Ukraine, Italy), and in Oceania (Australia, New Zealand). The dependent variable is the *percentage of agricultural land*, while explanatory variables include *agricultural value added (% of GDP)* and *total population*. A binary dummy variable was introduced to specifically identify Madagascar, along with an interaction between this dummy and agricultural value added. The analysis is based on a two-way fixed effects model to control for unobserved effects specific to countries and years.

The R^2 coefficient of 0.268 indicates that the model explains about 27% of the variations in the proportion of agricultural land, a common level in multi-country studies given the influence of other difficult-to-measure factors such as climate conditions, agricultural policies, or infrastructure (Table 2). Among the tested variables, only agricultural value added shows a clear and statistically significant effect: a one-percentage-point increase is associated with an average decrease of 0.55 points in the proportion of agricultural land, supporting the land sparing hypothesis. Total population does not show a direct significant effect, suggesting that other factors may offset demographic pressure. Thus, while agricultural productivity can help limit the expansion of cultivated land, it must be accompanied by targeted policies and strategies to prevent freed-up land from being converted to other intensive uses.

4.4 Results for Madagascar

The results of the regression model show that more than 60% of the variation in agricultural land area in Madagascar is explained by two factors: the value added of the agricultural sector and total population (Table 3). This level of model performance suggests that it captures a significant portion of the underlying dynamics, while still leaving room for other determinants not included in this specification.

Agricultural value added, measured in constant dollars, appears to be a key factor. The associated coefficient, although numerically very small (due to the monetary scale), is *statistically significant at the 1% level* (Table 3), which reinforces the robustness of this relationship. In other words, an improvement in the economic performance of the agricultural sector is, on average, correlated with a slight increase in the share of land used for agricultural purposes. This positive relationship can be interpreted as evidence of an expansion in cultivated land in response to sectoral growth.

In contrast, total population does not show a *statistically significant* link with agricultural land area. The estimated coefficient is negative, which could suggest increasing land pressure from other land uses (urbanization, infrastructure, etc.), but this result remains *statistically uncertain*. Therefore, it does not allow us to conclude that there is a systematic effect of population on the share of agricultural land.

4.5 Model stability

The regression model presents generally consistent results, with residuals that appear to follow a normal distribution. However, some statistical tests suggest that adjustments could be considered to improve the model's quality. Signals related to error variance, temporal dependence of the residuals, and model specification indicate that a reevaluation or enhancement of the current framework could be beneficial. Furthermore, the relationship between certain explanatory variables may slightly affect the stability of the coefficients. Thus, while the results are usable, paying close attention to the model's assumptions would help strengthen the reliability of the interpretations.

5 Discussion

5.1 Awareness of sustainable agriculture

One of the main obstacles to the development of sustainable agriculture in Madagascar is the lack of awareness and adoption of environmentally friendly farming practices by producers, especially in remote rural areas. The majority of farms are small-scale family operations that rely on traditional methods, which increase pressure on available land, often at the expense of natural ecosystems.

The report highlights that in response to increasing climate-related hazards and declining yields [7], households often choose to expand cultivated land rather than adopt sustainable intensification. While this strategy provides an immediate response to poverty and food insecurity, it leads to a vicious cycle of soil degradation, biodiversity loss, and growing land-use conflicts.

To break this dynamic, it is essential to strengthen awareness-raising efforts around sustainable agriculture [4]. This involves implementing targeted educational campaigns that include local leaders, farmer groups, and NGOs active in the field. These initiatives should promote practices such as crop rotation, moderate use of chemical fertilizers, soil conservation, and participatory management of natural resources.

Furthermore, agroecological technologies—such as locally adapted seeds or intercropping systems—should be promoted not only for their environmental benefits but also for their socioeconomic suitability. Improved communication about the long-term advantages of these practices can encourage adoption, especially when paired with economic incentives (microcredits, ecological bonuses, etc.).

5.2 Land tenure reform

Land tenure is at the heart of agricultural dynamics in Madagascar. The absence of clear and effective regulation of rural land is a major obstacle to the adoption of sustainable practices [19]. The land system remains largely dominated by informal customary arrangements, which weakens land use rights, encourages uncontrolled land occupation, and discourages long-term investments.

Without a functional cadastre or an operational land-use policy, agricultural expansion occurs spontaneously, often at the expense of forests and protected areas. This situation leads to increasing fragmentation of the territory, overexploitation of natural resources, and

Table 2: Determinants of the % of Agricultural Land (Fixed Effects Model)

	% Agricultural Land
Agricultural Value Added (% of GDP)	-0.546^{***}
	(0.035)
Total Population	-0.000
	(0.000)
Observations	726
R^2	0.268
Notes:	*** Significant at the 1 percent level.
	** Significant at the 5 percent level.
	* Significant at the 10 percent level.

Table 3: OLS estimation result

	Estimate	Std. Error	t value
(Intercept)	48.140	4.182	11.512^{***}
agri_value	9.704e-09	2.567e-09	3.780^{***}
population	-2.634e-07	1.551e-07	-1.698
Observations	28		
R^2	0.607		
Adjusted R^2	0.575		
Residual Std. Error	1.486 (df = 25)		
F Statistic	19.290^{***} (df = 2; 25)		
Note:	$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$		

growing social tensions among farmers, herders, and conservation stakeholders.

Land tenure reform is therefore essential to regulate land use and enable coherent territorial planning [19]. It involves formalizing land use rights by generalizing the issuance of land titles or certificates, taking into account local specificities and customary rules. It also requires defining priority zones to identify and protect strategic agricultural lands while preserving sensitive ecosystems and forests. Additionally, the creation of mediation mechanisms is necessary to establish local bodies for conflict resolution related to land access, thereby facilitating peaceful coexistence among different users.

This reform must be accompanied by the strengthening of local governments and administrative structures responsible for its implementation. It must also incorporate an inclusive vision that ensures equitable access to land for all stakeholders, including youth and women.

5.3 Farmer capacity development

The low level of agricultural productivity in Madagascar is closely linked to the lack of training, limited access to modern inputs, and weak technical services. Smallholder farmers rarely have the financial or material means to adopt agricultural innovations, even when such innovations are available. Moreover, some improved crop varieties, although technically efficient, are not accepted by farmers due to culinary or cultural preferences.

In this context, strengthening farmer capacities appears to be a key lever for promoting more productive and sustainable agriculture. This requires personalized technical support aimed at enhancing agricultural extension services to provide advice tailored to local conditions, including best farming practices, climate risk management, and rational use of inputs [17]. It is also necessary to facilitate access to credit and agricultural insurance by developing financial products accessible to small-scale producers, particularly through cooperatives or dedicated funds, allowing them to invest in equipment, quality seeds, or irrigation systems.

Continuous and participatory training sessions should be organized regularly in collaboration with professional agricultural organizations, research centers, and technical institutions to strengthen farmers' skills in production, processing, and marketing. Finally, it is crucial to involve farmers in the agricultural innovation process by taking into account their needs, constraints, and preferences, which promotes the appropriation of new technologies and methods. Supporting the diversification of rural economic activities is also essential to reduce households' exclusive dependence on extensive agriculture. High value-added sectors such as agro-industry, ecotourism, or handicrafts can offer viable alternatives while contributing to the economic resilience of local communities.

6 Conclusion

In conclusion, agricultural intensification represents a crucial lever to limit human pressure on ecosystems, provided it is accompanied by appropriate regulatory mechanisms. While the *land sparing* mechanism appears to be generally supported at the global level, its local effects remain deeply ambiguous. In contexts marked by weak institutions, strong household dependence on agriculture, low initial productivity, and the absence of effective environmental regulations, yield gains tend to encourage expansion rather than contraction of cultivated areas. Madagascar fully embodies this paradox: despite the theoretical potential of *land sparing*, its effective implementation requires ambitious public policies aligned with the country's social, economic, and ecological realities. Without such policies, agricultural intensification may exacerbate land pressure and further compromise biodiversity conservation.

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