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# Can Local Agriculture Improve the Nutritional Quality of Diet While Reducing the Environmental Impact in Guadeloupe? A System Model Approach from Fork to Farm

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## **Can local agriculture improve the nutritional quality of diet while reducing the environmental impact in Guadeloupe? A system model approach from fork to farm**

### **Abstract**

In Guadeloupe, the agricultural sector is specialized in export crops, and the local supply of products for the domestic market does not meet demand. Moreover, various studies have highlighted public health issues related to food.

The goal of this study is to develop a "fork to farm" approach to analyze the capacity of local agriculture to meet the objective of improving the nutritional quality of food in Guadeloupe, while minimizing environmental impacts.

We evaluated two dietary scenarios through a diet optimization model. The first one aims at improving the diet quality of Guadeloupe population without impairing the food budget. The second add a constraint of increasing the share of local food in the diet. Results are integrated in a bioeconomic model of Guadeloupe agricultural sector to assess socio-economic impacts of this new dietary patterns. Finally, a Life Cycle Analysis (LCA) evaluate environmental effects. Results show that local food share could rise from 30% in the baseline to 75% in the second scenario which involves increased quantities of locally grown roots, tubers, fruits, vegetables, meat, fish, and eggs. To make this feasible, the bioeconomic model suggests land and workforce reallocation, notably from sugarcane and bananas to cattle and vegetable farming. The LCA reveals that climate change impacts remain similar across scenarios, with meat and fish consumption being the primary contributors. Even if the "local" scenario is the least impactful, it remains high in water eutrophication and land use.

While improving nutrition through local agriculture is feasible, it requires structural changes such as increased agricultural labor and expanded farmland. Policy recommendations include promoting plant-based diets, adopting sustainable farming practices, and encouraging the next generation to join the agricultural workforce. This study underscores the importance of addressing environmental, economic, and social factors to create a resilient and sustainable food system in Guadeloupe.

## **1- Introduction**

Guadeloupe is an archipelago of 1,702 km<sup>2</sup>, composed of five islands, located in the Caribbean. It includes "continental" Guadeloupe (Basse-Terre to the west and Grande-Terre to the east) and the neighboring islands (Les Saintes, La Désirade, Marie-Galante). It is a French overseas territory which estimated population is nearly 400,000 inhabitants.

In Guadeloupe, the agricultural sector is highly specialized in export crops, limiting the capacity of local production to meet domestic demand. Processed products represent the majority of imports, including meat, fish, processed fruits and vegetables, dairy products, and bakery goods (ODEADOM, 2018). More than 70% of trade is operated with the European Union, two-thirds of which is with mainland France (INSEE, 2019). This dependence is further reinforced by imports from Asia, the Caribbean, and Central and Latin America.

The consumption of processed foods, high in salt, sugar, and fats, has contributed to a nutritional transition marked by an increase in diet-related public health issues, such as high prevalence rates of obesity, diabetes, hypertension, and cardiovascular diseases (Colombet et al., 2019a). These high prevalence rates are due to diets that do not align with nutritional recommendations, particularly among the most disadvantaged populations (Méjean et al., 2020). Moreover, food access remains highly unequal. In 2015, food prices in Guadeloupe were 32.9% higher than in mainland France, while the standard of living was 20 to 23% lower. Nearly 30% of the population lived on an annual income of less than 950 euros (Audoux et al., 2020). These disparities further hinder access to quality food. To address these nutrition and public health challenges, the development of local agriculture could be seen as a solution (Méjean et al., 2020), helping to improve diets and reduce inequalities while limiting the environmental impact associated with international trade.

The aim of this study was to evaluate the extent to which local agricultural production could contribute to improving the nutritional quality of the Guadeloupean diet while simultaneously reducing its environmental footprint. Given the region's high dependence on imported food (Lamani et al., 2024) and the growing prevalence of diet-related health issues (Colombet et al., 2019b), understanding how a shift toward a more localized food system could impact both nutrition and sustainability is crucial. This assessment was carried out using an innovative interdisciplinary "fork-to-farm" approach (Verger et al., 2018), integrating nutritional, environmental, and economic dimensions to provide a comprehensive analysis of the potential benefits and challenges of food relocalization.

The study followed a three-step process. First, we explored two dietary scenarios aimed at improving the nutritional quality of the Guadeloupean diet while increasing the share of locally produced food, without imposing additional financial constraints on consumers. These scenarios were designed to align better with dietary recommendations while taking into account cultural food preferences and economic accessibility. Second, we examined the economic repercussions of these scenarios on Guadeloupe's agricultural sector through a bioeconomic model, evaluating how increased demand for local food products might affect production systems, employment, and market dynamics.

Finally, we conducted an environmental impact assessment of both the current baseline diet and the proposed scenarios using a Life Cycle Analysis (LCA) approach. This allowed us to quantify the ecological consequences of dietary changes based on a large set of indicators.

In this study, our specific objectives were to:

- i) identify the necessary dietary changes to enhance the nutritional quality of food consumption, determining which products should be prioritized and in what quantities;
- ii) assess the capacity of Guadeloupean agricultural production to meet the food needs of the local population, considering both current capabilities and potential future adaptations;
- iii) quantify the environmental impacts associated with a transition toward a more localized food system, analyzing the trade-offs between sustainability and self-sufficiency.

Our article is structured into four main sections. Following an introductory section that contextualizes the study and its significance, and details the research objectives. The methodological framework employed, and the data sources used are presented in section 2. The section 3 presents the key findings. Section 4 discusses their implications, and provides recommendations for policymakers, farmers, and consumers seeking to promote a more resilient and health-conscious food system in Guadeloupe.

## **2- Materials and methods**

We developed a mathematical programming diet optimization model (Gazan et al., 2018) to assess two scenarios. The first one explores the possibility of increasing the nutritional quality of the Guadeloupean diet without impairing consumers' budget. The second scenario replicates the first one incorporating more local foods in the diet. The modelling approach includes three main components. First, it is fed by four input datasets: (1) observed diet and origin of foods (local or imported) (2) food composition, (3) nutritional recommendations, and (4) food prices.

Second, the model comprehends a group of equations defining the optimization problem. Third, the solution provides a theoretic optimal diet, as well as the origin of the food.

Diet adequacy was assessed by accounting for cultural acceptability (objective function and constraints), fulfilment of nutritional recommendations (set of nutritional constraints), diet affordability (budget constraint), and a constraint including an increasing share of foods from local origin in three identified food groups (Fruit and vegetables, roots and tubers, food of animal origin).

The objective function is a minimization of the sum of squared relative differences between the optimal diet and the observed diet. It is designed to account for consumers' preferences (i.e. acceptability) reflected in observed food choices as it induces the model to find the minimal variations from the observed diet (Drogue et al., 2020; Perignon et al., 2019).

Data for the mean observed diet of the general population, its nutrition composition and origin and its cost were estimated based on data.

In the second stage, all the quantities of foods in the observed and optimal diets (in grams per day and per person) have been converted in tons per year multiplying them by the number of inhabitants in Guadeloupe. The objective was to assess the productive capacity of the territory to meet the expected demand from both scenarios.

The bioeconomic model MOSAICA was used to simulate the impacts of a transition toward the optimized diets on the agricultural sector in Guadeloupe (Chopin et al., 2017; Chopin et al., 2015). MOSAICA is a mathematical programming model producing new agricultural landscapes at the regional scale by optimising the allocation of cropping systems regionally at the field scale. It accounts for the constraints and opportunities at the field level (e.g. soil types), the farm level (e.g. the availability of production factors), and the regional level (e.g. the policies implemented).

The data used in MOSAICA are:

- The graphical parcel register (RPG), which compiles farmers' land-use declarations, allowing us to geolocate parcels and identify their usage.
- A soil and climate database, providing information on soil characteristics and rainfall.
- A technical itineraries database, detailing agricultural practices specific to Guadeloupe.

Coupling these data sources, defines the possible land-use options for each parcel and each farm, considering crops and practices suited to each geographical area.

The model simulates farmers' decision-making, as we consider that land-use decisions are made at this level. The underlying assumption is that farmers seek to maximize the income of their farms, which consist of multiple land parcels.

The quantities of raw product resulting from the diet modeling have been used as production target in MOSAICA. The model allows the determination of the (in)ability of the Guadeloupe farm sector to produce the targeted volumes and the redesigning of the cropping system it would induce.

Finally, in the third stage, a LCA has been performed (Loiseau et al., 2020). The objective of the LCA is to compute all the environmental impacts measured by 16 indicators (climate change, ozone depletion, acidification, eutrophication, human toxicity, water use, land use, etc.) First, to compare the impacts, a functional unit has been defined as “feeding the Guadeloupe population during one year” and the frontiers of the system limited to all stages from cradle to markets, the last stage before consuming. It does not encompass the journey to the end consumer.

The second phase of LCA is called the life cycle inventory. This stage consists of quantifying material and energy flows consumed or emitted by the system studied at each stage of the life cycle. To ensure that the analysis is adapted to local specificities, we have used the Agribalyse database 3.1.1, specifically adapted to the French overseas departments and region (ADEME, 2024; Colomb et al., 2015). In addition, the field surveys carried out for MOSAICA has enabled us to model the production techniques specific to local agricultural production.

Once these steps have been completed, the results obtained can be used to analyze the environmental impact of each scenario of each scenario according to the 16 indicators already mentioned.

Data for the observed diet (quantity and nutritional composition of foods and dishes) come from the KANNARI food consumption survey conducted in adults > 15 years in Guadeloupe (Dereumeaux C and Saoudi A., 2018); prices were collected for each declared food item from the websites of stores. In addition, the prices of certain foodstuffs (mainly fresh produce, which is poorly represented on drives) were collected on site between January and December 2023, in supermarkets and hypermarkets, specialist stores, markets and roadsides. Finally, we also used the Ministry of Agriculture prices database on local foods. The origin of food was computed based on an estimated ratio of food imports over total consumption. Data for the MOSAICA model come from the department of statistics of the French Ministry of Agriculture and from

field surveys (for agricultural practices). Finally, data on environmental impacts come from AGRIBALYSE 3.1.1 (ADEME, 2024; Colomb et al., 2015).

### **3- Results**

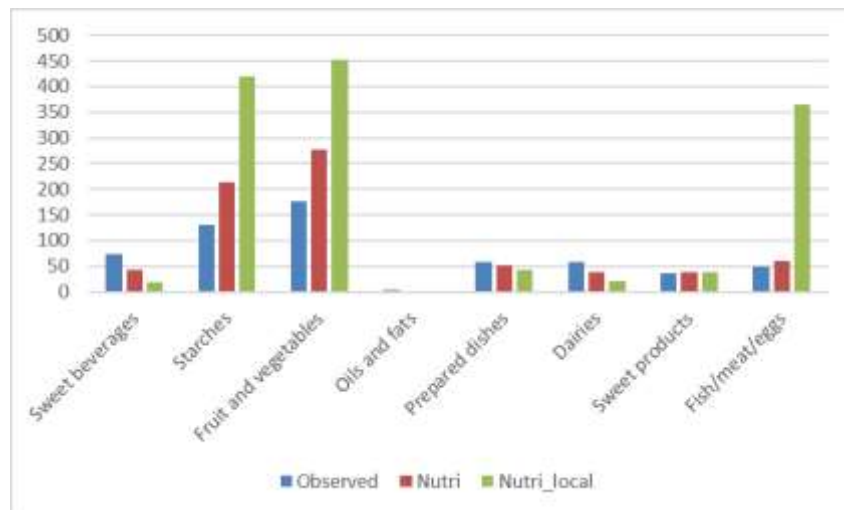
The first stage of the study was to simulate dietary scenarios. We first, calculate the daily food budget per person. The cost calculated with the lowest prices is €7, the median cost is €13, and the average cost is €15. We have also computed thanks to mathematical programming the minimum budget required to meet nutritional recommendations. This minimized cost was found to be €6.

The results from these first two steps confirm the high cost of food in the region but also suggest that it is possible to improve the nutritional quality of the diet while reducing food expenses. Consequently we built a mathematical model that allowed us to explore two dietary scenarios, comparing the results to the current observed situation (Observed) considered as the baseline.

- In the first scenario (Nutri), the model was used to determine the dietary changes necessary to improve the nutritional quality of the diet without increasing the cost beyond €7 per day, while making minimal modifications to the initial diet.

- In the second scenario (Nutri\_local), the same model was used to improve the diet's nutritional quality while also increasing the proportion of local foods, still maintaining the €7 per day budget. This scenario emphasized a higher consumption of roots and tubers, legumes, fruits and vegetables, eggs, meat, and fish, all products that could be grown or produced locally.

The results (see fig. 1) indicate that in the Nutri scenario, the main dietary modifications would involve reducing the consumption of sweet beverages, increasing the intake of starchy foods (especially unrefined ones), increasing the share of fresh fruit and vegetables, and maintaining or slightly increasing the proportion of animal proteins, primarily from eggs and fish.



**Figure 1.** Daily consumption in grams/day

These changes are even more pronounced in the Nutri\_local scenario, where the diet incorporates a greater share of products that could be 100% locally sourced, such as unrefined starches (roots and tubers, legumes), fruits and vegetables, meat, fish, and eggs.

Finally, the proportion of local products in the diet was calculated for all three situations (Observed, Nutri, and Nutri\_local). In the baseline, local products account for approximately 30% of the diet. This share increases to 40% in the Nutri scenario and reaches 75% in the Nutri\_local scenario.

Results showed that the share of local products can be increased up to 75% while increasing the nutritional quality of the diet and without increasing the baseline cost of 7 €/day/person.

In the second stage, we analyzed to what extent and under what conditions the previous scenarios could be met by the Guadeloupean agricultural production system using the MOSAICA optimization model. The objective of our study was to assess the capacity of local agricultural production to supply food products in sufficient quantity and quality to meet the needs of the population. We also examined the impacts on local agriculture, such as changes in cultivated areas and effects on other crops due to land-use substitution.

We used the simulation results of both scenarios Nutri, and Nutri\_local; while the Observed scenario was considered as the baseline, reflecting the current agricultural system. The assumptions made for these scenarios included maintaining the Utilized Agricultural Area (UAA) constant, meaning that no new land was cultivated and farm structures remained unchanged. We did not consider farm expansion or the introduction of external labor, and we

based our analysis on current production techniques, meaning that yields and agricultural practices were fixed according to existing values and methods.

This study was conducted at the territorial scale using the MOSAICA bioeconomic model, which relies on mathematical programming (Chopin et al., 2017; Chopin et al., 2015). The model was used to choose the land allocation among different crops, incorporating various constraints such as land and labor availability, as well as banana production quotas in order to maximize the farmers' income. This approach allowed us to simulate the agricultural situation in Guadeloupe and accurately reproduce the current land-use distribution.

With this calibrated model, we adjusted certain parameters to explore the impacts of different scenarios and observe how cultivated areas could be redistributed among different crops to meet the simulated demand. The model outputs included key indicators such as labor requirements, gross margins, farmers' income, labor demand, and production volumes. These results were then aggregated at the territorial level to evaluate the overall impact on food production, employment, and agricultural income. Results are resumed in table 1.

<b>Area (ha)</b>	<b>Observed</b>	<b>Nutri</b>	<b>Nutri_local</b>
Fruits	931	1045	1831
Vegetables, roots and tubers	1451	1899	3591
Cattle	6096	6362	16263
Banana export	1717	1601	61
Sugar cane	12908	12084	1767
Fallow	416	475	39
<b>TOTAL</b>	<b>23519</b>	<b>23466</b>	<b>23552</b>

**Table 1.** Results of simulation of the 3 scenarios with MOSAICA

In the Nutri scenario, the dietary adjustments had only a minor impact on total production volumes. The area dedicated to vegetables and tubers increased from 1,451 ha to 1,899 ha, while the areas for fruits, cattle farming, export bananas, and sugarcane remained largely unchanged.

In the Nutri\_local scenario, the increased demand, particularly for cattle farming, led to a significant reduction in sugarcane cultivation. In the Nutri\_local scenario, the land required for increased cattle production was taken from banana plantations, while the labor needed for vegetable farming came from sugarcane farms. The production of fruits, vegetables, tubers, and cattle increased by more than 2.5 times. However, the area for export bananas fell from 1,717 ha to 61 ha, sugarcane from 12,908 ha to 1,767 ha, and fallow land from 416 ha to 39 ha. To implement this scenario, it would be necessary to reallocate land from export bananas, sugarcane, and fallow fields.

To make this scenario feasible, additional agricultural labor would be required. Even with a constant UAA, the production volumes needed cannot be achieved without a significant increase in labor, ranging from 10% to 60%, depending on the scenario. In some areas, such as small-scale sugarcane farms in the Eastern part of the island (Nord Grande-Terre), labor availability would be insufficient to transition towards vegetable farming. This raises concerns about the sustainability of these new practices, particularly regarding health risks in areas contaminated with chlordecone<sup>1</sup>.

Finally we performed a LCA to assess the environmental impacts of these scenarios. One of the first observations concerns the impact of current food consumption in Guadeloupe on climate change. Our results show that the Observed correspond to 2.4 tons of CO<sub>2</sub> equivalent per person per year, a figure very close to that observed in mainland France.

Further analysis reveals that agricultural production is the main contributor to greenhouse gas emissions, as is the case in mainland France. However, there are notable differences in the transport and storage phases. The proportion of emissions linked to transport is slightly higher in Guadeloupe, mainly due to the use of air freight for certain fresh products, such as fish. Similarly, the storage, transport, and distribution phases have a greater impact in Guadeloupe. This is partly explained by the energy mix in Guadeloupe, which is more carbon-intensive due to the use of coal and fuel oil for electricity production. These specificities contribute to the

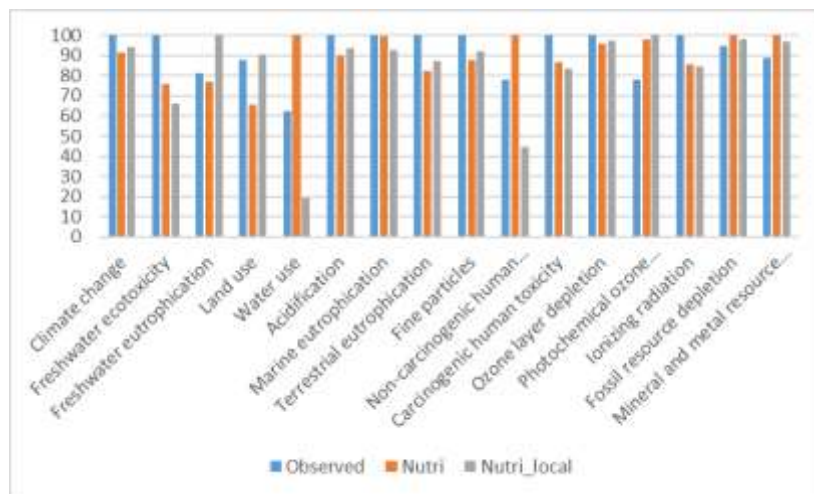
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<sup>1</sup> The soils of Guadeloupe are contaminated with chlordecone, an organochlorine pesticide that was widely used in banana plantations between the 1970s and 1990s. Due to its persistence in the environment, this pollutant continues to affect agricultural land, water sources, and the food chain, posing significant health and environmental challenges.

differences observed in these phases compared to the food consumption impact in mainland France.

Focusing again on the climate change impact of food consumption in Guadeloupe, it is relevant to examine which foods are the main contributors. Once again, the results align with general observations: meat and fish rank among the highest contributors. Among them, the most significant contributors are: beef (17.3%), chicken (10.3%), pork (6.9%) and fish (6.4%).

When examining the impact of food consumption in Guadeloupe on climate change across the scenarios Nutri and Nutri\_local, a striking observation emerges: despite the strong contrasts between these scenarios—both in terms of dietary composition and the share of locally produced food—their climate change impacts remain broadly similar. One of the main reasons for this convergence is that in all scenarios, meat and fish still represent a significant share of food consumption. This highlights the dominant role of these food categories in the overall environmental footprint, regardless of the agricultural practices, origin, or distribution channels associated with them.



**Figure 2.** Environnemental impacts of Guadeloupe diet  
Comparison of scenarios

It is also important to consider the full range of environmental indicators (see fig. 2). A closer look at these indicators reveals that the Observed scenario is often the most impactful, particularly for nine out of the 16 evaluated indicators (including human toxicity, ecotoxicity, marine and terrestrial eutrophication, acidification, fine particulate matter, ionizing radiation, and ozone layer depletion). In contrast, the Nutri scenario stands out for its high impact on water

resource use, due to its significant rice consumption. Rice is a highly irrigation-intensive crop, particularly in regions such as India, where water consumption for rice production reaches extremely high levels.

Regarding the Nutri\_local scenario, it ranks highest in only three out of 16 environmental indicators, one of which is freshwater eutrophication. This phenomenon results from an excess of nutrients, mainly phosphorus, in aquatic environments such as rivers and lakes. In Guadeloupe, this issue is closely linked to local yam production, which requires a relatively high amount of phosphorus-based fertilizers. Since phosphorus is highly mobile in runoff water, it rapidly contaminates nearby water bodies. This problem is further exacerbated in high-rainfall areas, such as certain regions of Guadeloupe.

This scenario also stand out in terms of land use impact, primarily due to the significant presence of cattle farming, which requires large land areas per kilogram of meat produced.

#### **4- Discussion and conclusions**

This study aimed to determine first, whether it is possible to improve the nutritional quality of diets in Guadeloupe while increasing the share of locally produced food, without exceeding the current household food budget. Additionally, it assessed whether local agriculture could meet the demands of these new dietary patterns and finally, what environmental consequences such a transition would entail. Our findings indicate that achieving these goals is feasible, but only under certain conditions. The diet scenarios require a drastic decrease in sweet beverages and a significant shift toward the consumption of locally grown fruits, vegetables, roots, tubers, meat, eggs and fish and. However, ensuring that local agriculture can meet this new demand without destabilizing existing sectors requires structural changes, including increasing the agricultural workforce and mobilizing additional farmland. Moreover, our results highlight that while certain scenarios can reduce specific environmental impacts; others, particularly those requiring extensive land use, may create trade-offs. Without careful planning, the balance between food sovereignty, economic sustainability, and environmental responsibility could be compromised. Our findings underscore the complex interplay between food choices, land use, and environmental outcomes (Clark and Tilman, 2017). While increasing local food production offers potential economic and food security benefits, it also presents significant trade-offs. The redistribution of agricultural resources must be carefully managed to avoid unintended

consequences, such as land shortages, biodiversity loss, or adverse economic shifts in key agricultural sectors. These challenges highlight the need for well-informed policy measures that support a resilient and sustainable food system in Guadeloupe.

To mitigate potential negative impacts and ensure a successful transition toward a more local and sustainable food system, several policy recommendations emerge from this study:

Improving diet quality should involve promoting plant-based eating habits and increasing the consumption of plant proteins, particularly legumes, which are traditionally part of Guadeloupean cuisine (Perignon et al., 2017). Public awareness campaigns, school meal programs, and incentives for local production of pulses could facilitate this transition.

In order to maintain economic stability within the agricultural sector, it is crucial to revise farming techniques and production methods that align with sustainable practices while ensuring that existing sectors are not disproportionately affected. Increasing agricultural productivity through sustainable intensification techniques, such as agroecological practices, can help meet food demand without requiring excessive land expansion (Kerr et al., 2021).

Encouraging the next generation to get into the farming profession can significantly increase local food production capacity. Incentives such as financial aid, land access facilitation, and training programs could support this effort.

Another significant finding of this study is the potential economic impact of phasing out sugarcane and banana cultivation. Redirecting financial and land resources from these traditional export crops to the development of fruit and vegetable production could foster a more self-sufficient and nutritionally diverse food system. However, such a shift must be approached cautiously to avoid economic disruptions and labor displacement in these historically significant sectors.

Despite the potential benefits of food system relocalization, our results do not provide conclusive evidence that relocalization alone reduces the environmental footprint of food consumption. Depending on the indicators used, the outcomes are mixed. For instance, the Nutri\_local scenario significantly lowers water consumption while simultaneously increasing land use, illustrating a pollution trade-off between these two factors. These findings highlight

the importance of adopting a nuanced perspective when assessing environmental sustainability and ensuring that policies are designed to address multiple dimensions of impact.

Across all modeled scenarios, one factor remains constant: the large share of products from animal origin in the Guadeloupean diet contributes most to environmental degradation—particularly meat and fish. This reinforces the idea that dietary shifts toward plant-based foods are among the most effective strategies for reducing the ecological footprint of food consumption in Guadeloupe (Perignon et al., 2017).

It is also essential to recognize the limitations of this study. The relocation model analyzed here is constrained by the current structure of Guadeloupe’s agricultural production. Introducing new crops, such as plant-based protein sources and cereals, could significantly alter these results. Likewise, transitioning toward agroecological practices could further modify the environmental and economic dynamics of local food production.

Furthermore, this study primarily focuses on the food supply function of agriculture. However, food systems play a broader role, encompassing economic functions—such as employment generation, energy production, and soil fertility management—as well as cultural and social dimensions. Future research should extend the scope of analysis to assess these wider implications and explore how local agricultural policies can better integrate economic, social, and environmental priorities.

A deeper investigation of land-use competition will also be critical, particularly regarding the ongoing debate over the balance between export-oriented agriculture, domestic food security, and the challenges posed by soil contamination from chlordecone. Addressing these issues holistically will be key to shaping a food system that is both resilient and sustainable.

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