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# AGRICULTURAL PRODUCTION AND GHG EMISSIONS IN THE BRAZILIAN AMAZON

## PRODUÇÃO AGRÍCOLA E EMISSÃO DE GASES DE EFEITO ESTUFA NA AMAZÔNIA BRASILEIRA

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## ABSTRACT

This study aimed to analyze the impact of agricultural production in the Brazilian Amazon on greenhouse gas (GHG) emissions. This impact was measured using the Johansen cointegration test and the estimation of a vector error correction model (VECM) to explore short and long-run relationships between the equivalent of $CO_2$ emissions, agricultural production, cattle heads, deforestation, and agricultural value added to GDP. The results indicated no evidence of long-run equilibrium in equivalent $CO_2$ emissions for agriculture in the Amazon. However, in the short run, agricultural production, deforestation, and agricultural value added to GDP impacted GHG emissions. Extensive production expanded the Amazon's agricultural frontier and increased GHG emissions, while investments in sustainable practices in rural areas and compliance with environmental institutions contributed to reducing the impact of agriculture on GHG emissions.

**Keywords**: vector error correction model; cointegration; commodities; sustainable agriculture.

## RESUMO

Este estudo teve como objetivo analisar o impacto da produção agrícola Amazônica brasileira nas emissões de gases do efeito estufa (GEE). Esse impacto foi medido através do teste de cointegração de Johansen e um modelo de vetor de correção de erros (VECM) foi estimado para explorar a relação de curto e longo prazo entre emissões equivalentes de $CO_2$, produção agrícola, cabeças de gado, desmatamento e valor adicionado bruto da agropecuária ao PIB. Os resultados indicaram não haver evidência de equilíbrio de longo prazo nas emissões de $CO_2$ equivalentes da agricultura na Amazônia. No entanto, no curto prazo, a produção agrícola, o desmatamento e o valor adicionado bruto da agropecuária ao PIB impactaram as emissões de GEE. Enquanto a produção extensiva expande a fronteira agrícola amazônica e aumenta as emissões de GEE, os investimentos em práticas sustentáveis no meio rural e o cumprimento de instituições ambientais contribuem para reduzir o impacto da agricultura nas emissões de GEE.

**Palavras-chave**: modelo de vetor de correção de erros; cointegração; commodities; agricultura sustentável.

## 1 INTRODUCTION

In the 1960s, the Brazilian government's diagnosis of the Amazon showed an impoverished population and an economy focused on regional relations, in addition to a significant portion of the population living in the countryside and performing subsistence activities (Brasil, 1966). To break the cycle of poverty, and to reorganize the Amazon's economy to align with the major national foreign centers, the government established a new strategy based on more efficient uses of rural areas through the production of commodities.

The emerging agribusiness has helped to transform the productive and social dynamics in the Amazon; agrarian development policies have also produced reflexes in urbanization, increasing demographic density (Jepson, 2006). Regarding the changes in the agrarian environment, incentives towards agribusiness addressed the allocation of productive factors to the region, in particular through 1) work: through the migration of people from other regions of the country; 2) financial resources: with the availability of loans with subsidized interest and tax waivers; and 3) logistics infrastructure: with the construction of roads and other equipment for the outflow of production (Fearnside, 2005; Nepstad *et al*., 2014). The purpose of this mobilization of productive resources directed to the Amazon was to activate the use of land for agribusiness.

The success in increasing pasture and cropland has enabled the Amazon to become the largest national agricultural frontier with major importance for the national economy, as well as for world food security (Soterroni *et al*., 2022). However, this expansion of agricultural production in the Amazon region has had some undesired effects, largely regarding environmental externalities, such as deforestation to increase economically available areas (Carrasco *et al*., 2017) and the emission of greenhouse gases (GHGs) as a result of intensified agricultural activities.

The agricultural sector was responsible for 54% of global non-$CO_2$ greenhouse gas emissions in 2005, mainly from soil management ($N_2O$) and enteric fermentation ($CH_4$) (EPA, 2012). These GHGs are generated through of the use of synthetic fertilizers, rice cultivation, drainage of organic soils, crop residues, and burning crop residues, in addition to the fuel used for farm machinery. In livestock, emissions originate from manure management, manure applied to soils, or manure left on pastures and enteric fermentation (Smith *et al*., 2014).

The GHG emissions from the cattle industry in Brazil as a whole have already been analyzed (Bustamante *et al*., 2012), creating an overview for the late 1990s and first half of the 2000s (Cerri *et al*., 2009). In this study, we aimed to analyze the impact of agriculture greenhouse gas emissions in the Brazilian Amazon. To test the hypothesis of the existence of environmental externalities correlated with the agricultural expansion in the Amazon, agricultural GDP value added and deforestation are also included in the analysis to measure the impact of sector growth.

## 2 LITERATURE REVIEW

The relationship between externalities caused by productive activities is extensively analyzed in the literature by classical theorists. Nineteenth century authors such as Malthus and Ricardo previously highlighted the limitations of the diminishing returns of the expansion of agricultural productions due to the carrying capacity of the land (Mueller, 2007). Despite these authors devoting little attention to improvements in productive factors, they opened a path for the study of the relationship between the economy and natural resources.

In practical terms, the expansion of the economic system is related to the improvement in quality of life, mainly through the supply of goods and services. However, the expansion of production capacity imposes environmental problems, either due to the need to acquire more raw materials from the natural environment, or due to the generation of residues and tailings disposed of in nature. The analysis between the economy and the environment has included investigations from the perspective of long-term correlations, with the use of time series (Peng; Wu, 2020; Yusuf *et al*., 2023). These studies make it possible to analyze the trajectory of the variables over time, as well as the main factors which affect the environment.

The agricultural sector consequently plays a role in the production of negative environmental externalities. In Brazil, the most prominent issue is the fact that agricultural production and incentives to this sector are the major cause of the deforestation of native forests, mainly in the Amazon (Assunção *et al*., 2020; Fearnside, 2001; Frey *et al*., 2018). However, agricultural production also increases GHG concentrations through the intensive use of inputs, enteric fermentation, as well as other processes, including the emissions from deforestation of native forests.

Khan, Ali, and Ashfaq (2018) investigated the nexus between value-added agriculture, coal electricity, hydroelectricity, renewable energy, forest area, vegetable area and greenhouse gas (GHG) emissions in Pakistan using annual data from 1981 to 2015. Their results confirmed the long-run causality of GHG emissions, value-added agriculture, and forest area. Ben Aïssa, Ben Jebli, and Ben Youssef (2014) examined the relationship between renewable energy consumption, trade, and production in a sample of 11 African countries covering the period 1980-2008. Research results revealed evidence of a bidirectional causality between production and exports and between production and imports, both in the short and long term. Dar and Asif (2020) studied the short-run and long-run impact of agricultural contribution, renewable energy consumption, real income, trade liberalization and urbanization on carbon emissions for a balanced panel of five South Asian Association for Regional Cooperation (SAARC) countries spanning the period 1990-2013. The results revealed that agricultural contribution and renewable energy consumption improve environmental quality in the long run, while urbanization and per capita real income degrade it.

Thus, investigations on the relationship between environmental degradation and socioeconomic variables were encouraged by Granger (2004). Bustamante *et al*. (2012) studied greenhouse gas emissions associated with cattle ranching in Brazil, focusing on the period from 2003 to 2008 and the three main sources: 1) portion of deforestation resulting in the establishment of pastures and consequent burning of cleared vegetation; 2) burning of pastures; and 3) bovine enteric fermentation. Among the results, it is evident that emissions from livestock are responsible for approximately half of all Brazilian emissions.

Agriculture plays a role in climate change since it increases GHG concentrations through emissions from various sources. Zafeiriou and Azam (2017) suggest that $CO_2$ emissions from agriculture may have an inverted U-shape curve when correlated to agricultural income per capita in developed economies. However, in their empirical study, they did not find these results for all countries investigated, indicating that more investments and policies should be directed to the agricultural sector to increase efficiency and reduce GHG emissions.

The relationship between livestock growth and environmental impact was studied by Patiño-Domínguez, Oliveira and Mourão (2021) with data from Colombia from 1961 to 2017. They observed long-term relationships between $CO_2$ emissions from dairy cattle and emissions from slaughtered cattle, deforestation, pastures, and forestry development. Their results support the fact that extensive livestock models continue to lead to deforestation, as well as resulting in $CO_2$ emissions.

Efforts to quantify the impact of the increase in agricultural production on the emission of greenhouse gases have been developed using different methodologies adopted according to the objective of the study. To guide national public policies, the Intergovernmental Panel on Climate Change (IPCC) presented a report comparing national emissions from agriculture (Smith *et al*., 2014). The indicators used in this publication are based on the System of Environmental-Economic Accounting methodology (FAO; UN, 2020) prepared by the UN to analyze the relationship between national accounts and natural resource accounting. These statistics show the tradeoff between aggregate production and emissions, statistically supporting the research on the subject (Flachenecker; Guidetti; Pionnier, 2018).

International recognition of the impact of agriculture on the environment requires innovations to reduce GHG emissions in this sector. This is especially true for Brazil, which is highlighted for its role in environmental issues and is a huge agricultural producer. Investment in modern technologies contribute to both sustainable development and the growth in agricultural production (Balafoutis *et al*., 2017).

## 3 MATERIAL AND METHODS

### 3.1 DATA

This study employed annual time series data from 1990 to 2016. Eight Brazilian Amazon states were considered in the analysis (Acre, Amapá Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins). The state of Maranhão was not included, since only municipalities west of meridian 44° are part of the Brazilian Legal Amazon and therefore it was not possible to subset the date from this state.

Data from greenhouse gases (GHGs) from the agricultural sector was obtained from the Brazilian National Emissions Record System (*Sistema de Registro Nacional de Emissões* - SIRENE) (Brasil, 2022), measured in GWP-SAR (Global Warming Potential – Second Assessment Report). Data on agricultural production (AGR), measured in hectares, considered both permanent and temporary crops over a year. Agricultural production and cattle heads (CH) were obtained from National Agricultural Research and National Livestock Research, respectively (IBGE, 2021).

Deforestation (DEF) is measured in km² and the data was obtained from the *Programa de Cálculo do Desflorestamento da Amazônia* (PRODES) at the National Institute for Spatial Research (INPE, 2022). Agricultural Value Added for Gross Domestic Product (AGDP), measured in thousands of Brazilian Currency, was obtained from IpeaData (IPEADATA, 2022). All currency variables (Brazilian currency) were updated to 2016 prices using the IGP-DI index from the Getúlio Vargas Foundation.

## 3.2 MODEL SPECIFICATION

The objective of this study was to verify the short and long-term relationships between agricultural production and the greenhouse gas emissions in the Brazilian Amazon. Agricultural production and cattle heads were considered as the main drivers of the agricultural economy in the Amazon. Deforestation in the Amazon is responsible for the main increase in new crop and pasture areas over time and contributes to emissions of GHGs. Agricultural Value Added GDP is used as a proxy of the economic importance of this sector and its growth stimulates future investments. To investigate the short and long-term effects of selected variables on GHG emissions we employed the following Cobb-Douglas function (Equation 1):

$$GHGs_t = f(AGR_t, CH_t, DEF_t, AGDP_t) \tag{1}$$

The natural logarithm of each variable was taken, and the model to be analyzed is given in Equation 2.

$$lnGHGs_t = \beta_0 + \beta_1 lnAGR_t + \beta_2 lnCH_t + \beta_3 lnAGDP_t + \beta_4 lnDEF_t + \epsilon_t \tag{2}$$

The stationarity of each variable was checked using the Augmented Dickey-Fuller test (ADF-Test) using both the I(0) and I(1) order of variables. Lag's selection was performed using the Schwarz information criterion (SIC). Considering that all variables are stationary at first difference, the Johansen cointegration test was performed to analyze the long-term relationship between selected variables using both trace and maximum eigenvalue.

The model in equation 2 was reformulated to include both the short-term relationship of the variables in a first differenced VAR and long-term effects over equilibrium in the form of an Error Correction Term (ECT). Equation 3 represents the Vector Error Correction Model (VECM) applied in this study with the variable GHGs as the dependent.

$$\Delta lnGHGs_t = \sum_{j=1}^{q} \delta_{1j}\Delta lnAGR_{t-j} + \sum_{j=1}^{q} \delta_{2j}\Delta lnCH_{t-j} + \sum_{j=1}^{q} \delta_{4j}\Delta lnAGDP_{t-j} + \sum_{j=1}^{q} \delta_{3j}\Delta lnDEF_{t-j} + \lambda ECT_{t-1} + \upsilon_t \quad (3)$$

Where $\Delta lnGHGs_t$ is the first difference of the dependent variable of the target model's equation; j represents the lag for short-run first differenced independent variables; $ECT_{t-1}$ is the error correction term, which shows the long-term equilibrium relationship between variables, considering $\lambda$ the adjustment coefficient, which represent the speed and direction of adjustment; and $\upsilon_t$ is the error term. All statistical procedures were performed in R v. 4.1.2 (R Core Team, 2023).

## 4 RESULTS

To check the stationarity of the variables, we performed the Augmented Dickey-Fuller test (ADF-test). Schwarz information criterion was selected to determine the lag length in the ADF-test. The null hypothesis of the ADF-test tau test suggests that the series is non-stationary. First we tested if the variables are stationary in level –I(0)– considering the three suggested models for the ADF-test (intercept and trend, only intercept, neither intercept nor trend). None of the selected variables showed stationarity at I(0), so we proceeded to test at first difference –I(1). All variables showed stationarity at the first difference in the first model tested (intercept and trend), except for the CO2e variable, which is stationary only in the model without intercept and trend (Table 1).

Table 1 – Tau-statistics of the Augmented Dickey-Fuller test for unit root **analysis**

| **Variable** | **I(0) – in level** | | | **I(1) – first difference** | | | **Lag Length Schwartz Criteria** |
|---|---|---|---|---|---|---|---|
| | None | Intercept | Intercept & trend | None | Intercept | Intercept & trend | |
| *GHGs* | 1.61 | -1.14 | -1.87 | -2.07* | -2.87 | -2.88 | 2 |
| *AGR* | 1.80 | -0.02 | -3.05 | - | - | -3.63 * | 2 |
| *CH* | 1.25 | -2.00 | -1.69 | - | - | -3.64 * | 2 |
| *AGDP* | -0.36 | -0.95 | -2.16 | - | - | -3.52 * | 1 |
| *DEF* | 1.90 | -1.22 | -2.46 | - | - | -4.77 * | 1 |

Note: * denotes significance at 5%. = greenhouse gas emissions; = agricultural production; = cattle herd; = agricultural value added for gross domestic product; = deforestation.

A set of variables are cointegrated if all elements are integrated in order d and if there is a non-zero vector (cointegrating vector) which is the linear combination of these variables (Enders, 2014). Considering that the variables are integrated into order I(1) with the ADF-test, we tested the long-run cointegration using the Johansen cointegration test (Johansen, 1988) with a linear deterministic trend for error correction term and none for VAR. Schwarz information criterion was employed to determine the lag length for the cointegration test as two. The results demonstrate that both the trace statistics and maximum eigenvalue are significant at 5% for the existence of at least one cointegrating vector (Table 2).

Table 2 – Johansen cointegration test

| Cointegration vectors | Trace statistic | Maximum Eigenvalue |
|---|---|---|
| None | 73.56* | 39.68* |
| At most 1 | 33.95 | 21.88 |
| At most 2 | 22.08 | 9.27 |
| At most 3 | 13.22 | 21.88 |
| At most 4 | 6.13 | 6.16 |

Note: * denotes significance at 5%.

As the results of the Johansen cointegration test showed at least one vector of cointegration we proceeded with the estimation of the VECM model proposed in equation 3. The estimates are presented in Table 3 and show statistical significance for differenced lagged variables in the short run: AGR, AGDP and DEF. The VECM model's R-squared was 0.68.

Table 3 – VECM estimates. T-statistics in parenthesis

(continua)

| ***ECT* variable estimates** | | **Short-run estimates** | |
|---|---|---|---|
| Variable | Parameter | Variable | Parameter |
| $lnGHGs_{(t-1)}$ | 1 | (adjustment parameter) | 0.45 (1.83) |
| $lnAGR_{(t-1)}$ | -0.56 (-12.55) | $\Delta lnGHGs_{(t-1)}$ | -0.10 (-0.23) |
| $lnCH_{(t-1)}$ | -0.79 (-10.31) | $\Delta lnGHGs_{(t-2)}$ | 0.37 (0.99) |
| $lnDEF_{(t-1)}$ | 0.08 (11.9) | $\Delta lnCH_{(t-1)}$ | 0.81 (1.37) |
| $lnAGDP_{(t-1)}$ | 0.71 (5.02) | $\Delta lnCH_{(t-2)}$ | -0.71 (-1.4) |
| Constant | -2.83 (-4.22) | $\Delta lnAGR_{(t-1)}$ | 0.47 (2.5) * |

Table 3 – VECM estimates. T-statistics in parenthesis

(conclusão)

| *ECT* variable estimates | | Short-run estimates | |
|---|---|---|---|
| Variable | Parameter | Variable | Parameter |
| | | $\Delta \ln AGR_{(t-2)}$ | -0.42 (-2.52) * |
| | | $\Delta \ln AGDP_{(t-1)}$ | -0.26 (-0.93) |
| | | $\Delta \ln AGDP_{(t-2)}$ | -0.71 (-2.56) * |
| | | $\Delta \ln DEF_{(t-1)}$ | -0.16 (-3.59) * |
| | | $\Delta \ln DEF_{(t-2)}$ | 0.07 (1.43) |

Note: * denotes significance at 5%.

The diagnostic tests validated the estimated output. Serial correlation was not detected in the Langrage Multiplier test ($X^2$ = 36.44, p-value = 0.07) nor in the Portmanteau test (Q-stat = 46.66, p-value = 0.44). The White-test did not highlight homoscedasticity of residuals ($X^2$=344.98, p-value = 0.27). The Jarque–Bera test matched the residuals as normally distributed (JB = 14.99, p-value = 0.1322). ARCH effects were not detected ($X^2$ = 234.31, p-value = 0.32).

The ECT showed no significance at 5%, implying that there is no long-run equilibrium in the set of variables for $CO_2$ equivalent emissions. In the short run, parameter values are elasticities, AGR parameters indicate that a 1% increase in agricultural area changes $CO_2$ equivalent emissions by 0.47% and -0.42% for one and two lags, respectively. The increase in agricultural value added to GDP was significant only with two lags, with an elasticity of 0.71% and deforestation was significant with one lag (elasticity of -0.16%).

We tested granger causality between variables of the model. Considering GHG emissions as a dependent variable, AGR (p-value = 0.0002), AGDP (p-value = 0.0377), and DEF (p-value = 0.0006) showed significance to Granger cause GHGs.

## 5 DISCUSSION

Agricultural production in the Brazilian Amazon is historically based on an increase in pasture and arable land through clearing native forest areas. Even though cattle ranching is highlighted as the main driver of deforestation in the Amazon (Almeida *et al*., 2016; Moffette; Skidmore; Gibbs, 2021; Rivero *et al*., 2009) it showed no significance in the short run regarding an increase in $CO_2$ equivalent emissions in Brazilian agriculture. Some studies state that cattle ranching has low stocks of cattle heads per unit of area in the Amazon (Bulte; Damania; López, 2007; Müller-Hansen *et al*., 2019). A consequence of this inefficiency is the lower emissions of GHGs through use of inputs, despite previous deforestation, pasture burning and digestion of cattle contributing to an increase in the rate of $CO_2$ equivalent emissions.

Crop production showed a significant short-run impact on $CO_2$ equivalent emissions. The positive relationship in the first lag is followed by a negative influence with two lags. The increase in arable lands in the Amazon is mainly due to the expansion of commodities, such as soybean, maize, and cotton, which represented 89.8% of cropland in 2016 (IBGE, 2021). These activities show a lower impact on GHG emissions in the initial years while new areas for cultivation are being prepared, however, additional financing, the use of inputs, machinery, and intensive land use (Araújo *et al*., 2019) –increasing harvests to two or more in a year– tends to increase GHG emissions.

The deforestation rate in the first lagged period showed a negative correlation to $CO_2$ equivalent emissions in the Brazilian Amazon. Even though it is expected that deforestation is strongly associated with emissions of GHGs, the emissions are contemporaneously associated, meaning that the effects of deforestation on GHGs are noticed in the same year. However, clearing areas through deforestation produces long-term impacts on GHG emissions due to the use for pasture or cropland in subsequent years. Aragão *et al*. (2018) showed that despite Brazilian Amazon deforestation decreasing between 2003 and 2015, periods of drought were correlated with forest fires, and the concentration of GHGs increased. However, Brazilian official data does not account correctly for these emissions.

Our results did not indicate a long-run equilibrium in $CO_2$ emissions by agricultural production in the Brazilian Amazon. These results can be explained by some characteristics of rural expansion in the Amazon in the last decades. The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), introduced in 2004, and greater institutional constraints in Brazilian legislation, have resulted in the slowing down of deforestation (Börner *et al*., 2014), as well as increased investment in agricultural production, including sustainable practices. In recent years, command and control policies have been insufficient and an extensive model was prevalent, as the expansion of the Amazon agricultural frontier persisted, increasing the conversion of native forests to cropland and pasture, which also impacted GHG emissions.

This expansion of agricultural land is driven by the temporal gap between the availability of land, as a property right, and the use of this land for agricultural activities, which, in turn, can be explained by the existence of a land market (Costa, 2012). Thus, as the demand for land increases, there is an increase in deforestation rates and, subsequently, in fires and $CO_2$ emissions. Thus, despite government efforts to contain environmental degradation through command and control, without better incentives for sustainable practices, deforestation and GHG emissions tend to be driven by market logic.

The growth in agricultural production, investments, and societal pressure for the most important commodities supply chains leads to a more efficient use of inputs and the adoption of more sustainable technologies (Nepstad; Stickler; Almeida, 2006; Souza; Gomes, 2015). Agricultural added value to GDP showed negative correlation to $CO_2$ equivalent emissions (Table 1). Investments in the agricultural sector contribute to a reduction in GHG emissions. However, as Brazilian agricultural continues to depend on more intensive production systems, there is a consequent increase in the use of inputs and therefore GHG emissions. Thus, some important Brazilian policies (such as the ABC program) could be improved to encourage rural investments to focus on sustainability resulting in lower GHG emissions. The negative correlation between added value and GDP can also be connected to more sustainable practices that are being adopted in rural areas, where the increase in total output is also followed by the efficient use of inputs and adoption of technologies that reduce GHG emissions, contributing to both the economy and the environment.

At same time, official Brazilian records on GHG emissions, as also highlighted by Aragão *et al*. (2018), do not capture all emissions from the agricultural sector, thus making it difficult to estimate how different practices and activities contribute to $CO_2$ equivalent emissions. In this sense, discussions on the advancement of agriculture and livestock in the Amazon, regarding GHG emissions, should focus on mitigation actions aimed at grain production, which occupies most of the Brazilian agricultural frontier, and the fight against deforestation.

Incentives towards correct soil management, the responsible use of inputs and the expansion of strategies to combat illegal deforestation, should be the focus of policies to control emissions in the Amazon. To increase the positive benefits of protecting forests, incentives should be directed towards the carbon market in Brazil (Silveira; Oliveira, 2021), to provide rural areas with new possibilities to move from degrading activities to new sustainable markets.

## 6 CONCLUSION

The study aimed to verify the long-term relationship between GHG emissions and agricultural production in the Brazilian Amazon. To perform this analysis the cointegration of series was tested and followed by an estimation of the short and long-run effects using the VECM model. Our results demonstrated that GHG emissions from agricultural production in the Amazon did not show long-term equilibrium, which can be explained by the dynamics in the region, including the land market, which temporarily creates a gap between landowner rights and agricultural use, which lead to GHG emissions.

Another possible cause is that extensive models – mainly in cattle ranching – are still prevalent, resulting in an increase in GHG emissions. However, the results also indicated that the increase in Agricultural value added to GDP contributes to reducing GHG emissions, which can be a consequence of the sustainable practices –such as certifications, carbon markets, and increasing efficiency –that are being adopted in agricultural commodities crops, as well as investments that occur in rural areas.

While the agricultural frontier expands further in the Brazilian Amazon, deforestation and consequently GHG emissions will increase. However, Brazilian record keeping of GHG emissions may make it more difficult to determine all sources of these emissions. We suggest that future studies look at how other activities (including those not related to agriculture) contribute to GHG emissions in the Brazilian Amazon.

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