Load Generation Drivers in the Brazilian Electricity System

A Time Series Modeling Approach

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1. Introduction

This work aims to identify the determinants of load generation in the Brazilian electricity system, based on time series modelling of different levels of variables, such as: macroeconomic, institutional and technological progress.

The central idea of this work is to design an essay to discuss these determinants, to establish possible models that can explain them and, finally, to guide more robust research.

The paper is divided into three sections as follows:

The first one discusses the literature review of the sector and the determinants that have already been identified over time. In this way, the review aims to raise possible hypotheses and conclusions already published in order to enrich the debate within the proposed project.

The second section deals with data and methodology. In this sense, the data sources, tests, guidelines for the selection of variables and, consequently, the proposed tests and models are presented.

Finally, the conclusion focuses on the comparison between the initial hypothesis of the study and the results obtained by the models. There is also an explanation of the limitations of the study, as well as suggestions that could form part of a new round of exploratory analysis of the topic now established.

2. Literature Review

The main objective of generating electrical energy in a given country is to provide this input to different sectors of the economy intermittently and with different power patterns throughout the day. Industry, households, and even the service sector have different consumption patterns throughout the day, month, and year. Given this fact, national energy management systems are faced with the challenge of anticipating fluctuations in market demand in order to guarantee the supply of this good to the entire civil society (Eminoglu & Hocaoglu, 2005).

Faced with this uncertainty, several forecasting models have been established over time to address this challenge facing the energy industry. In addition to autoregressive models, important advances have been made in recent years. Deep learning methods using neural techniques and random forest approaches are used, taking into account data from the load generators themselves (Aslam et al, 2021).

However, there are events that are allegedly not captured by these models and challenge the analysis using the national system's own data set. Issues related to the uncertainty of the political and economic scenario and macroeconomic proposals to support business sectors and family consumption can be elements that anticipate the stress of load generation demand in a given country.

In addition, fluctuations in demand due to the constant installation of residential solar panels in a way that is not monitored by the government can contribute to the ineffectiveness of specific forecasting models for the sector. In addition, sectors with high load consumption are increasingly disconnecting from the grid, which also poses a challenge to the national power system. (Gui et al, 2006).

In central countries, there are already institutions that aim to capture this load management at the residential and industrial level. However, the current measures are still only for control and mapping and do not have a direct connection to the grid. In this way, mapping becomes a mere prop in the face of the challenges posed by the democratization of individual sources of electrical energy. Current literature estimates that energy load fluctuations will increase significantly by 2050 (Brinkel et al, 2024).

There are lines of research that suggest that the strategy of coordinating energy production will be unilaterally managed by the state. However, there are also proposals based on multifocal management with different levels of action, such as the triple helix strategies of local, territorial control and general coordination. The success of these policies is largely linked to the literacy of civil society and the transparent integration between public and private actors (Mahmoud & Lehtonen, 2020).

From this brief explanation, it is possible to see that the exposed problem is almost always observed, studied and managed from the perspective of the agents in this market i.e the solution lies in the review of energy consumption and production strategies. The following essay aims to bring to light from the literature a new approach to anticipate the movements that stress load generation in Brazil, which deviates from the current academic approach, based on the insertion of macroeconomic, institutional and technical progress variables in the models. analysis and forecasting of load generation.

3. Data and Methodology

The objective of this chapter is to present the data and methodology that provide empirical support for the assessment of electricity generation in Brazil. First, the variables and sources of time series data are presented. The software used for the econometric estimation is Stata 16 and the set of commands is available in the appendices. Next, the methodological design and the econometric tests that provide the empirical results of the research are explained.

3.1 Data and Sources

The variable that drives the centrality of the research is the monthly energy generation load Brazil, provided by the National Operator of the Brazilian Electricity System (ONS). This variable aims to empirically demonstrate the load generation of the Brazilian electricity system in megawatts of the five regional systems. The choice of this variable was determined by the fact that it can show the variation in energy consumption at a global level, both for families and for companies, without distinguishing between the final economic agents.

Table 1 - Descriptive Variables

Variable	Unit of Measure	Acronym	Source of Data	Classification
Monthly energy generation load Brazil	MegaWatt	ENE_Brazil	National Operator of the Brazilian Electric System	Predetermined
Economic Policy Uncertainty Index for Brazil	Index	EPU_Brazil	EPU Index	Predetermined
Central Bank of Brazil's Economic Activity Index	Index	EAI_Brazil	Central Bank of Brazil	Predetermined
PIM-PF - Brazilian Monthly Industrial Survey - Physical Production	Index	PMI_Brazil	Brazilian Institute of Geography and Statistics (IBGE)	Predetermined
Effective real average earnings of employed persons in Brazil	Currency BRL	CUR_Brazil	Institute of Applied Economic Research of Brazil (IPEA)	Predetermined
Patent applications in Brazil	Total	PAT_Brazil	World Bank Data	Predetermined

The second variable exposed in the project is the Economic Policy Uncertainty Index specifically for Brazil. This variable is an aggregate that, based on the collection of information from the market, newspapers and websites, aims to measure the level of political and economic uncertainty in a given country. The purpose of including this variable in the model is to try to gain insight into the possibility that countries with a low level of predictability may have a positive or negative impact on energy production in a given region.

The third variable is a proxy for Brazil's gross domestic product. The Economic Activity Index of the Central Bank of Brazil is an index provided by the Central Bank, with monthly samples, that anticipates expectations regarding the exposure of official GDP figures. The variable has been included in the model with the aim of observing how Brazil's economic growth affects the generation of energy load over time.

The fourth variable is the PIM-PF - Brazilian Monthly Industrial Survey - Physical Production, provided by the Brazilian Institute of Geography and Statistics (IBGE). The central idea of the allocation of this variable is to understand whether industrial and commercial activity is a driver that stresses load generation in the Brazilian national electricity system.

The fifth dataset is a monthly proxy for GDP per capita. The Effective Real Average Earnings of Employed Persons in Brazil, provided by the Institute of Applied Economic Research of Brazil, measures the average earnings of the economically active population in Brazil on a monthly basis. The main purpose of using this variable in the study is to understand how household consumption can affect energy production in the short and long term.

Finally, there is the variable Patent Applications in Brazil, which is a proxy for research and development, provided by World Bank data. The inclusion of this variable in the time series model aims to capture how technological progress affects the Brazilian electricity system and whether or not it has the capacity to contribute to the need to increase load in the country.

In short, the variables were chosen to capture different outcomes in some study blocks, they are: the institutional block (economic policy uncertainty), macroeconomic (GDP, family consumption and industrial activity) and technological progress (patent applications in Brazil).

3.2 Initial Analysis and Possible Correlations

The dataset consists of historical data between January 2003 and December 2021, on a monthly basis, giving a total of 228 observations for each dataset. It is important to carry out some simple tests and regressions to start interpreting the data, with the aim of clarifying the proposed hypotheses.

Table 2 - Summary Statistics of Time Series

Variables	Obs	Mean	Std. Dev.	Min	Max

ENE_Brazil	228	57081.2	8992.46	40495.1	73142.2
EPU_Brazil	228	166.485	95.649	22.2963	676.955
EAI_Brazil	228	130.798	13.7555	96.15	152.13
PMI_Brazil	228	107.185	8.78601	75.3652	122.389
CUR_Brazil	228	2486.52	503.601	1700.59	3341
PAT_Brazil	228	384.715	41.7307	322.167	456.667

The first regression provides some interesting insights for the study. Here are the first considerations:

EPU_Brazil is statistically significant with a positive coefficient. In this sense, the uncertainty of economic agents promotes stress in load generation, given the unpredictability of the scenario.

EAI_Brazil is statistically significant at 1% and has a positive sign. First of all, it can be concluded that the increase in product has a positive impact on the need to generate load in the system.

PMI_Brazil is statistically significant at 1% and is the only variable that has a negative sign in this first analysis. A possible explanation for this inverse relationship could be the improvement in the energy efficiency of industries.

CUR_Brazil is statistically significant at 1% and has a positive sign. Therefore, it can be concluded that the increase in family income is a driver of the increase in the load generated by the national electricity system.

Table 3 - Time Series – First Regression

Variable	**Global Period**
EPU_Brazil	5.319**
	(2.630)
EAI_Brazil	200.3***
	(37.93)
PMI_Brazil	-140.1***
	(41.81)
CUR_Brazil	10.03***
	(0.968)
PAT_Brazil	26.68**
	(10.44)
Constant	9,822**
	(3,806)
Observations	228
R-squared	0.888

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Finally, PAT_Brazil has a positive sign and is statistically significant at 5%. In this sense, it is possible to state that technological progress is a driver of the increase in the load of the system, considering that research activities suggest an intensive use of energy.

This initial analysis, without a full treatment of the database, is intended to be the basis for the hypotheses listed below.

H1: Political and macro-economic uncertainty stresses the national electricity system and makes it difficult to manage the country's load generation.

H2: Industrial activity and household consumption tend to be agents of similar weight in the uncertainty of load generation in the national system and increase energy generation.

H3: Technological progress acts as an element to increase load generation in the Brazilian national system.

Below we have a correlation matrix between the variables over time. In short, all variables have a statistically significant correlation of 10%, except for the relationship between load generation in the national system and industrial activity, as well as industrial activity and the variable explaining the average income of families and the number of patents.

Table 4 - Correlation Matrix

Variables	ENE_Brazil	EPU_Brazil	EAI_Brazil	PMI_Brazil	CUR_Brazil	PAT_Brazil
ENE_Brazil	1					
EPU_Brazil	0.4979*	1				
EAI_Brazil	0.7418*	0.2224*	1			
PMI_Brazil	-0.0457	-0.3242*	0.5045*	1		
CUR_Brazil	0.9261*	0.4696*	0.7302*	-0.0557	1	
PAT_Brazil	0.8554*	0.5260*	0.6619*	-0.1113	0.8618*	1

Note: *** p<0.01, ** p<0.05, * p<0.1

Such conditions may suggest an independence between industrial production and family income, as well as indicating that innovations and patent registrations are driven by other factors and not by Brazilian industrial activity.

3.3 Estimation methods

In order to analyse the data set, the proposal aims to use two time series models in order to compare them and obtain a better robustness for the study. The first model is the vector autoregressive model (VAR). The central idea of the model is to use multivariate time series based on an autoregressive model. The equation has the ability to present lagged values over time for a more robust analysis of the data set (Sims, 1980).

In this way, all variables are treated as endogenous based on the equation below:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \epsilon_t$$

Where:

Y = Time series vector

A = coefficient matrices

ϵt = Error term

In a second step, the study uses an analysis based on vector error correction (VEC). The model is nothing more than a VAR with cointegrated data correction. The central idea is to correct errors by adjusting short-term variables towards long-run equilibrium. (Johansen, 1988).

A basic impulse response test is then carried out to guide possible future studies in this area based on the forecast-error variance decompositions (FEVDs) technique (Koop et al, 1996).

The first step in processing the data is to carry out unit root tests. The Dickey-Fuller (1979) and Phillips-Perron (1988) tests have been carried out. Variables are not stationary in their pure form. In this way we carry out the second differentiation process, subtracting successive values from the time series to remove trends and making the series stationary to remove a quadratic trend. After applying this method, the series became stationary.

We then carried out the Granger causality tests (Granger, 1969). The results are shown below:

There is evidence of Granger causality from EAI_Brazil, PMI_Brazil, CUR_Brazil and PAT_Brazil to ENE_Brazil. It is important to note that there is also significant evidence of Granger causality from ENE_Brazil to EPU_Brazil. In contrast. There is no evidence of Granger causality from EPU_Brazil to ENE_Brazil, nor from EPU_Brazil to other variables.

After carrying out the test, the vector autoregressive (VAR) and vector error correction (VEC) models give the following results:

Table 5 - Time Series Regression Analysis – Vector Autoregressive (VAR) Model

Variable	ENE_Brazil	EPU_Brazil	EAI_Brazil	PMI_Brazil	CUR_Brazil	PAT_Brazil
L.ENE_Brazil	0.110	1.091	-0.0229	0.0534	0.307**	-0.00458
	(0.0685)	(1.075)	(0.0721)	(0.0638)	(0.136)	(0.0437)

L2.ENE_Brazil	-0.104	2.283**	0.0827	-0.147**	0.0352	0.00761
	(0.0668)	(1.048)	(0.0702)	(0.0621)	(0.133)	(0.0426)
L.EPU_Brazil	0.000923	-0.492***	-0.0108**	-0.00593	-0.00329	0.00197
	(0.00403)	(0.0632)	(0.00424)	(0.00375)	(0.00802)	(0.00257)
L2.EPU_Brazil	0.00428	-0.317***	-0.000952	-0.00479	-0.0200**	0.00163
	(0.00405)	(0.0636)	(0.00426)	(0.00377)	(0.00807)	(0.00259)
L.EAI_Brazil	-0.262***	-0.344	-0.465***	-0.0428	-0.238**	-0.0335
	(0.0586)	(0.919)	(0.0616)	(0.0545)	(0.117)	(0.0374)
L2.EAI_Brazil	-0.203***	-0.248	-0.361***	-0.000302	0.0635	-0.0164
	(0.0599)	(0.939)	(0.0630)	(0.0557)	(0.119)	(0.0382)
L.PMI_Brazil	0.231***	0.00675	0.359***	0.0546	0.130	0.0270
	(0.0789)	(1.238)	(0.0830)	(0.0734)	(0.157)	(0.0504)
L2.PMI_Brazil	0.137*	0.0566	0.235***	-0.0380	0.0260	-0.00625
	(0.0807)	(1.265)	(0.0848)	(0.0750)	(0.161)	(0.0515)
L.CUR_Brazil	0.00286	-0.252	-0.120***	0.00215	-0.238***	0.0527**
	(0.0321)	(0.503)	(0.0337)	(0.0299)	(0.0639)	(0.0205)
L2.CUR_Brazil	0.0212	0.650	-0.202***	-0.0331	-0.293***	0.0195
	(0.0323)	(0.507)	(0.0340)	(0.0301)	(0.0644)	(0.0206)
L.PAT_Brazil	0.123	1.878	0.00623	0.0685	0.0552	0.0143
	(0.106)	(1.659)	(0.111)	(0.0984)	(0.211)	(0.0675)
L2.PAT_Brazil	-0.0876	2.203	0.106	0.0543	-0.207	0.00604
	(0.105)	(1.649)	(0.110)	(0.0978)	(0.209)	(0.0671)
Constant	0.00283	-0.00692	0.00290	0.000616	0.00252	0.000741
	(0.00186)	(0.0292)	(0.00196)	(0.00173)	(0.00371)	(0.00119)
Observations	225	225	225	225	225	225

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

VAR model:

EPU_Brazil is statistically significant at 5% and has a positive coefficient on EPU_Brazil for the two-period lag. Increases in economic policy uncertainty, as captured by the Economic Policy Uncertainty Index for Brazil, are associated with increases in monthly electricity generation in the country. In this way, the national system tends to be stretched to the limit in order to satisfy energy consumption in Brazil. This indicates an inefficient use of the national installed capacity.

In addition, economic policy uncertainty can contribute to the volatility of energy markets, leading to fluctuations in electricity prices. This leads to capital capture by distributors to the detriment of consumers.

Another important issue is that economic policy uncertainty can motivate companies and consumers to diversify their energy sources. If this happens in an uncoordinated way, the national system will not be able to anticipate the load to be provided.

PMI_Brazil is statistically significant at 5% and has a negative coefficient. The negative coefficient indicates that an increase in industrial production is associated with a decrease in the need for monthly energy generation in Brazil. This may indicate that the growth of the industrial sector promotes its energy efficiency. As industries adopt more efficient technologies and sustainable production practices, they may be able to achieve higher levels of production with lower energy consumption. In this way, incentives for the industrial sector do not put pressure on the national electricity system.

CUR_Brazil is statistically significant at 5% and has a positive coefficient. A positive coefficient indicates that an increase in the average real earnings of workers in Brazil is associated with an increase in monthly energy consumption. This may indicate that as consumers' purchasing power increases, they have more capacity to consume energy. In this way, policies aimed at increasing the real minimum wage or expanding social spending through subsidies suggest that their implementation anticipates future consumption patterns.

Moreover, an improvement in the wage bill can influence consumption patterns and household lifestyles, leading to an increase in the use of electrical appliances, motor vehicles and other energy-dependent equipment.

EAI_Brazil is statistically significant at 1% and has a negative coefficient. In the Brazilian case, we can conclude that an increase in economic activity may be associated with improvements in energy efficiency and technological innovations that reduce the energy required to carry out certain economic activities.

In addition, an increase in economic activity may be related to changes in consumption patterns. Consumers end up prioritising products and services that require less energy, i.e. there is a choice for sustainable products.

The other variables were not statistically significant when cross-checked with ENE_Brazil.

VEC Model:

For the VEC model, it was not possible to estimate the variable PAT_Brazil, as it is not cointegrated.

Table 6 - Time Series Regression Analysis – Vector Error-Correction (VEC) Model

Variable	ENE_Brazil	EPU_Brazil	EAI_Brazil	PMI_Brazil	CUR_Brazil
L._ce1	-0.00522***	-0.0374	-0.0230***	-0.000857	-0.0221***
	(0.00157)	(0.0294)	(0.00143)	(0.00146)	(0.00321)
ENE_Brazil	-0.389***	-0.214	-0.0312	0.0841	0.0813
	(0.0651)	(1.220)	(0.0593)	(0.0606)	(0.133)
EPU_Brazil	-0.00194	-0.584***	-0.00206	-0.00157	0.0158***

	(0.00296)	(0.0555)	(0.00270)	(0.00276)	(0.00607)
EAI_Brazil	0.100	1.933	0.200***	-0.0116	0.611***
	(0.0690)	(1.293)	(0.0629)	(0.0643)	(0.141)
PMI_Brazil	-0.0151	-0.224	-0.377***	-0.447***	-0.382**
	(0.0788)	(1.478)	(0.0719)	(0.0735)	(0.162)
CUR_Brazil	0.0371	-0.310	0.316***	0.0159	-0.207***
	(0.0324)	(0.608)	(0.0296)	(0.0302)	(0.0665)
Constant	0.000419	-0.00160	0.00114	0.000120	0.00143
	(0.00239)	(0.0448)	(0.00218)	(0.00223)	(0.00490)

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. L._ce1 = ECM - Error Correction Model Lag

ENE_Brazil is statistically significant at 1% with a negative coefficient for the variable itself. This suggests a negative autoregression effect, i.e. an increase in generation in one month is followed by a decrease in generation in the following months and vice versa. This suggests something that is actually related to energy production, namely seasonal consumption.

The other variables do not have statistically significant values.

From now on we will discuss the impulse response outputs - dynamic multiplier functions and forecast error variance decompositions (FEVDs).

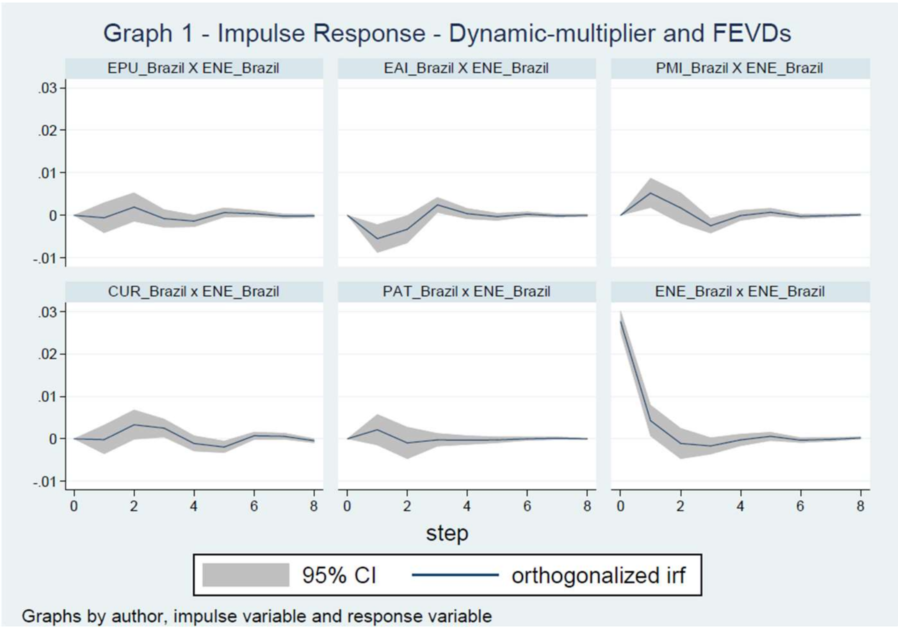
Table 7 - Impulse Response - dynamic-multiplier functions and forecast-error variance decompositions (FEVDs)

Step	ENE_Brazil x ENE_Brazil - Lower	ENE_Brazil x ENE_Brazil - Upper	EPU_Brazil X ENE_Brazil - Lower	EPU_Brazil X ENE_Brazil - Upper	EAI_Brazil X ENE_Brazil - Lower	EAI_Brazil X ENE_Brazil - Upper
0	0.027612	0.025061	0	0	0	0
1	0.004287	0.000639	0.007935	-0.000601	-0.004143	0.002942
2	-0.001096	-0.004689	0.002498	0.001928	-0.001446	0.005301
3	-0.001668	-0.003597	0.000261	-0.00079	-0.002893	0.001314
4	-0.000249	-0.001632	0.001133	-0.001354	-0.002731	0.000023
5	0.000576	-0.000405	0.001556	0.000654	-0.000451	0.001759
6	-0.000306	-0.000895	0.000283	0.000393	-0.000348	0.001133
7	-0.000111	-0.00057	0.000348	-0.000205	-0.000719	0.000308
8	0.000226	-0.000027	0.000478	-0.000135	-0.00054	0.00027

Step	PMI_Brazil x ENE_Brazil - Lower	PMI_Brazil x ENE_Brazil - Upper	CUR_Brazil X ENE_Brazil - Lower	CUR_Brazil X ENE_Brazil - Upper	PAT_Brazil X ENE_Brazil - Lower	PAT_Brazil X ENE_Brazil - Upper
1	0.005251	0.001775	0.008727	-0.000147	0.003239	0.00214
2	0.001706	-0.001883	0.005295	0.00335	-0.000112	0.006813
3	-0.002482	-0.004238	-0.000726	0.00255	0.000424	-0.00175
4	-0.000046	-0.001237	0.001145	-0.001083	-0.002882	-0.000293
5	0.000712	-0.000216	0.001639	-0.001887	-0.003264	-0.000217
6	-0.000246	-0.000797	0.000304	0.000707	-0.000177	0.000048
7	-0.00009	-0.0005	0.000321	0.000621	-0.000122	0.000144

8	0.000087	-0.000178	0.000351	-0.000452	-0.000945	0.0000083

Although there is a short term impact on the generation of the energy load, there is a long term stability of all variables. This may indicate that the addition of one unit in all variables stimulates and stresses the national electricity system in the short term. However, the responses stabilise in the long term.



Graph 1 - Impulse Response - Dynamic-multiplier and FEVDs

Graphs by author, impulse variable and response variable

In this way, it can be concluded that economic policies aimed at promoting industry, increasing wages and research and development initially create a greater burden on the national system. Investment in research and development can lead to technological advances and innovations that boost industrial production and economic activity. There is therefore a tendency to develop and choose more energy-efficient products.

4. Conclusion

The objective of this study was to identify the factors that put pressure on the Brazilian national electricity system. Based on the hypotheses presented in section 1, the final considerations are presented below.

Regarding hypothesis number one, it is confirmed. The models presented produce results that support the thesis that an unstable political and economic scenario acts as a stress factor for the national electricity system. Therefore, countries with a high level of institutional instability, such as Brazil, tend to have difficulties in forecasting energy consumption. This phenomenon burdens the end consumer to the point where energy generating units are willing to offer load to the market at above-average prices.

The second hypothesis is partially rejected. The model provides different signals for industry and household consumption. In the industrial sector, the development of new production units implies a reduction in load generation to the point where sectoral policies can be promoted by the energy efficiency allocated to production over time. For families, the sign is positive and the increase in income is indeed associated with the increase in load.

Finally, about hypothesis number three, the variable was not statistically significant in either model, thus highlighting the limitations of the model and suggesting new estimates using other research and development proxies that can clarify the relationship. with energy production in the Brazilian scenario.

From these results, it becomes possible to design new models for forecasting long-term load generation by state actors, based on a prior analysis of macroeconomic and institutional indicators.

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