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Itaipu Binational Dam: A Quantitative Analysis of the Economic and Social Impacts in Paraguay. Successful or not?

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Abstract

The Itaipu Binational dam is a giant hydroelectric project situated on the Parana River, which began its construction in 1973 and was completed in 1983. It was undertaken by Brazil and Paraguay, two countries with enormous geopolitical and economic differences. With 14,000 MWh of installed power, it is the second largest hydroelectric dam in the world. Both countries are partners in this project, but the socioeconomic results have not been as expected. In this regard, although Paraguay's GDP per capita, between 1983 and 2020, increased by 341%, Itaipu did not represent a true economic development engine for Paraguay. On the other hand, it had serious negative impacts especially on social, demographic, and environmental aspects. A structural equations model (SEM) was designed, in its Path Analysis modality, which includes 10 variables: 3 exogenous (Royalties from Itaipu, Electric power exports, and External debt) and 7 endogenous (GDP per capita, Proportion of agricultural sector in GDP, Proportion of service sector in GDP, Population with needs unsatisfied, Housing deficit, Changes of land use, and CO2 emissions). The model exposes an adequate simulation range, and the results show a high degree of goodness of fit, using different indices (CMIN, FMIN, CFI, and RMSEA). The corresponding tests upon the model validate the hypotheses raised.

JEL Classification: O13, O54, H54, H60, F34, C18

Plain Language Summary

Itaipu Binational Dam: A Quantitative Analysis of the Economic and Social Impacts in Paraguay

This article is a study that covers four decades (1980–2020), on the economic and social impact of a large hydroelectric dam, Itaipu Binational, built on the Parana River, by Paraguay and Brazil. The starting hypothesis is that Itaipu did not represent the engine of economic development expected for Paraguay. However, the conclusions mention that, in addition to testing the hypotheses, there are some macroeconomic indicators that have improved notably, such as the GDP per capita. The applied methodology was the Structural Equations Model (SEM) in its Path Analysis modality. Of the 15 original variables, 10 were finally selected, 3 exogenous and 7 endogenous. The results of the model are satisfactorily adjusted to the proposed hypotheses, which implies the contrasting of these. The main limitation of the study lies in the environmental impact generated by the dam in the ecosystem of the region. This analysis has been left pending, due, on one hand, to the fact that the objective of the article is the socioeconomic impact generated by Itaipu, and because it is considered that the environmental effects should be included in a subsequent research.

Keywords

Itaipu dam, socioeconomic impact, Brazil, Paraguay, SEM

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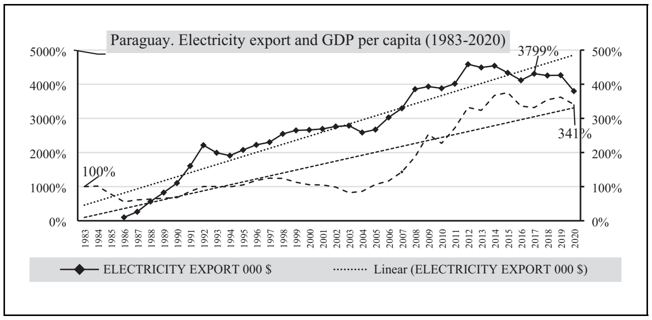

Figure 1. Paraguay. Electricity export and GDP per capita.
Note. It shows the evolution of GDP per capita and the Electricity export, between 1983 and 2020.

Introduction

Itaipu is often held up as an example of efficiency in the use of clean energy, resources, and human capital. However, without debating the above, the main objective of this research is to analyze the socioeconomic impact in Paraguay of this enormous hydroelectric dam. It represents 16% of the energy consumed by Brazil and 76% by Paraguay (Itaipu, 2021). Next, Figure 1 shows the increases in GDP per capita and in electricity exports in Paraguay, between 1983, the last year of construction of the dam, and 2020 (Central Bank of Paraguay, 2021a, 2021b).

The evolution of GDP per capita was 341%, and the export of electricity, 3,799%. They were an important quantitative growth. But, if these ratios are related to other economic, social, and environmental variables, this apparent positive economic impact could acquire different edges.

Despite the notorious gestures of friendship in recent decades between Paraguay and Brazil, it is worth mentioning that this was not always the case. For example, the Treaty of Itaipu was the result of more than a century of territorial disputes, whose initial trigger was the so-called War of the Triple Alliance (1864–1870). Therefore, the corollary occurred a century later, in 1969, with Brazil's invasion of Paraguayan territory to seize the Guaira Falls (Pozzo-Moreno, 2013), a wonder of nature that disappeared a few years later with the construction of the dam. Faced with this situation, Alfredo Stroessner and Ernesto Garrastazu—former military presidents of Paraguay and Brazil, respectively—began negotiations. The signing of the Treaty was in 1973, and has three annexes: "Annex A," based on administration; "Annex B," regarding the civil works; and "Annex C," which contains the core of the Treaty. This last Annex regulates the quantity and sale price of the energy that Paraguay sells to Brazil, as well as royalties and other compensations. The subsequent modifications, known as "Transversal Notes," include one from 2002, which obliges Paraguay to sell 43% of its energy exclusively to Brazil.

That is, Paraguay would keep only 7%, instead of the 50% that corresponds. Likewise, the contractual sale price was fixed at $25 MWh (Canesse, 1980). This amount multiplied by the annual amount of energy sold—about 40,000,000 MWh—should have generated revenues of $1,000 million in the General Budget of Paraguay. However, from 1983 until 2008, Paraguay received only $232,7 million annually (Ministery of Finance, 2019). The reason for this difference, that up to 2021 represented more than $20,000 million, is based on two pillars.

a. An economic-financial nature: from an initial budget of $2,033 million, the Itaipu dam ended up costing more than $17,000 million (Fruet, 2013). The main companies that won the bids were Centrales Eléctricas Brasileiras, S.A. (Eletrobras) and Consorcio de Empresas Paraguayas, S.A. (Conempa). Most of the civil works were carried out by Eletrobras (Eletrobras, 2018). The financial resources for the construction of the dam were obtained by Brazil in the international financial markets, as the country with the best credit rating. In turn, Brazil loaned to Paraguay half of these funds. As a result, Paraguay assumed a main debt of $8,500 million. This liability generated an interest rate that exceeded the levels of international markets. Until 2023, these debt service payments will be deducted from the price of $25 MWh, which is the reason for the difference of more than the $20,000 million mentioned above. This entire financial scheme will imply that, until 2023, Itaipu Binational, as owner of the dam, must pay Eletrobras, in concept of debt services, a total of $65,000 million (four times more than the final cost of the dam). Therefore, half of the $65,000 million, $32,500 million ($8,500 million of principal and $24,000 million of interests), corresponds to Paraguay.
b. A geopolitical nature: the Treaty, which has a somewhat puzzling wording, gives path to Brazil to take over the management of Itaipu. This situation was partially renegotiated in 2009, between former presidents Luiz *Lula* da Silva of Brazil and Fernando Lugo of Paraguay. And, since then, there has been a slight improvement in Paraguay's budget revenues.

The economic and social influences of the Itaipu dam on the Paraguayan economy and society, include a change in the orientation of the country economy. On the one hand, its raises economic efficiency and overall increases in GDP, but it also has clear implications on the general framework of the society (Illustration 1). The

Illustration 1. Itaipu dam and reservoir lake.
Source. Itaipu Binational.

country is geared to an export led growth based on agricultural goods, with some social and ecological problems associated which could lead to further difficulties. In this sense, several macroeconomic variables are related to a Path Analysis model, that would permit detecting these potential questions.

Literature Review

The hydropower plants have played a key role in the Brazilian electric sector for over a century, state De Albuquerque-Sgarbi et al. (2019). As the different options for the generation of electricity are being increasingly scrutinized in terms of their sustainability, the assessment of the social, economic and environmental impacts has become a strategic factor to support investment decisions geared to expand the power supply. The research of Morán et al. (2018), has a significant economic bias, including some social and environmental aspects. They examine the overestimation of benefits and underestimation of costs. Likewise, the authors analyze changes that are needed to address the social and environmental concerns of people living in areas where dams are planned. present A method of distribution of royalties based on a striking calculation of the flow of the Paraná River at the site where the Itaipu dam is located, is presented by Simões Lorenzon et al. (2017). Fearnside (2016) states that Brazil plans to continue building dozens of hydroelectric dams in the Amazon and in neighboring countries. But the author maintains that, from the cost-benefit studies, it is inferred that the benefits are much less than what is usually claimed. This is since electricity is exported in electro-intensive products such as aluminum, which generate little employment in Brazil. Likewise, from the social and environmental point of view, the impacts are serious. For example, there is the displacement of the population and the loss of livelihoods, such as fishing, the loss of biodiversity and the creation of greenhouse gas emissions. A study of the role of dams in development, considering hydroelectric energy as the main source of renewable energy and the potential it has to promote regional development, is analyzed by Tortajada (2015). The research of Zarfl et al. (2014) state that human population growth, economic development, climate change, and the need to close the electricity access gap have stimulated the search for new sources of renewable energy. Thus, at least 3,700 major dams, each with a capacity of more than 1 MWh, are being constructed worldwide, primarily in countries with emerging economies. The construction of a dam in Ghana enabled improvements in water use, resettlement and offsets compared to previous similar projects (Obour et al., 2015). A study on energy policy in Venezuela, suggest the diversification of energy sources from oil to focus on the construction of hydroelectric dams (Pietrosemoli & Rodríguez, 2013). In a research carried out in North India, Lata et al. (2013) state that electricity is one of the keys to economic growth. However, the authors mention that not only should the benefit function be maximized, but also that the function that minimizes the costs of negative social and environmental impacts should be determined. To do this, the interests of the affected population must be heard and addressed during planning. On the other hand, Baruah (2012) points out that the large dams built on the rivers of the eastern Himalayas are highly controversial because they will lead to even greater inequality in the distribution of wealth. Its reservoirs will have a devastating impact on the lives of millions of people, especially the poorest in rural areas who depend on river water. The study of Bohlen and Lewis (2009) examined the effects of dams in Maine, USA, on the value of adjacent residential properties. They designed a project to remove three dams that had a positive impact on the value of these properties. The research of Jackson and Sleigh (2000) studied the socio-economic repercussions of the world's largest dam complex, the Three Gorges on the Yangtze River in China. The first impact was that 1.3 million people had to be relocated. And this problem worsened the level of unemployment and the deterioration of public health services.

Regarding social impacts, Hoogendam and Boelens (2019) presented research on the Misicuni hydraulic megaproject, Bolivia. The project involved the construction of a large 120-m-high dam and a 19-km tunnel to transfer water to rural indigenous communities. Unfortunately, the project caused them to lose their productive land and homes. As an example of solidarity of a huge country with its smaller neighbor, Saklani and Tortajada (2019) presented a case in Asia. The article examined India's development cooperation with Bhutan through a hydropower project. However, in recent years, allegations of negative social impacts on the beneficiary population have been widespread. An analysis of 220 environmental conflicts related to dams was carried out by Del Bene et al. (2018). In all of them there was a common denominator: the social and environmental unsustainability of dams. Through a survey, Alarcón-Corrales and Pesallaccia-Zaldívar (2018) analyzed the perception of citizens of five cities of Alto Paraná, Paraguay, on the socioeconomic, cultural, and environmental impact of Itaipu. Most of the surveyed had difficulties in identifying the contribution of the dam beyond the generation of electric power. A sample of 217 articles published in the last 25 years on dams and social impacts was analyzed by Kirchherr and Charles (2016). They found that almost always they focused on dams' size and their impacts on resettlement. The social impacts, considering space, time, and value as key dimensions, as well as infrastructure, community and livelihood, were looked by Kirchherr et al. (2016). Related to the sociodemographic aspects, Campos (2003) studied the massive migrations as a collateral effect of the construction of Itaipu. This population increase was caused by the immigration of Paraguayan labor for the hydroelectric project, as well as by Brazilian immigration for the beginning of soybean monoculture.

Andrade and Olaya (2021) mention in their study that the world went from having 9,056 large dams in 1960 to more than 32,500 in 2010. Asia stands out as the continent with the most dams, especially due to China's hydroelectric development. Likewise, the authors affirm that some of the common impacts were flooding of natural habitats, loss of wildlife, forced displacement of people, deterioration of water quality, hydrological changes in the river downstream, loss of cultural and intangible heritage, among others. On the other hand, it would be important for Itaipu Binational to include new analysis criteria such as "Environmental, Social and Governance (ESG)" (Lisin et al., 2022; Varyash et al., 2020). This criterion, which combines a series of economic, social and environmental ratios which are related to "Corporate Social Responsibility" in the business sector, would try to improve the quantification of the impact of the dam in these three aspects. Anderson et al. (2018) analyzed that the connection of Andean rivers to the Amazon controlled numerous natural systems and human habitats in the Amazon region. They documented 142 constructed and 160 planned dams on rivers in the Amazon. And they found that the 142 existing dams had fragmented the tributaries of Amazonian rivers originating in the Andes. Likewise, Latrubesse et al. (2017) argued that more than 100 hydroelectric dams were already built in the Amazon River basin and more similar projects were under consideration. The cumulative negative ecological impacts of existing and planned dams would trigger even more environmental degradations in the world's largest river basin. Benchimol and Peres (2015) mentioned that large hydropower dams are still considered green sources of renewable energy. However, apart from the social, economic, and environmental costs there is evidence of widespread defaunation of natural forest cover. Similarly, Campos (2003) showed that in the 1960s and 1970s, the accelerated increase in population in the Itaipu area had a negative impact on the loss of more than 20,000 km^2 of forest.

Econometric multi-equational models can be included within the framework of path analysis representations. These provide a practical approach to specify and estimate the relations between several endogenous variables and their explanatory counterparts. As in most multivariate techniques, once the causal relations have been defined, the identifiability problem must be considered to be able to provide the economic interpretation to an equation (Caridad, 2016). A practical application of SEM, related to our research, can be found in Campos (2019) who proposed a causal model with latent and observable variables to represent the poverty in rural peasants in Paraguay, years after the completion of the Itaipu dam. The use of SEM in different economic sectors was especially recommended by the research of Bollen and Hoyle (2012). Likewise, Elosua (2011) introduced a SEM model to analyze preferences related to quality-of-life for the elder population. Furthermore, Badri et al. (2000) proposed some results related to business environments and used them to compare different strategies. There are samples of industrial firms in Singapore and in the Arab Emirates, for example, which use path analysis techniques to study the influences of the environment on choices among alternative decisions.

Badri and Alshare (2008) and Duncan (1985) also utilized path analysis models for market valuation associated to the introduction of web technologies in the public administration, and to relate path analysis with regression models. The seminal work referred to in the academic literature is the research of Bagozzi and Heatherton (1994), which introduced several non-observable variables to represent personality constructs. The elaboration of a SEM model implies that sampling errors will always be present. In this sense, many authors give some recommendations about the minimum number of cases to be collected. Regarding the mentioned above, Browne and Cudeck (1993) referred to the approximation error linked to this random variability; but they also point out the goodness of fit of the model. This includes the sampling error, and the overall fit should always be considered, but it is not a straightforward process, as it is not clear how to measure deviations. Caridad (2016) proposed the use of several fit indices: the log-likelihood statistics of the model (G^2, or in AMOS terminology, CMIN) that should be as small as possible, with high p-values for the global test, and the classical determination coefficient for each equation that are used to estimate a conjoint R^2 for the model. Furthermore, Bentler (1990) stated that the CFI index, or the proportion of covariation explained by the model or Tucker-Lewis' measure, should conveniently be over 0.9. Likewise, the root mean square error, RMSEA, is recommended to be less than 0.1. Several measures based on the theory of information, such as the Akaike or the Bayesian information criteria, or several others are calculated by AMOS.

Methodology

This section presents the selected statistical method, which will help to test the hypotheses put forward.

SEM: Path analysis

SEM are multi-equational models, as a generalization of several structures, such as the General Linear Model. It includes many multivariate methods such as Factor Analysis, Canonical Correlations and General Linear Models. It entails non-observable or latent variables, which can form a multi-equational model. Each latent variable is causally related to several observable numerical variables, such as Factor Analysis. In the classical formulation, the observed variables are endogenous, with their own errors, although they can also act as an exogenous explanatory of latent variables. The exogenous variables and the errors of the endogenous variables can be related among them. Path Analysis is a particular case of SEM, where all the variables, except errors, are observable and numerical, with the possibility of introducing dummy variables. It is represented with a causal graph, where the exogenous variables can be the cause of variability of the endogenous variables, which in turn can be explanatory of other endogenous variables. Each endogenous variable is explained by the model, with a random error term. The number of equations is equal to the number of endogenous variables. The relations are linear, although non-linearities can be introduced, for example, by transformations of variables (Caridad, 2016).

Data Analysis

In the first stage of model specification, the original matrix included 15 observable variables, from 1981 to 2020; that is, 600 data for 40 years. They were Royalties from Itaipu, External debt, Electricity power exports, GDP per capita, GDP, Proportion of agricultural sector in GDP, Proportion of industrial sector in GDP, Proportion of service sector in GDP, Housing deficit, School attendance rate, Population with basic needs unsatisfied, Children mortality rate, Changes in agricultural land use (soya), Changes in agricultural land use (livestock), and CO2 emissions. The bibliographic source of the first eight cited economic variables—from Royalties from Itaipu to Proportion of service sector in GDP—has been the Statistical Annex of the Economic Report of the Central Bank of Paraguay, 2020. For the four social variables—from Housing deficit to Children mortality rate—the source has been the General Directorate of Statistics, 2021. For the last three agricultural and environmental variables, the bibliographic source has been the Ministry of Agriculture and Livestock (MAG/DCEA, 2020), the General Directorate of Statistics, 2020 and the World Wild Fund for Nature (WWF, 2020). SPSS v. 26 and AMOS softwares were used to treat the variables.

Table 1. Selected Variables,

Acronyms	Variables	Type of variables
X1	Royalties from Itaipu	Exogenous
X2	Electric power exports	
X3	External debt	
Y1	GDP per capita	Endogenous
Y2	Proportion of agricultural sector in GDP	
Y3	Proportion of service sector in GDP	
Y4	Population with basic needs unsatisfied	
Y5	Housing deficit	
Y6	Changes of land use (soya)	
Y7	CO2 emissions	

Note. The 10 selected variables are those that have been used in the SEM.

Selected Variables

In the second phase—the estimation stage—of the 15 original variables, 10 were selected, which presented a better fit in Table 1. Therefore, of the 600 original cases, 400 have been validated.

Based on the foregoing and from the perspective of the literature review, this research aims to test four hypotheses that concern the relationship among: (i) the failure of an investment of $17,000 million (2.8 times Paraguay's GDP in 1983), which did not become the axis of the engine of economic and social development in the country (Campos, 2016); (ii) the increase in GDP per capita was not strong enough to propel social indicators (Baruah, 2012; Kirchherr et al., 2016); (iii) the monoculture of soybeans carried out mainly by Brazilian immigrants who settled in Paraguay after the construction of the dam, weakening family farming, the basis of the

Table 2. Goodness of Fit Measures and Likelihood Ratio Test.

Index	Proposed model	Saturated model	Independence model
CMIN	17.73	0.00	1,500.80
FMIN	0.46	0.00	22.26
CFI	0.99	1.00	0.00
RMSEA	0.05	0.00	0.62

Note. The default model is the proposed; the saturated model is for a perfect fit with no degrees of freedom, and the independence model corresponds to a set of uncorrelated variables.
The goodness of fit measures of the proposed model are, in all cases, close to their optimum possible values stated in the saturated model, separated from the independence model.

sustainability of the rural economy (Campos, 2019); and (iv) the evident deterioration of the region's ecosystem due to the construction of the mega dam (Anderson et al., 2018; Latrubesse et al., 2017). Below are the four hypotheses (H).

H1 Itaipu did not become the expected engine of socioeconomic development in Paraguay.
H2 GDP per capita increased, but social indicators did not grow at the same rate.
H3 Itaipu facilitated the introduction of soya monoculture to the detriment of family farming.
H4 The ecosystem of the region was negatively affected by the construction of the dam.

Calculation

This section presents the practical development of the research concentrated on the graph designed with Amos. It results from the relationships among the variables selected and mentioned in the previous section.

Model Estimation

To homogenize them, the original 600 values of the mentioned variables (15 variables for 40 years) were converted to percentages and tabulated in a matrix treated with SPSS. The typology of the estimated model is in Figure 2, where the causal relations are represented with a unidirectional arrow, while the interdependences are shown as a double arrow. The structural coefficients are presented in Tables 3 to 5. The proposed model allows testing the proposed hypotheses through statistical tests to assess the causal relations proposed.

The exogenous variables are the royalties received from Itaipu, the level of external debt and the electricity exports. On the other hand, seven endogenous variables are included: GDP per capita, contribution of the agricultural and service sectors to GDP, housing deficit measured as home ownership, proportion of the population with unsatisfied basic needs, land use change (for soybean cultivation), and CO2 emissions (in gigagrams).

Results

The model presents an adequate goodness of fit and all of its parameters are significant. Regarding the global significance of the model and different fit criteria, it have been followed Browne and Cudeck (1993) recomendations: the likelihood ratio statistic with a fairly large *p*-value, corresponding to an adequate global fit, and several measures such as the minimum discrepancy function, FMIN, the Comparative Fit Index, CFI, and the Root Mean Square Error, RMSEA, that is an index based on the reproducibility of covariance matrix estimated with the model.

Measures of Goodness of Fit

The rationale in the estimation of a SEM or Path Analysis model is to reproduce the covariances or the correlation matrix, **S**, of the observed variables using the constraints imposed with the system of equations defined by the causal specification proposed. If the model is to be considered acceptable, the matrix estimated using the parameters in the model should approximate the observed covariance matrix **S**. The difference between these is the residual matrix. A global fit test is derived to accept (or reject) that the estimated covariance matrix, restricted upon the model, can be considered equal to the unrestricted **S**. If this hypothesis is accepted, the model can be globally considered as a plausible representation of the covariance structure of the data. A log-likelihood statistics G^2 or CMIN (in AMOS terminology) is defined to decide between these two alternatives. Its asymptotic sampling distribution is a chi-square, with the degrees of freedom associated to the model. The chi-square statistics obtained is $G^2 = 17.73$. Its *p*-value is $p \approx P\,[\chi^2 \geqslant 17.73] = 0.34$, with $d = 16$ degrees of freedom. Large values of *p* lead to accept the null hypothesis (of equality of restricted and unrestricted covariance matrices); that is, to consider the model as globally acceptable, as it is the case, for any reasonable value of α (not only the usual .05, but also .10, and even more than .30) (Caridad, 2016).

There are several fit measures associated to these types of models, to analyze different aspects of the fit. In all cases, the results are favourable to accept the proposed model. Fit indexes in SEM are structured in different groups. Some can be labeled as discrepancy indexes, as are the statistics CMIN, or FMIN, and the residual-based measures as the RMSEA. Other ratios compare to the proposed model with the observed data, as CFI.

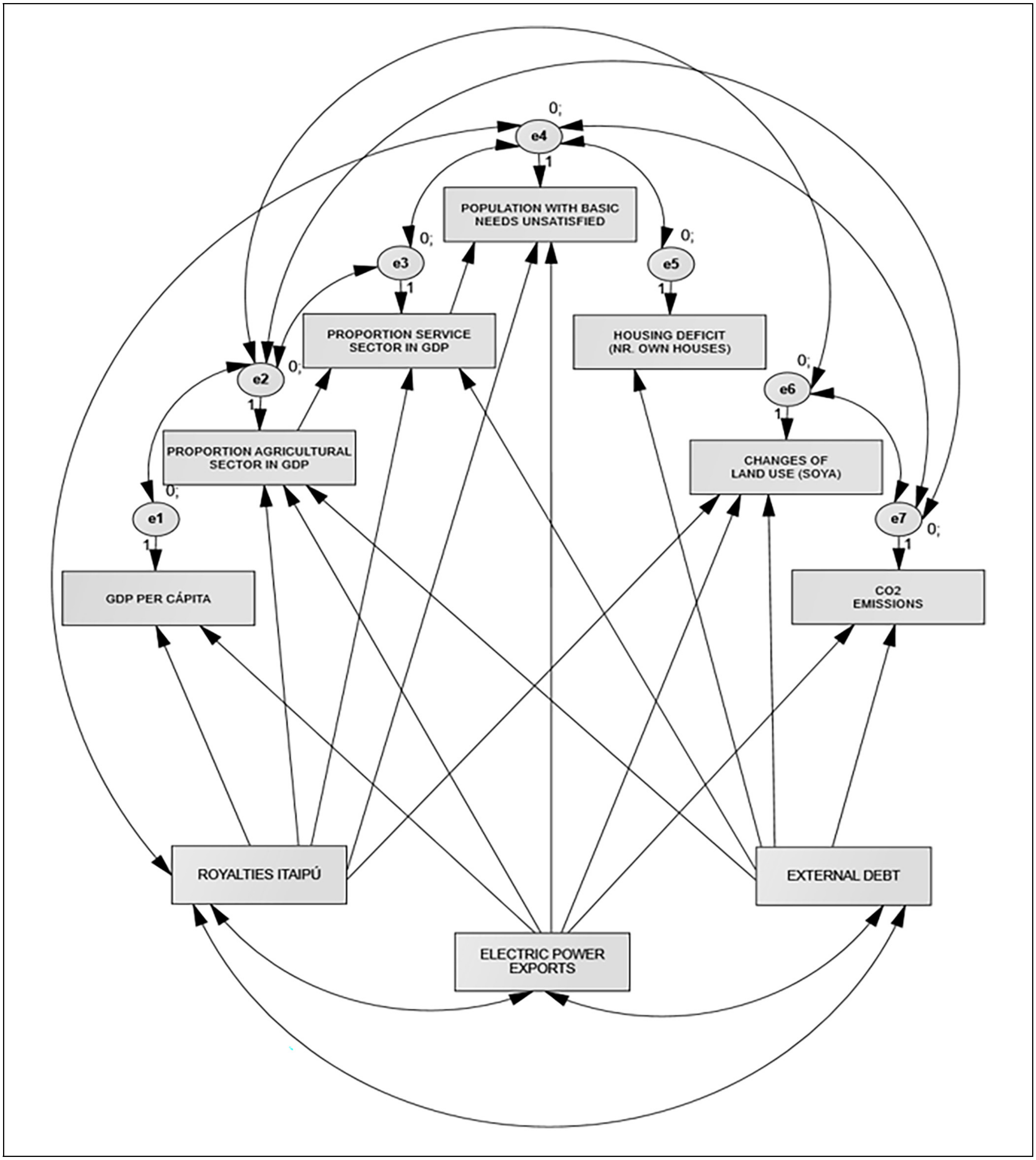

Figure 2. Path analysis model to test the four research hypotheses.
Note. It shows the exogenous and endogenous variables of the designed model.

Alternative groups are related to Information Theory measures, such as the Akaike or the Bayesian Information Criteria. Other measures treat problems associated at non-centrality indexes. Some of these are presented for the proposed model, as well as an interval of possible values corresponding to the independence model as the worse possible limit, and for the saturated model, that is, a best possible model with no degrees of

Table 3. Estimated Coefficients of the SEM Model and the Corresponding z-tests (*CR*).

Variables			Estimate	*SE*	CR	*p*-Value
Agricultural sector/GDP	←	Electricity exports	0.037	0.007	5.211	<.001
Agricultural sector/GDP	←	External debt	−0.168	0.039	−4.258	<.001
Agricultural sector/GDP	←	Royalties from Itaipu	4.643	0.579	8.025	<.001
Service sector/GDP	←	External debt	0.746	0.116	6.411	<.001
Service sector/GDP	←	Agricultural sector/GDP	2.496	0.242	10.323	<.001
Service sector/GDP	←	Royalties from Itaipu	−3.724	1.893	−1.967	.049
GDP per capita	←	Electricity exports	0.037	0.007	5.490	<.001
CO2 emissions	←	Electricity exports	0.012	0.001	9.996	<.001
Land changes to soya	←	External debt	0.340	0.081	4.196	<.001
Housing deficit	←	External debt	−0.006	0.004	−1.713	.087
Population with deficit basic needs	←	Electricity exports.	−0.020	0.002	−8.155	<.001
Land changes to soya	←	Electricity exports	0.089	0.010	8.795	<.001
Population with deficit basic needs	←	Service sector / GDP	0.062	0.009	6.845	<.001
GDP per capita	←	Royalties from Itaipu	3.501	0.414	8.452	<.001
CO2 emissions	←	External debt	0.059	0.007	8.022	<.001
Land changes to soya	←	Royalties from Itaipu	2.138	0.901	2.373	.018
Population with deficit basic needs	←	Royalties from Itaipu	−0.688	0.195	−3.532	<.001

Note. The estimated coefficients are all significant with the z-tests, supporting the global acceptance of the model and the research hypothesis.

Table 4. Estimated Covariances in the Model.

Variables			Estimate	*SE*	CR	*p*-Value
Electricity exports	↔	External debt	201,589.051	57,937.255	3.479	<.001
External debt	↔	Royalties from Itaipu	4,322.043	1,046.351	4.131	<.001
Electricity exports	↔	Royalties from Itaipu	21,735.471	5,809.634	3.741	<.001
e3	↔	e2	−1,868.242	438.898	−4.257	<.001
e1	↔	e2	1,286.946	313.740	4.102	<.001
e6	↔	e7	170.220	54.833	3.104	.002
e4	↔	e7	−40.560	10.415	−3.894	<.001
e6	↔	e2	103.155	48.921	2.109	.035
e7	↔	e2	33.535	8.638	3.882	<.001
e4	↔	e3	−77.095	22.626	−3.407	<.001
e4	↔	e5	6.980	4.372	1.596	.110
e4	↔	Royalties from Itaipu	69.238	22.275	3.108	.002

Note. All the estimated covariances are significant with the z-tests; most with *p*-values under .001.

Table 5. Variances.

Variables	Estimate	*SE*	CR	*p*-Value
Electricity exports	1,774,056.344	403,282.318	4.399	<.001
External debt	50,688.916	11,478.779	4.416	<.001
Royalties from Itaipu	473.853	107.307	4.416	<.001
e1	1,373.742	313.123	4.387	<.001
e2	1,900.741	379.820	5.004	<.001
e3	5,309.721	1,450.610	3.660	<.001
e4	116.488	32.451	3.590	<.001
e5	28.444	6.441	4.416	<.001
e6	3,157.573	725.999	4.349	<.001
e7	52.976	11.438	4.631	<.001

Note. All the estimated variances are significant with the z-tests; most with *p*-values under .001.

freedom. In the case of this research, the proposed model indexes are, in all cases, near the optimum value corresponding to the saturated model.

The minimum value of discrepancy function, FMIN, is a general index of model fit, that has advantages over the log-likelihood statistics, as it considers the sample size and the number of parameters. In the proposed model, FMIN = 0.46, is clearly considered satisfactory.

Once the covariance matrix associated to the model, and the observed, **S**, are assessed, the discrepancy between them is summarized in the comparative fit index, CFI, that measures how the fit will diminish if the proposed model is changed to the independence model. It is recommended a 0.9 threshold for this index, or 0.95 for a very good fit. In the proposed model, CFI = 0.99, is an almost optimum level.

The sum of the squared residuals is a goodness of fit measure, divided by the degrees of freedom and the square root of the resulting value is the RMSEA. Obviously, the perfect fit will be associated to the 0 value. It is usual to consider a range between 0.05 and 0.1 as acceptable; lower values are associated with a very good fit. The RMSEA of 0.05, confirms the very good results obtained with other fit measures.

In Table 2, this goodness of fit measures are summarized with the range of optimum values (corresponding to the saturated model), as its worse values (for the independence model).

Model Parameters

It can be mentioned that, in general terms, all the observed results—the coefficients of regression (Table 3), the estimated covariances (Table 4) and the estimated variances (Table 5)—are significant in all cases, indicating that the corresponding causal relations should be maintained in the model. All its *p*-values, for the individual tests on the coefficients are very small (most below .001), leading to including the proposed causal links, that is, to the acceptance of the research hypothesis.

As a corollary of this section some further conclusions regarding the hypotheses tested using SEM are in order. It is important to mention that with the variables Itaipu Royalties and Energy Export, although they influence the growth of GDP per capita, their impact on the improvement of the variable Population with unsatisfied basic needs, is irrelevant. Itaipu energy exports influenced the participation of the agricultural sector in the Paraguayan economy, but did not become the expected engine of socioeconomic development in Paraguay. This situation could be seen in the negative influence in the service sector, and in the proportion of population with deficits in basic needs. This statement can be deduced from the significant parameters in the model regarding the influence of electricity exports on the service sector and on the later proportion (Table 3), supporting the proposed research hypothesis 1 and 2 (H1 and H2).

Regarding H3, the Itaipu Royalties and Energy Export variables, although they have a favorable impact on the growth of the Agricultural Sector variable on GDP, it is evident that Itaipu favored the widespread implementation of soya monoculture in most of the arable land in Paraguay, to the detriment of family agriculture, one of the bases of the rural economy. This fact can also be corroborated in the research by Campos (2019), in which it is mentioned that 94% of arable land corresponds to monoculture plantations, with serious implications for food, environmental, and migration aspects from the countryside to the cities. Also, the significant ($p < .001$) coefficient of the influence of electricity exports to the transition of land changes to soya is in line with the proposed hypothesis 3. As regards H4, the deterioration of the regional ecosystem caused by Itaipu, which, obviously, is not exclusive to this mega dam, is reflected in the negative effect that the variables Itaipu Royalties and Energy Export have on the increase in CO2 emissions.

Discussion

As the title of this paper indicates, the objective is the presentation of "… A quantitative analysis of the economic and social impacts in Paraguay." Therefore, the weaknesses of this study would concern the environmental impacts generated by the dam. The strengths of the article are concentrated in that, (i) the starting hypotheses have been satisfactorily contrasted by the model, (ii) the paper is one of the few studies carried out in Paraguay on Itaipu, and (iii) in 2023 it will be renegotiated the Itaipu Treaty between Brazil and Paraguay.

The solidarity between a large country toward a small neighbor, is not usually a common denominator in international relations (Saklani & Tortajada, 2019). The abuse of the largest countries with their weaker neighbors usually uses to be a normal behavior. Maybe, some countries try to hide these misdeedses, but the results are the same: the appropriation of vast geographical areas and their natural riches. In South America, this fact is evidenced by comparing, on the one hand, the line drawn in the Treaty of Tordesillas, signed in 1494, between the Kingdoms of Spain and Portugal, and, on the other, observing the current map of Brazil. In this context, and in relation to socioeconomic aspects, the most intensive and extensive way of mobilizing water is precisely the construction of dams since a century approximately (Illustration 2). Water, like other natural resources, can be used to generate wealth in an asymmetric relationship based on power and control of land ownership, or in an equitable relationship. In the case of Paraguay, Itaipu was built within the framework of an diverse relationship. It was the least benefited, both economically, socially, and environmentally. In this sense, the economic matters have been mentioned in the introduction. In the social sphere, for example, the lands where 38 indigenous communities lived until 50 years ago (General Directorate of Statistics, 2020), today are forbidden territories for them and are occupied by clubs and private condominiums. And, environmentally, it is important to highlight that Paraguay has the most flooded territory by the immense lake of the reservoir dam. Suggestively, these projects are presented as symbols of technological, social, and economic progress, while the rural families and indigenous communities, and their subsistence crops, are represented as a socioeconomic backwardness destined to disappear. In this sense, the article of Simões Lorenzon et al. (2017), in which they recommended the royalties and compensations of Itaipu, should be distributed according to the supposed flow of the river, is quite striking. The authors mention that in the location of Itaipu, the Parana River, one of the largest in the world, Brazil has 99% of the flow and Paraguay, only 1%. Supposedly, these percentages would constitute the contribution of each country for power generation. The article, scientifically, does not hold up for two reasons: first, because regarding the percentages of the flow, hydrologically, it has no scientific rigor whatsoever. Second, because the most important characteristic for power generation is the fall of the dam—not the flow—and in Itaipu there is a 118 m fall. Evident proof of this is that in times of drought, Brazil sacrifices other upstream dams, which have the same river flow rate, but which together produce five times less because their height is low, so that Itaipu continues to function. Another valid argument which will support the mentioned above, is the energy production of the other mega dam, Yacyreta, built by Argentina and Paraguay. In this dam, the downstream river has a higher flow yet, but produces five times less energy than Itaipu because it is three times lower in height. Therefore, the objective of the mentioned article is simply to justify the distribution of royalties between Paraguay and Brazil.

Regarding environmental aspects—seriously affected by the construction of the dam and which are not studied in depth in this research—it is only mentioned that the approaches of political ecology have two aspects: the structuralist, which deals with the degradation of nature, and the poststructuralist, who tries to understand environmental changes from history and culture (Forsyth, 2003). In this, from the power relations, experiences, and daily life of different social actors in relation to their environment are analyzed by Pengue (2017) and Radovich (2011). The analysis of Pengue (2009) focuses on coercion, violence, and state policies on the environment. In the case of Brazil, the dams in the Amazon were not only built to respond to the region's need for energy, but also to satisfy economic and political interests (Latrubesse et al., 2017). In the case of Paraguay, everything indicates that the requests to pay royalties and fair contractual compensation have been only a parody. The fundamental objective was, and continues to be, that the high positions and juicy salaries of Itaipu Binational be a booty for politicians and their close circles. On the other hand, if one observes that a gigantic energetic monument of cement and iron like Itaipu, the human footprint in environmental deterioration is evident. In the literature reviewed, all the hydroelectric dam constructions built in other Latin America countries, USA, Africa, and Asia, have had major irreversible negative impacts on human lives and natural ecosystems. The studies by Varyash et al. (2020) and Lisin et al. (2022), where a series of ratios from different disciplines are mixed, are notable. But, in practice, the results obtained from such a diversity of ratios combined and introduced as variables in a multiple linear regression analysis tend to contain important biases. However, Itaipu's administration could consider an analysis of this type, to measure the impact of the dam in different points of view.

It is also important to highlight that, in addition to the good adjustment of the statistical model designed and the contrasting of the hypotheses, some positive biases of Itaipu in the Paraguayan economy are pointed out. In this way, Table 3 shows that, when measuring direct influences using the quantitative model proposed, positive gains have been registered in several macroeconomic variables. For example, electricity exports are directly and positively related to the growth of the agricultural sector, and to the increase of wealth per capita. Within this general picture, we have tried to highlight some of the social costs involved, including in the model some variables such as the orientation to a much more specialized agriculture, more and more dependent on one main crop: soya. Included in the model are variables to represent some of these problems to detect changes that can be difficult to advance when examining the main macroeconomic variables. These are shown on some estimated coefficients, and this approach can be considered a novelty in respect to several previous publication which focus on the main effects of the economic development involved, or those orientated to social aspects primarily, such in Jackson and Sleigh (2000). The inclusion of different type of variables in the model has permitted the assessment of previous studies, as stated, and, at the same time, to measure some impacts that can have some negative social and environmental consequences.

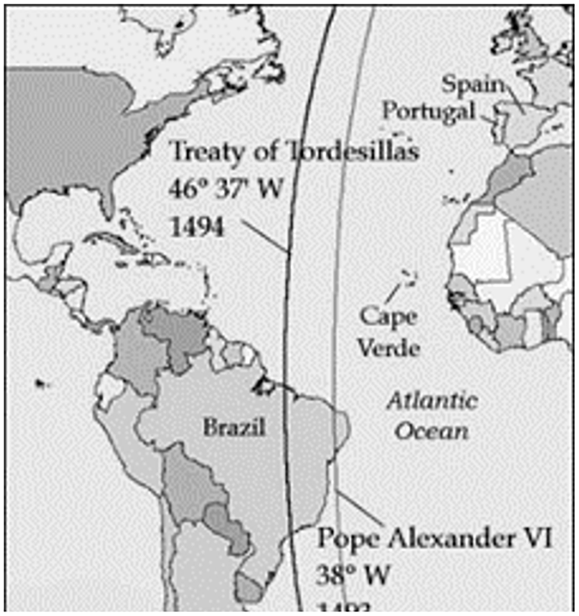

Illustration 2. Treaty of Tordesillas.
Source. Encyclopedia Britannica Inc.

Conclusions

According to the results of this research, which contrast the main starting hypothesis, it can be stated that Itaipu represented an unfulfilled dream for Paraguay. The hopes placed in the megaproject to be the motor of the development of the country vanished immediately after the completion of the works in 1983.

Thus, the considerable increase in GDP per capita, during the 40 years analyzed, has been a mirage, because other crucial statistical data point to very unfavorable results. For example, the increase in public external debt by 928%. In this context, the renegotiation of the Treaty to be carried out during this year 2023 is key. For example, it should certify that all of Paraguay's debt has already been cancelled, according to reports from Itaipu Binacional (Financial Management Itaipu, 2021) and studies carried out by leading international experts (Sachs, 2013, 2018).

Finally, it is worth mentioning that hydroelectric dams will continue to be built around the world. Above all, because compared to other renewable energies, and despite configuring a large initial outlay, it constitutes a more profitable economic and financial investment in the medium and long term (Harberger, 1972; Liu, 2003). Nevertheless, the environmental and social risks involved can be high and, hopefully, objective social and environmental cost-benefit analyzes would be carried out before projects are initiated.

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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