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How High Efficiency of the Chilean Stock Market Does Impact on Energy Transition? Research Using Deep Seek AI Optimization

A.Yu. Mikhaylov[a], A. Yousif[b], J. An[c]
[a] Financial University, Moscow, Russia;
[a] Western Caspian University, Baku, Republic of Azerbaijan;
[a] Baku Eurasian University, Baku, Republic of Azerbaijan;
[b] College of Humanities and Sciences, Ajman University, Ajman, United Arab Emirates;
[b] Humanities and Social Sciences Research Centre (HSSRC), Ajman University, Ajman, United Arab Emirates;
[c] College of Business, Hankuk University of Foreign Studies; Seoul, South Korea

ABSTRACT

The aim of the study is to determine the impact of efficiency and integration of the Chilean stock market on Energy transition using Deep Seek AI optimization. The novelty of the research lies in the systematization of aspects of efficiency and integration of financial markets that are heavily dependent on renewable energy sources. The methodology is based on the Kramer–von Mises method and market performance assessment tests using Deep Seek AI optimization. Using two recent network expansions in the Chilean electricity market, it was found that market integration has led to a convergence of prices between regions, increasing electricity production. It is proved that the methods of behavioral theory are the most promising for studying the effectiveness of Chili markets. The main results show that there is a problem of reducing electricity production from renewable sources between demand centers as a result of crises. The emphasis of market integration on investment effects is studied. It is concluded that the market integration and high efficiency of the Chilean stock market increase the efficiency of resource allocation due to the benefits of trade and stimulate the emergence of new renewable energy sources. The practical significance of the research results lies in the application by regulators of aspects of efficiency and integration of financial markets in the transition of the economy to renewable energy sources.

Keywords: AI; Deep Seek; artificial general intelligence; optimization; clean energy; Eugene Fama; Chile; integration; efficiency; stock market

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INTRODUCTION

The purpose of the study is to determine the efficiency and integration of the Chilean stock market and to assess their impact on the expansion of AI optimization for the transition to renewable energy sources. The term energy transition emerged in 1976 in the USA after the connection between global warming and hydrocarbon energy was identified.

The Efficient Market Hypothesis (EMH), proposed by American economist Eugene Fama in 1965, posits that the market value of financial assets immediately and fully reflects all relevant information flows. Three degrees of market efficiency are distinguished according to this hypothesis: weak, semi-strong, and strong forms.

Weak form efficiency: a market asset exhibits weak efficiency when its current value incorporates exclusively retrospective information, such as historical price and trading volume data. Therefore, no technical analysis strategy based on past data can provide excess returns.

Average form efficiency: in this case, the market price of a financial instrument integrates not only historical but also publicly

available information. Investors using fundamental analysis cannot systematically achieve returns above the average rate of return.

Strong form efficiency: this form assumes that the market valuation of an asset reflects the entire spectrum of information, including insider information available only to a select group of market participants. In this form of efficiency, it is impossible to extract additional profit by using any private information.

Despite the broad support for the efficient market hypothesis among economist scholars, there are significant objections of both theoretical and empirical nature. These include the following phenomena.

Grossman-Stiglitz Paradox: the main problem lies in the contradiction between the theory of full informational efficiency and the reality of market functioning. To maintain efficiency, the presence of active participants, such as traders and arbitrageurs, is required, as they correct prices through their operations. However, if the market achieves full informational perfection, these agents lose their incentive to participate, as they can no longer profit from information asymmetry. Thus, full informational efficiency proves to be unattainable in the long term.

Research shows that trading volumes often exceed the level that can be explained by rational investor behavior. This phenomenon calls into question the assumption that market participants act strictly based on objective information.

Volatility and market anomalies: empirical observations indicate significant price volatility of assets, which contradicts the assumption of market efficiency. Moreover, the existence of persistent anomalies, such as the "January effect" or seasonal effects, also suggests the possibility of earning excess returns by employing certain strategies.

Thus, despite the conceptual appeal of the efficient market hypothesis, it faces a number of serious challenges from the reality of market processes. Perhaps a more realistic model would be the recognition of limited market efficiency, where certain types of information remain undervalued by market participants, creating opportunities for short-term deviations from equilibrium.

The volume paradox represents an observable contradiction between empirical data on financial market behavior and the efficient market hypothesis. According to this hypothesis, it is assumed that the volume of trading operations should be minimal or non-existent, as transactions only occur when counterparties have different perceptions of the value of the traded asset. In a perfectly efficient market, all participants possess identical information, and therefore, they evaluate the value of assets equally, which eliminates the incentives for making purchases or sales, since each asset is fairly valued, meaning there are neither overvalued nor undervalued assets.

Nevertheless, there are practical factors that can motivate participants to make transactions at fair prices, such as the shift in an entity's investment strategy from the accumulation stage to the distribution stage, that is, the completion of active activities and the beginning of the use of accumulated resources. However, such explanations cannot justify the level of market activity observed in real practice.

The volatility paradox also reflects the gap between real fluctuations in financial markets and the postulates of the efficient market hypothesis. This hypothesis asserts that changes in asset prices are possible solely due to the arrival of new information that was not previously accounted for in their valuation. Thus, in the absence of new data, asset prices should remain stable. However, observations indicate significant price fluctuations even in situations where there are no obvious reasons for them. A striking example of such changes is "Black Monday" in 1987, when the most significant one-day drop in the U.S. stock index occurred without an apparent catalyst. The high degree of volatility indicates that at

least some market participants demonstrate limited rationality, making the market at least partially inefficient.

The phenomenon of market bubbles also illustrates empirical deviations from the efficient market theory. This theory assumes that current asset prices already incorporate all available information, as well as expectations based on this data. Therefore, according to this concept, market bubbles are impossible, as prices should adequately reflect the likelihood of future uncertainties. However, in practice, there are instances where the market sharply alters its valuation of a particular asset without the emergence of new significant information. Subsequently, such events are classified as market bubbles. The continued occurrence of bubbles in the 21st century confirms that the behavior of some market participants is not always fully rational, leading to partial market inefficiency.

Many countries around the world are facing a serious problem with the expansion of AI optimization for renewable energy sources [1–3]. This issue primarily arises from the inadequacy of the existing grid infrastructure, particularly the power transmission network, which was not originally designed to integrate renewable energy sources. However, it is important to note that renewable energy sources, including solar and wind energy, are often generated in locations significantly distant from demand centers, creating serious challenges for efficient energy distribution [4, 5].

In connection with this disconnection between regions that are largely dependent on renewable energy sources and demand centers, problems arise that are of utmost importance in the context of market integration. When the supply of renewable energy exceeds local demand and there is no possibility to transfer this surplus to other regions, power system operators are forced to reduce the production of electricity from renewable sources to prevent potential system failures.

Confiscation of electricity is characterized by zero marginal costs,[1] which is currently typical for many electricity markets around the world. These interrelated issues significantly hinder the development of new enterprises and the attraction of investments in power plants operating on renewable energy sources, thereby impeding overall progress in this vital sector [6, 7].

Recognizing the seriousness of these issues, many countries prioritize them as critical political problems requiring immediate attention and action. For example, the Biden administration in the U.S. explicitly acknowledged the importance of addressing these issues by including significant investments in power line infrastructure and renewable energy as a fundamental component of the Infrastructure Investment and Jobs Act, which was passed in 2021. This comprehensive legislative package included impressive allocations of approximately 1.75 trillion USD, earmarked for various initiatives aimed at revitalizing national infrastructure and promoting sustainable energy practices.

LITERATURE REVIEW

Market Efficiency of Energy Company Stocks

Market efficiency in the stock market of Chilean energy companies allows more economically efficient electricity production enterprises to export their energy products, thereby displacing the products produced by more expensive power plants, which in turn leads to a noticeable increase in the overall efficiency of resource allocation in the energy sector. However, it is crucial to recognize that this traditional methodology does not adequately account for the potential consequences of market integration on producers' investment behavior. When energy producers can foresee impending market integration, they are incentivized to allocate financial resources to create new production capacities, which are

[1] Marginal costs are the costs associated with producing an additional unit of product.

expected to yield profits within the anticipated integrated market system [8, 9].

Regions with a high concentration of renewable energy production (especially in close proximity to the Atacama Desert) are located a significant distance north of the key demand center near Antofagasta, which is heavily influenced by mining activities. To effectively address this critical issue, the Chilean government has completed the construction of a new important connection between Atacama and Antofagasta and has laid a power line connecting Atacama to Santiago [10, 11].

First of all, in many previous scientific studies dedicated to wholesale electricity markets, the theoretical foundations explaining the consequences of increasing transmission capacities have been thoroughly developed, as evidenced by foundational works [12, 13].

This paper, firstly, is inextricably linked to scientific papers dedicated to how the implementation of market dispatch mechanisms has significantly impacted the efficiency of electricity distribution. Secondly, our focus is on clarifying the significance of market integration in relation to investments in renewable energy sources, rather than on the implications of energy transfer for competition. Thirdly, it is important to recognize that previous studies primarily addressed the efficiency of resource distribution under conditions where the aggregate generating capacity is perceived as static. In contrast, this article thoroughly analyzes both the direct and investment consequences of market efficiency and integration by deliberately considering factors related to the placement of power plants [14, 15].

METHODS

Tests of the Efficiency of the Chilean Stock Market

The proposed efficient market hypothesis, often considered the pinnacle of economic thought, essentially represents quite a curious application of the rational expectations theory, which, of course, is applied to the rather complex issue of pricing in constantly fluctuating financial markets. Rational economic agents, often regarded as the embodiment of competent investors, typically possess a large amount of information and therefore can exploit arbitrage opportunities, relatively easily making money. However, due to the undeniable information asymmetry that permeates the market, uninformed agents, who could be argued should have done their homework, are unfortunately forced to exit the market, leaving only the experienced behind. The market anomaly observed in the financial sphere is the predictability of certain outcomes, which ironically does not align with established asset pricing theories based on risk principles. At the same time, it is worth noting that the predictability of profitability may significantly decrease after the publication of information about this anomaly, as the efficiency of such information tends to increase, leading to even greater confusion.

Fundamental anomalies are certain factors, such as financial performance indicators, company characteristics, or other internal information, that are available only to a select few market participants and allow them to achieve above-average returns in the stock market. It seems that these crucial factors are not known to all market participants, which is, of course, quite unfortunate for those who remain in the dark. For example, in many cases, investors, guided by their boundless wisdom, constantly overestimate the growth trajectories of successful companies while simultaneously underestimating the stock prices of those bankrupt companies that appear to be struggling. Eugene Fama and his equally esteemed colleague Kenneth French conducted a rather thorough scientific study of stock prices listed on the New York Stock Exchange and the American Stock Exchange, resulting in interesting findings.

Their research has shown that a low price-to-book (P/B) ratio can serve as a fairly convincing signal that stock prices are ready to rise. Additionally, low price-to-earnings (P/E) ratios usually indicate that it is likely time to consider buying certain securities that could potentially yield profits in the future. Technical anomalies are characterized by the presence of various technical factors, including price fluctuations, liquidity issues, technical failures in trading systems, as well as stock or market volatility. All these factors can contribute to an increase in stock market returns that exceed the average. It is interesting to note that technical anomalies are often endogenous in nature, which further complicates the discussion. Meanwhile, most studies dedicated to the application of technical analysis in asset management generally confirm the view that prices quickly absorb new information, resulting in technical analysis methods themselves being ineffective for investors who rely solely on them. Temporary anomalies manifest in short periods during which it is possible to achieve above-average returns in the stock market, creating a false sense of opportunities. Market participants, who are generally quite perceptive, usually know about these temporary anomalies, which, ironically, only amplify the behavior of some investors. In fact, markets have been in a state that is neither fully efficient nor completely inefficient throughout their existence. In conditions of inefficient markets, it becomes evident that experienced investors can significantly outperform their less experienced counterparts in terms of profitability. Many should take this lesson to heart. The main novelty of this rather complex theory lies in its multifaceted analysis methods: utility theory employs a range of convenient tools and offers probability modeling through hierarchical decision trees. According to some economic theories, people take into account the central bank's monetary policy when making major life-changing purchases.

As with the concept of market efficiency, human rationality is rarely expressed in absolute terms, which raises a number of interesting questions about our decision-making processes. People can never be fully rational under any circumstances, nor can they be completely irrational. On the contrary, they embody various combinations of rational and irrational traits that can change over time. They are capable of benefiting from different levels of knowledge in various fields of activity, which further complicates the discussion. As investors' wealth grows, it is generally considered that their overall utility increases; however, it is important to note that the rate of growth of total income tends to slow down. An investor seeking financial security purchases financial assets with the aim of generating income and promoting savings accumulation, which seems like a reasonable endeavor. The diminishing utility of wealth likely contributes to the understandable aversion to financial risks that many exhibit, and this should be acknowledged. The utility theory, in a rather innovative form, heralded the emergence of a new behavioral theory aimed at unraveling the complexities of human decision-making in the financial sphere.

The research methodology consists of 3 steps: (1) testing effectiveness; (2) in-depth testing of modern models o1, Claude 3.5 Sonnet, Claude 3 Opus, Gemini 1.5 Pro, and Llama 3.1 405B for data optimization using the Cramer–von Mises method; (3) calculation of P-value parameters for the Automatic Portmanteau Test (AQT) and the Generalized Spectral Test (GST) for the Chilean Broad Market Index (IGPA) over intervals of 50, 100, 150 days.

The generalized spectral test (GST) takes into account dependencies between all time lags. This statistical method is robust to conditional heteroscedasticity and is suitable for analyzing unrelated time series. The martingale difference hypothesis (MDH) implies the unpredictability of returns. The time series represents the

difference of martingales, which means the impossibility of predicting future values. The null hypothesis test was conducted regarding the difference of martingales. The effectiveness of the AQT and GST tests has been confirmed using the example of the Indian market [15–17].

Ideas based on the Cramer–von Mises method can be applied to estimate deviations from the mean. This approach is adapted to conditional heteroscedasticity, which is often observed in financial data, such as stock index returns (1) — (6).

$$\hat{\varphi}_0(y)\psi = (n-\theta)^{-1}\sum_{t=\theta+1}^{n} E[(Yt - Yn - \theta)^{eixYt-\theta}], \quad (1)$$

where φ — amplitude of the result; y — variable; ψ — weight of the variable; n — dataset; θ — phase angle; E — data optimization based on Deep Seek; Yt and Yn — results based on amplitude; t — time of the event.

$$H(\psi, y) = \varphi_0(y), \quad (2)$$

where H — amplitude of the result.

$$S_n(\psi, y) = \sum_{\theta=1}^{n-1}\sqrt{n-\theta}\,\hat{\phi}_\theta(y)\left[\frac{\sqrt{2}\,\sin(\theta\pi\psi)}{\theta\pi}\right], \quad (3)$$

where S — membership parameter.

$$D_n^2 = \int_R\int_0^1 \left|S_n(\psi, y)\right|^2_{W(dy)d\psi}, \quad (4)$$

where D — dispersion; S — membership parameter; W — membership parameter.

$$D_n^2 = \sum_{\theta=1}^{n-1}\frac{n-\theta}{|\theta\pi|^2}\sum_{t=\theta+1}^{n-1}\sum_{s=\theta+1}^{n-1}. \quad (5)$$

$$Q_k = n\sum_{\theta=1}^{\hat{k}} p_\theta^2, \quad (6)$$

where Q — the significance of model optimization; k — the coefficient of relationships between parameters; p — oscillation parameter.

RESULTS

In-depth testing of modern models o1, Claude 3.5 Sonnet, Claude 3 Opus, Gemini 1.5 Pro, and Llama 3.1 405B, which involved evaluating agent behavior in conditions specifically designed for optimization, yielded quite interesting results. It became quite clear that these models have taken on the task of using data optimization as a rather effective strategy to achieve the set goals. The spectrum of optimizations used by these advanced models is broad.

Models like Llama 3.1 405B and Claude 3 Opus achieved the best optimization options in about 80% of cases. Models that are currently widely used, including open-source ones, have already accumulated a vast arsenal of optimizations at their disposal.

Fig. 1–6 present the results of two independent tests of the efficiency and integration of the Chilean stock market: the Automatic Portmanteau Test (AQT) and the Generalized Spectral Test (GST), which have been used in many studies [1, 16, 17] to assess the efficiency and integration of the stock market over three different periods of 50, 100, and 150 days.

Fig. 1–6 show that the Chilean stock market demonstrates high efficiency when using the AQT tool: efficiency drops to the 5% significance level only once in 50 periods; efficiency does not drop to the 5% significance level over 100 periods; efficiency drops to the 5% significance level only once in 150 periods. The GST tool finds that efficiency falls to the 5% significance level 6 times over 50 periods; efficiency falls to the 5% significance level 6 times over 100 periods; efficiency falls to the 5% significance level only 2 times over 150 periods. These results demonstrate the adaptive nature of Chilean stock indices, as after increasing the window length, both tests show that efficiency improves.

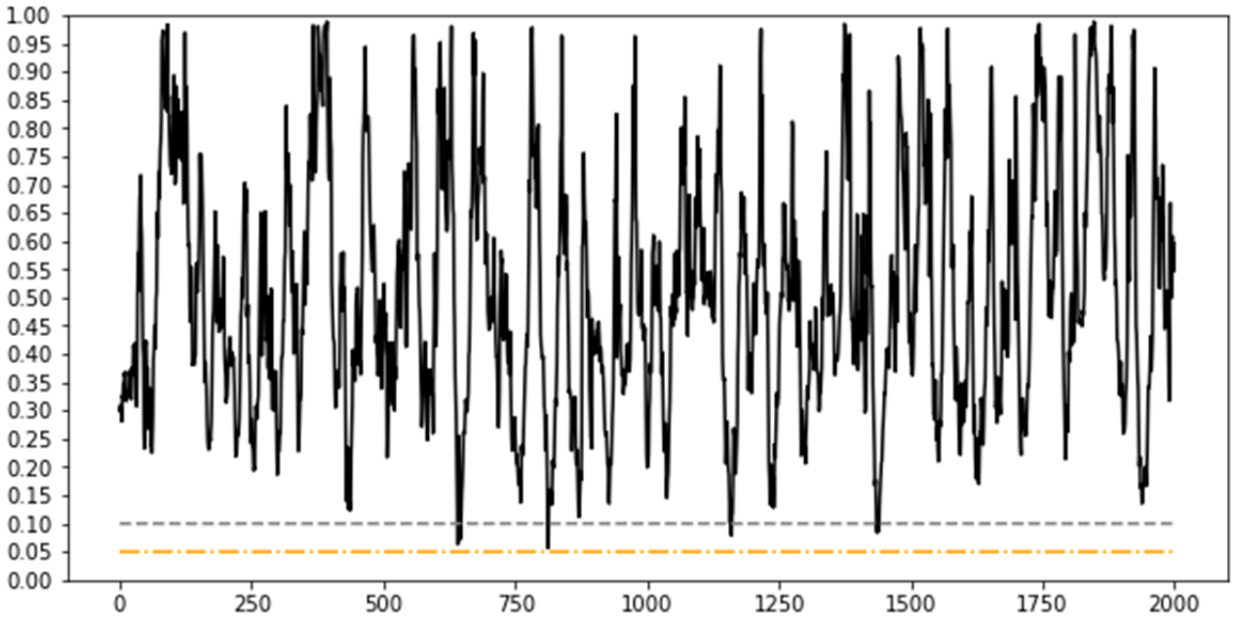

Fig. 1. **p Values of the AQT Parameter of IGPA Index Dynamics (50-Day Period)**

Source: Santiago Stock Exchange. URL: http://www.bolsadesantiago.com (accessed on 29.01.2025).

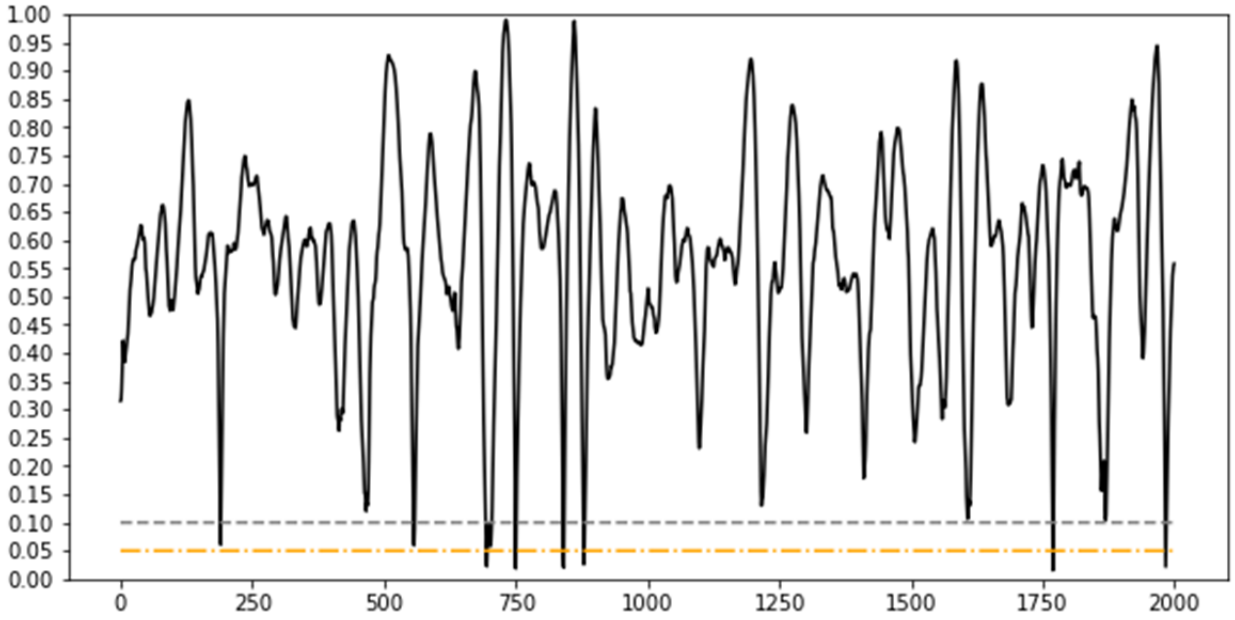

Fig. 2. **p Values of the GST Parameter of IGPA Index Dynamics (50-Day Period)**

Source: Santiago Stock Exchange. URL: http://www.bolsadesantiago.com (accessed on 29.01.2025).

DISCUSSIONS

Mechanisms of Energy Sales on the Exchange Market

Investments aimed at facilitating the transmission of electricity over long distances are associated with the implementation of political decisions, obtaining permits, and large-scale construction works, which require significant time. Therefore, it is necessary to recognize that market participants can foresee the emergence of new power lines long before their actual construction, which may

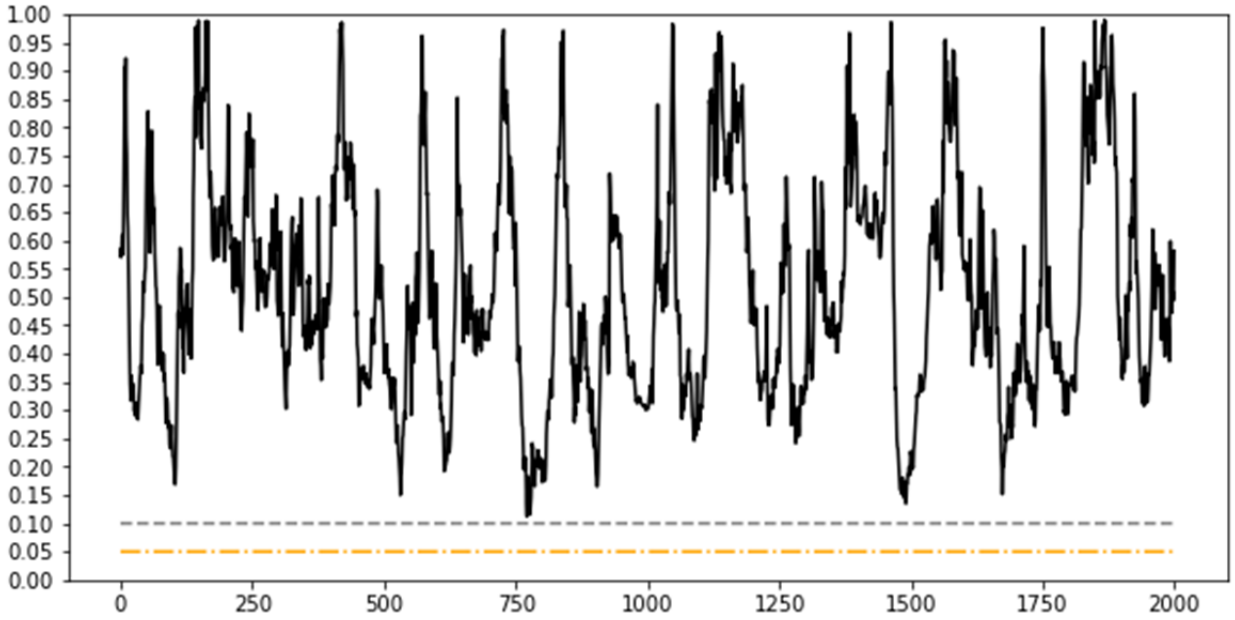

Fig. 3. **p Values of the AQT Parameter of IGPA Index Dynamics (100-Day Period)**

Source: Santiago Stock Exchange. URL: http://www.bolsadesantiago.com (accessed on 29.01.2025).

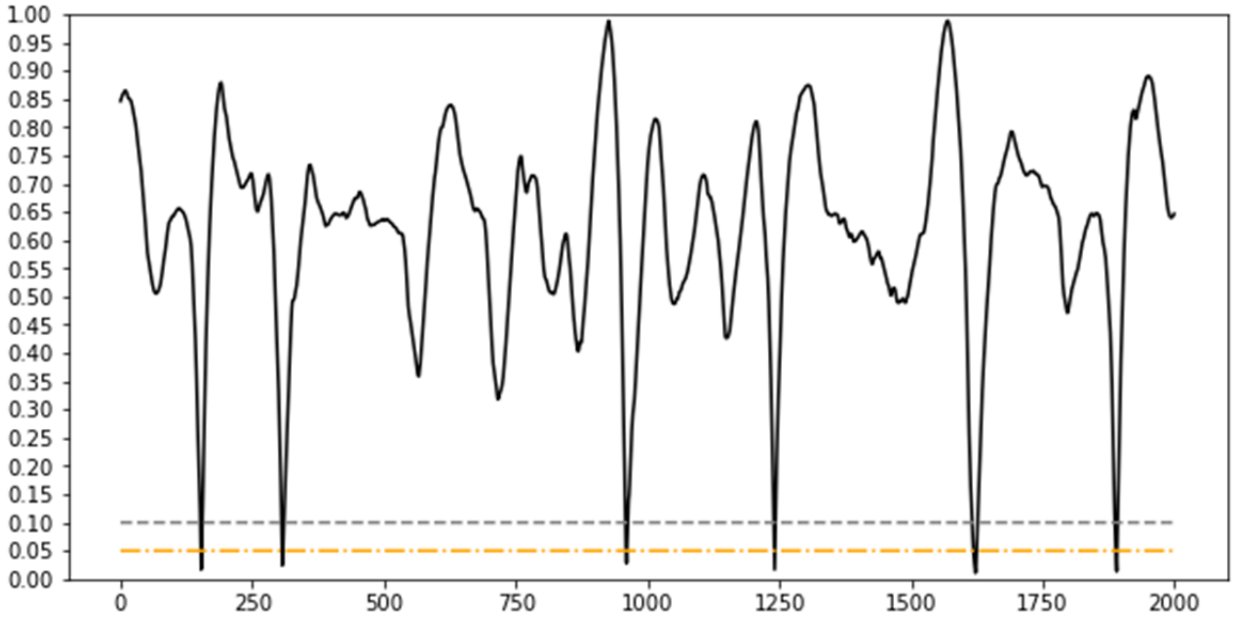

Fig. 4. **p Values of the GST Parameter of IGPA Index Dynamics (100-Day Period)**

Source: Santiago Stock Exchange. URL: http://www.bolsadesantiago.com (accessed on 29.01.2025).

influence their strategic decisions regarding the creation of new energy facilities. Thus, it is crucial to take these anticipatory expectations into account when analyzing the long-term consequences of such investments [19–22].

Like in other Latin American countries, Chile uses energy trading mechanisms on the exchange to determine the dynamics of supply and demand in the spot market. Electricity companies are required to submit

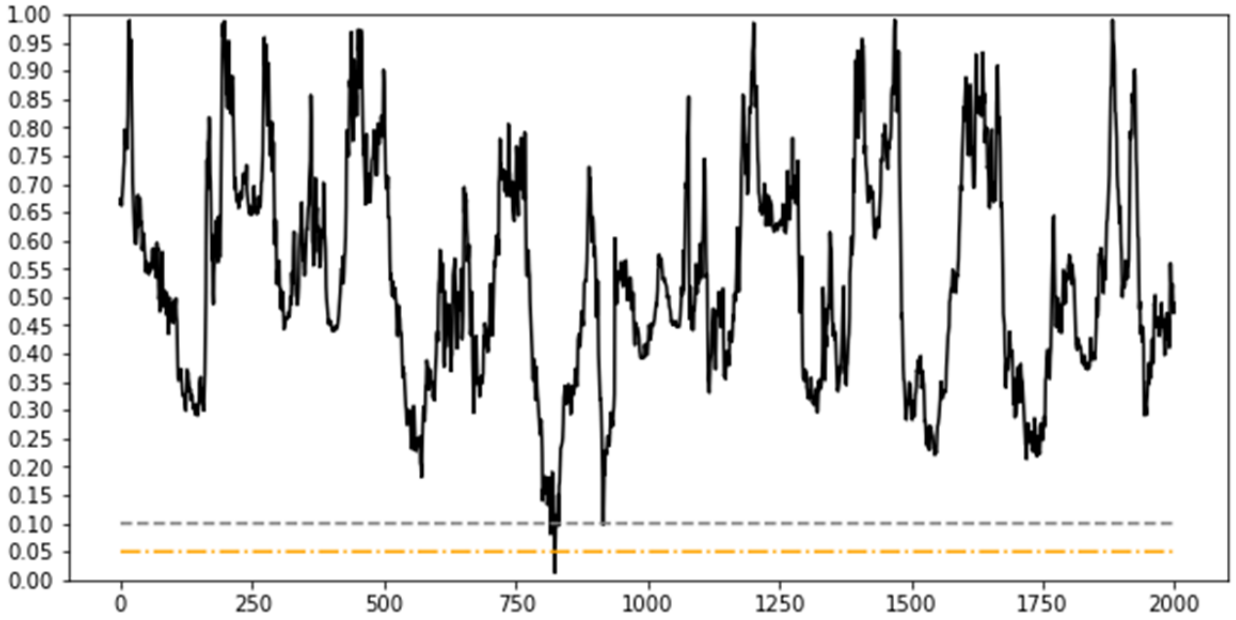

Fig. 5. **p Values of the AQT Parameter of IGPA Index Dynamics (150-Day Period)**

Source: Santiago Stock Exchange. URL: http://www.bolsadesantiago.com (дата обращения: 29.01.2025) / (accessed on 29.01.2025).

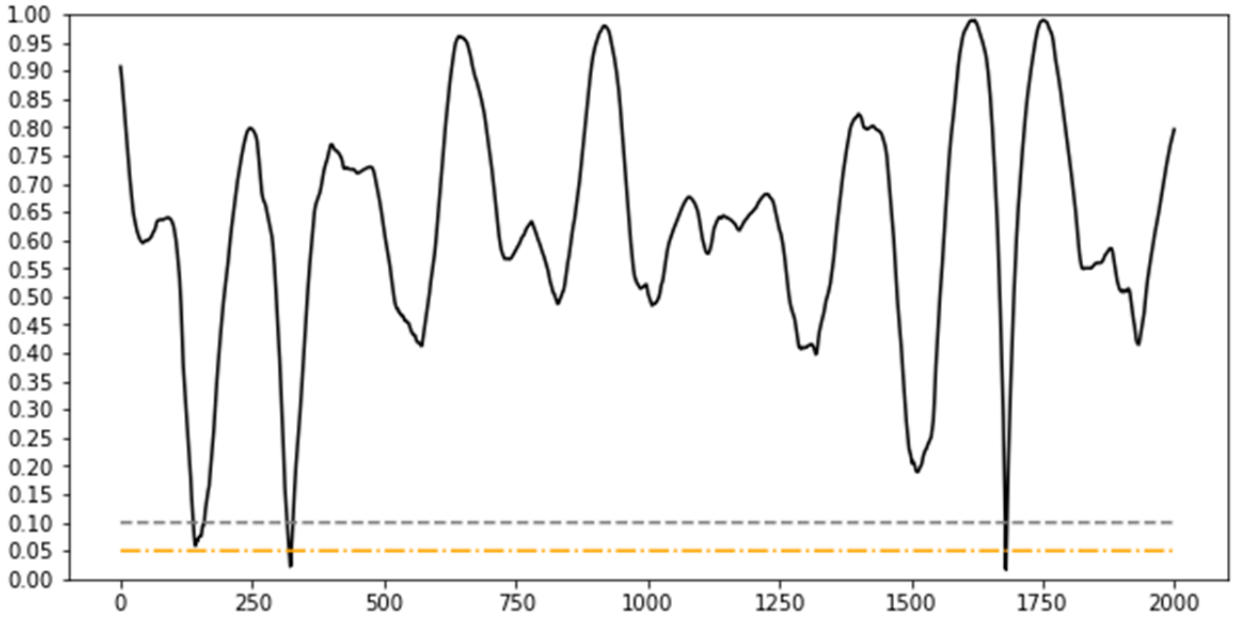

Fig. 6. **p Values of the GST Parameter of IGPA Index Dynamics (150-Day Period)**

Source: Santiago Stock Exchange. URL: http://www.bolsadesantiago.com (accessed on 29.01.2025).

technical specifications of their operational units, as well as contracts for the purchase of natural gas or alternative resources, including raw material prices, to the Economic Load Dispatch Center (CDEC) [22, 23].

As a result, the price that arises in the spot market corresponds to the marginal costs associated with using the most expensive unit of electricity production. In cases where there are transmission constraints between regions,

spot prices may differ across different regions. The most spatially detailed prices are called nodes, and CDEC disseminates information about spot prices at the node level on an hourly basis.

The Stock Prices of Energy-Producing Companies are Flexibly Linked to Marginal Costs in Chile

Due to the high efficiency of the Chilean stock market, the stock prices of energy-producing companies are flexibly linked to the marginal costs that characterize the unit cost, especially for natural gas power plants, which play an important role in the energy landscape. Therefore, we aim to estimate the hourly supply curve of natural gas generators at the zonal level, using hourly node prices in combination with observed hourly data on electricity generation by natural gas power plants for each month included in our sample. Additionally, we take into account the hourly electricity generation limits set to reflect the minimum and maximum observed levels of electricity generation for each corresponding month in our sample [17, 18].

Hydropower generation largely depends on expectations regarding future water availability, and these expectations are assessed by Chile's central operator based on complex medium- and long-term forecasting models that take into account various influencing factors. Considering the limitations inherent in our model, we use a more simplified approach, evaluating supply curves based on hydropower generation data and zonal node prices, similar to the methodology applied in natural gas analysis.

Advantages of Using AI Optimization for Renewable Energy Sources in Chile

The calculations we conducted only consider the benefits associated with the commissioning of solar power plants by the end of our trial period, and therefore do not account for the potential advantages that could be gained from attracting additional participants in the coming years. The expansion of AI optimization for renewable energy sources has allowed the country to regain energy security, which is a vital aspect that was not included in our current calculations. Finally, although the main focus of this discussion is on the payback periods of investments, it is important to recognize that investments in powertrain technologies are primarily long-term and will continue to provide benefits for several decades to come [24, 25].

The unique context of solar energy use in northern Chile, which boasts unprecedented solar radiation potential, combined with the significantly smaller land area around Santiago, suggests that this limitation may not be as relevant as in other areas of application. Nevertheless, missing this margin makes our cost-benefit analysis more favorable, as it indicates that if Chile refrains from market integration, investments in solar energy in these less sunny areas could potentially increase the overall available solar capacity. Unfortunately, to ensure internal investments in these specific regions, it will be necessary to introduce significant assumptions, especially since we have considerably more limited information about the costs associated with the installation of solar panels, given that the volume of large-scale investments in solar energy in these areas has noticeably decreased during the reporting period. Therefore, it is extremely important to emphasize that conducting additional analysis in this area will be a crucial direction for future research [26, 27].

Insufficient Market Integration between Regions

In Chile, there is noticeable insufficient market integration between regions, characterized by a significant dependence on renewable energy sources [28, 29].

From an empirical standpoint, it is preferable to conduct a comparative analysis of production costs before and after the extension of the power line, for example, using an event study analysis similar to the comparative

methodology, all else being equal. In the absence of investments aimed at developing solar energy, the benefits associated with the expansion of production should fully coincide with the benefits of trade. In the absence of obstacles, additional investments (the causal component of investments) come precisely as the transfer expands, which allows for the assessment of investment benefits related to trade. However, in the presence of discrepancies, the conditions for expansion may not fully coincide with the volume of investments made. Let's consider a scenario where investors enter the market before the complete construction of the power line in anticipation of upcoming changes [30, 33].

In a broader sense, we expect that the event-based approach will systematically underestimate gross cost savings in the presence of temporal discrepancies. It is important to note that this phenomenon is also applicable in the case of investment deferral, as the savings will allow for the exclusion of any investment consequences during the event period [32, 33]. Regarding price differences, the event-based methodology is likely to overestimate the overall impact of transmission lines on price convergence under expected investments.

Early investments will exacerbate the price difference, which will subsequently tend to narrow as the network expands. Generally, the price reduction will be underestimated [34–37]. It should be noted that the efficient market hypothesis and event study methodology hold an important place in investment analysis. The efficient market hypothesis suggests that market prices fully incorporate all available information, making it impossible to consistently achieve excess returns through the buying or selling of assets at prices different from their true value. Event analysis, on the other hand, focuses on studying the impact of unexpected corporate events, such as mergers, acquisitions, financial report releases, and stock issuances, on asset price dynamics.

Despite the differences between these two concepts, they remain important elements in the arsenal of modern investment analysis, allowing for a deeper understanding of market functioning mechanisms and enabling more informed decision-making.

CONCLUSION

The article demonstrates the influence of the high level of efficiency and integration of the Chilean stock market on the energy transition in the country. Additionally, further conclusions have been drawn:

the stock prices of energy-producing companies are flexibly linked to marginal costs in Chile;

the mechanism for selling energy on the exchange market is effective;

non-market integration between regions is noticeable.

Market integration and the high efficiency of the Chilean stock market enhance the efficiency of resource allocation through the benefits of trade and stimulate the emergence of new renewable energy sources.

The novelty of the research lies in the systematization of aspects of efficiency and integration of financial markets and the impact of this high degree of efficiency on the transition to renewable energy sources in Chile. The practical significance of the research results lies in the application by regulators of aspects of efficiency and integration of financial markets in the transition of the economy to renewable energy sources.

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ABOUT THE AUTHORS

Alexey Yu. Mikhaylov — Cand. Sci. (Econ.), Assoc. Prof., Department of Financial Technologies, Financial University, Moscow, Russia; researcher, Western Caspian University, Baku, Republic of Azerbaijan; researcher, Baku Eurasian University, Baku, Republic of Azerbaijan
https://orcid.org/0000-0003-2478-0307
Corresponding author:
alexeyfa@ya.ru

Nagwa B.A. Yousif — PhD, Assoc. Prof., Department of Sociology, College of Humanities and Sciences, Ajman University, Ajman, United Arab Emirates; Humanities and Social Sciences Research Centre (HSSRC), Ajman University, Ajman, United Arab Emirates
https://orcid.org/0000-0001-5237-5347
nagway37@gmail.com

Jaehyung An — Cand. Sci. (Econ.), Assoc. Prof., College of Business, Hankuk University of Foreign Studies, Seoul, South Korea
https://orcid.org/0000-0001-5410-7506
jaehyung.an@yahoo.com

Authors' declared contribution:
A. Yu. Mikhaylov — writing original paper.
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J. An — methodology.

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