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# ANALYSIS OF THE GREEN STOCK MARKET BUBBLE BASED ON FINANCIAL SATURATION THEORY

**[1]Darius Karasa**
*Laboratory of Energy Systems Research*
*Lithuanian Energy Institute*
*Breslaujos str. 3*
*LT-44403 Kaunas*
*Lithuania*
*Tel.: +370 6 2020 499*
*E-mail: darius.karasa@lei.lt*

**[2]Stasys Albinas Girdzijauskas**
*Kaunas Faculty*
*Vilnius University*
*Muitinės str. 8*
*LT-44280 Kaunas*
*Lithuania*
*Tel.: +3703 7 422 523*
*E-mail: stasys@girdzijauskas.lt*

[1]**Darius Karasa**, MSc, is a PhD student of Economics at the Laboratory of Energy Systems Research, Lithuanian Energy Institute. His research focuses on the topic of his dissertation "Evaluation of Investments in the Use of Renewable Energy Sources for Energy Production Using the Theory of Financial Saturation".

[2]**Stasys Albinas Girdzijauskas**, PhD, Habil. Dr, is an affiliated Professor at Kaunas Faculty of Vilnius University, Lithuania. His fields of research include social sciences, economics, (04S). S. Girdzijauskas is the author of more than 100 scientific publications and 6 books. He is interested in the saturation percentages, and created and developed the theory of financial saturation based on these percentages. He identified and studied the phenomenon of increasing returns, clarified the market (economic) equilibrium model, and corrected the proof of the water-diamond paradox. In research, the Professor classified economic bubbles and related them to financial saturation, analysed resonance phenomenon, justified business cycles, and clarified the concept of inflation.

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***ABSTRACT.*** ***The objective of this study is to analyse the financial saturation theory and to develop and apply a green stocks analysis model for bubbles formation based on the aforementioned theory. This paper suggests a methodology that considers both the financial saturation level and the dynamics of accumulated capital growth in the green stocks market. A green bubble analysis model has been developed to estimate the rate of growth of returns on capital. The model reveals that the achieved saturation of the CELS stocks index market capacity is 0.96 (96%) and the return on capital r is 15.25. The high financial saturation of the market and the high growth rate of over 95% (the third level of saturation) suggest that the market is expanding exceptionally rapidly and is exhibiting signs of explosive growth. This indicates that the market has reached the stage of a financial bubble.***

***KEYWORDS***: financial saturation, green bubble, green stock, renewable energy sources.

***JEL classification:*** E32, Q21, O44.

## Introduction

According to the International Energy Agency World Energy Investment 2023 report (*Global energy investment in clean energy and in fossil fuels*, 2023), around USD 2.8 trillion should be invested in energy in 2023. More than USD 1.7 trillion is earmarked to clean energy, including renewable power, nuclear, grids, storage, low-emission fuels, efficiency improvements, end-use renewables and electrification. The ratio has changed rapidly during the past six years. For every USD 1 spent on fossil fuels, USD 1.7 is now spent on clean energy. Six years ago, this ratio was 1:1. This shift reflects a rapid structural transformation in the energy sector regarding new technologies, which follows renewable energy to the new era.

Recently, economies across numerous countries and regions have been experiencing increasing financial pressures and significant financial saturation. This is reflected in the World Bank's financial depth statistics (*Global Financial Development Database*, 2022). As societies became more affluent, the capital accumulation became a continuous process, steadily increasing the financial depth of economies and, thus, the saturation of markets. In the post-industrial economy, this process has intensified, making it no longer possible to ignore financial saturation and its impact on markets. The relationship between financial depth and long-term economic growth revealed positive and negative trends. Shapoval (2021) highlighted both its positive effects, such as increased access to financial resources, and its risks, including the deterioration of the current account due to excessive lending, unproductive investment, and growth in employment in non-productive sectors (Shapoval, 2021).

Evidence of saturation and bubbles could be found in recent history. For example, in 2020, some wind power producers nearly doubled the market value. During this period, numerous other examples can be found. The shares of SunRun, a solar firm, and Tesla and Nio, manufacturers of electric vehicles, have recently risen threefold, sixfold, and ninefold, respectively. High valuations, aggressive interest from individual investors, and parabolic price action are all signs that there is a bubble forming in green energy stocks (Lehnert, 2023).

The high investment pace in renewable and green energy and the focus of companies and the public on corporate social responsibility and sustainability in energy have affected the whole RES sector. The increasing capital invested in the sector creates the conditions for potential financial saturation and the formation of financial bubbles. The presence of capital flow, financial saturation and financial market bubbles can significantly impact green investments and pose potential risks or advantages to green stocks and overall financial stability. Understanding that we are living in an emerging market bubble can help us make appropriate decisions to mitigate or turn the effects of the bubble into positive ones. Therefore, the research devoted to the analysis of the green stock market bubble based on financial saturation is relevant.

## 1. Literature Review and Problem Statement

The concept of a green stock market is multifaceted, encompassing a range of environmental, social, and economic factors. It is not limited to "pure enviro" companies, but also includes mainstream businesses with superior environmental performance (Srinivasan, 2008). Pimonenko (2018) defines the green stock market as a platform for the circulation of green securities, emphasising its role in promoting the efficient allocation of green financial resources (Pimonenko, 2018). The basic principles for boosting the green stock market include compliance with the goals of sustainable development, social justice, protection of investors, regulation, monitoring, legal regulation, and transparency. Some authors (Al Mheiri, Nobanee, 2020) underscore the importance of financial management and the creation of alternative resources in preserving green stocks. Some green stock markets are presented in green indexes that evaluate progress in achieving the key dimensions of Sustainable Development Goal 7, which entails ensuring "access to affordable, sustainable and modern energy for all". To illustrate, the calculation of the Inclusive Green Energy index of progress for 157 countries revealed that less than one in four of the countries in the sample have an Inclusive Green Energy index that is commensurate with having met their targets. This suggests that much remains to be done globally concerning being on track towards meeting their Sustainable Development Goal 7 by 2030 (Herrero *et al.*, 2020).

Bubbles are subject to debate and controversy. They are not well analysed and are hardly ever characterised in specific terms, especially in advance. Some authors define a financial bubble as a period of unsustainable growth, whereby the price of an asset increases ever more quickly, in a series of accelerating phases of corrections and rebounds (Sornette, Cauwels, 2014). During a bubble phase, the price follows a faster-than-exponential power law growth process. Because bubbles leave specific traces, they may be recognised in advance of their bursting.

Bubbles are repetitive and change phases past the critical point (crash) (Ghosh *et al.*, 2022). The valuation reaches a decent height through this repetitive process. However, events such as COVID-19, which was an extreme event, typically accelerate the pace of such occurrences, thus reducing the chances of fully exploring their context.

There could be a positive bubble, which has the potential to encourage and nurture innovation, leading to many more people becoming entrepreneurs. This could, in turn, result in a virtuous growth cycle. Bubble for companies may even bring in innovations and technological breakthroughs, which could prove beneficial to many other industries in the future. Bubbles, by their nature, seem to create an environment that attracts capital for technologically intensive projects, which can have tremendous positive economic impacts (Quinn, Turner, 2020).

The research results show that long-term R&D intensity for clean energy companies is beneficial for returns, shortening the cash conversion cycle value, and producing a positive effect on return on assets (Sun *et al*., 2023). In this context, stakeholders should optimise their investment strategies in various clean and traditional energy enterprises according to the time-lag effect and threshold effect.

Some researchers have observed a price bubble emerging in the green stock market. As Lehnert (2023) notes, given the high probability of large-scale adoption of "green technology", it is likely that there is not only a bubble forming in green energy stocks, but the boom is affecting the stock market as a whole (Lehnert, 2023). Using a recently developed recursive testing procedure and dating algorithm and S&P 500 stock market data, the author identifies well-known historical speculative bubbles and finds an explosive movement in today's market, starting in June 2021. The explosive movement in green stocks started roughly a year before it its migration to the whole stock market. Hence, the current bubble can be associated with the new "green technology."

Drawing an analogy to the dot-com debacle, Belle (2017) predicts investment in the hot properties of energy tech will lead to a bubble effect, eventually draining the financial resources of investors who linger too long (Belle, 2007). Conversely, others worry that firms focusing on clean energy and environmentally-friendly production may not be able to generate sufficient future revenue, and their current stock prices may be buoyed merely by their perceived environmental credentials (Chan *et al*., 2024). Inevitably, when the market discounts these prospects, the stock prices of such companies will decline, leading to an overvaluation of the green companies: the green bubble. An asset bubble refers to the price of an asset exceeding its intrinsic value (Brunnermeier *et al*., 2020). The green bubble and the carbon bubble are the bubbles that emerge within the green and brown sectors, respectively.

Other authors, namely Ghosh *et al.* (2022), adopted the log-periodic power law model (LPPL) methodology for the green bubble analysis. Over the past decade, the LPPL model has been employed extensively for detecting bubbles and crashes in a range of markets. The analysis yielded the following conclusions. The presence of green bubbles in green energy companies during the COVID-19 period is confirmed. The average drawdown was found to be four times that of the regular S&P 500 stock index under stressed conditions, such as COVID-19. These bubbles do not typically destroy public wealth in the long run; on the contrary, they can greatly increase economic activity, resulting in a sudden increase in the growth of green energy companies.

Other studies (i.e. Marcus *et al*., 2013; Criscuolo, Menon, 2015; Zhong, Bazilian, 2018; Mrkajic *et al*., 2019) have focused on either venture capitalist funding or the overall impact of bubbles in various sectors. Green bubbles have not been deconstructed to identify their embedded pattern and have not been evaluated through a new perspective on capital flows, investments, and possible financial saturation in the market. So far, there has been no assessment of the impact on the invested capital and how it could affect the green energy stock market. Although the authors analyse the green bubble, the analyses do not include financial saturation and the impact of capital/investment on bubble formation. The existing body of research in this field, especially from a theoretical standpoint, is insufficiently developed and applied.

## 2. The Aim and Objectives of the Study

The research aim consists of scientific and practical parts. The scientific part focuses on the expected results to analyse the financial saturation theory and develop a model for the practical part of the analysis. The practical part focuses on the expectations that can be derived from the use of the developed model based on financial saturation to analyse green bubble formation

The coherent aim of the research is to analyse financial saturation theory, develop a model for bubble formation analysis and apply it to green bubble formation. To achieve the aim, the following objectives were established:

- To analyse the formation of economic (financial) bubbles based on the theory of financial saturation;
- To develop a model for the analysis of green bubbles based on the theory of financial saturation;
- To apply the developed model for the analysis of green bubbles formation.

## 3. Materials and Methods

The research adopted a phenomenological approach, establishing a link between the theoretical and empirical levels. This method was employed for the analysis of the formation of economic/financial bubbles based on the theory of financial saturation. In the empirical part of the paper, logistic growth analysis was used based on the Loglet Lab 4 software package. The Microsoft Excel software was used for data analysis, distribution, and display.

We present price, growth, percentages and capital saturation using a moderately simplified version of the interpretation, in a descriptive, textual format. In the case of the material presented in textual format, only simplified arithmetic operations are used.

For the purposes of the study, we focus on one of the green equity indexes: the Nasdaq Clean Edge Green Energy Index (CELS). CELS is a modified market capitalisation-weighted index designed to track the performance of companies that are manufacturers, developers, distributors, and/or installers of clean-energy technologies. This index was launched on 17 November 2006, at a base value of 250.00 (*Nasdaq Clean Edge Green Energy Index (CELS)*, 2014). CELS, which includes companies in various green industries, has been found to outperform the Nasdaq as a whole (Boulatoff, Boyer, 2009). This suggests that green firms may have better financial performance and corporate governance. The index aligns with the philosophy of examining financially viable energy solutions that do not harm the environment (Wilder, 2004).

The data for the analysis of the index is taken from the Bloomberg terminal in quarters from the start of the index. The main research hypothesis stipulates that there is a high financial saturation in the market of green stocks, which indicates a financial bubble in the market. There are some assumptions and simplifications adopted in the work. They are presented in sub-section 4.2.

## 4. Results

### *4.1 Analysis of the Formation of Economic (Financial) Bubbles Based on the Theory of Financial Saturation*

In order to assess and analyse bubble formation, it is imperative to discuss the causes of the growth phenomenon and its measurement. Here it is important to explain that infinite growth does not exist in the long term. All growth, wherever it occurs, ultimately reaches its conclusion. Every system has its growth resources and when they run out, growth stops, and the system has to renew itself. The compound interests that we are used to, which measure the growth of capital, are only applicable in the short to medium term. However, they are not suitable for use in the long term. The general or saturation interests (percentages) which model saturation are fundamentally different from all previous models of simple or compound interests.

*4.1.1 General or Saturation Percentages*

A limited growth model, often called saturation or logistic growth, can estimate the financial saturation of a market. For this reason, the formula modelling saturation has an additional parameter: potential capacity.

The prototype of this model, published by the Belgian mathematician and demographer P. Ferhulst (Bacaër, 2011) in the first half of the 19th century, was used to estimate population growth and had no direct link to the compound interests function. The saturation (general-logistic) model used is slightly modified, with coefficients specifically adapted to economic problems and calculated in compound percentages (Girdzijauskas, 2002). The model's key element is the capital $K_p$ or potential (market) capacity. The amount of capital after the exact number of periods ($n$) (accumulated product value or capital after $n$ periods) is given by the saturation model

$$\text{Accumulated capital} = \frac{\text{Potential value (capacity)} + \text{n period compound interests}}{\text{Initial value (niche)} + \text{n period compound interests}},$$

where the potential value (capacity) is the total amount of financial resources that can be productively absorbed in an investment environment. The value of market capacity used in saturation models is usually measured in monetary (value) terms and is referred to as potential capital ($K_p$). In this case, the market capacity will also be the investment capacity. The initial value is an initial market niche, i.e. the unused part of the initial market capacity by a value equal to the difference between the market capacity ($K_p$) and the initial capital ($K_0$) ($K_p$–$K_0$). The accumulated capital is referred to as real capital or simply as investment volume.

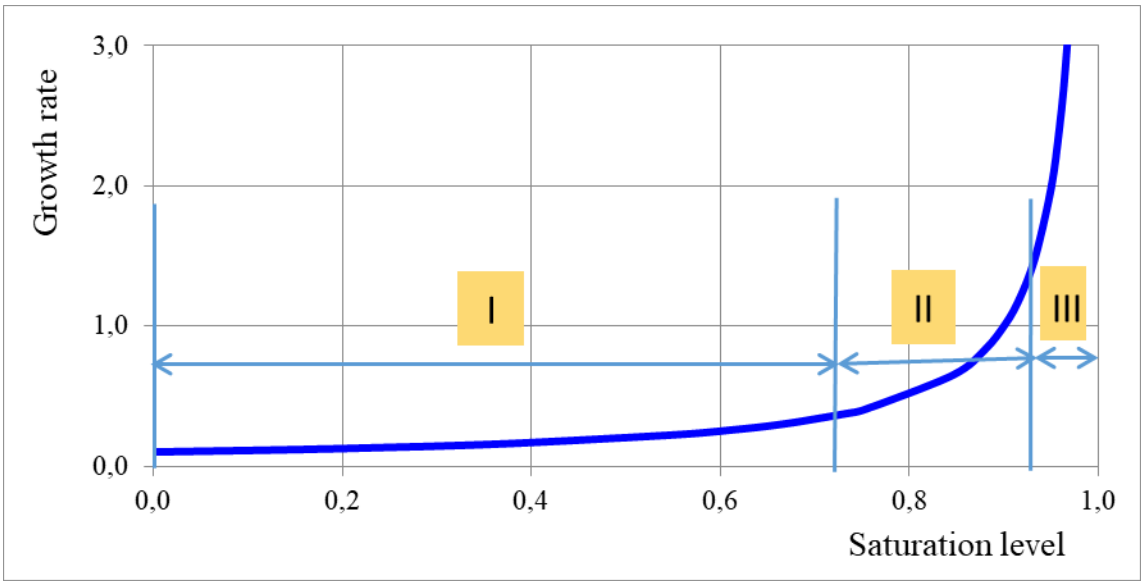
*4.1.2 The Paradox of Saturating Growth or Increasing Productivity*

The study of saturation percentages has revealed an unusual feature: the phenomenon of increasing productivity (profitability), called the saturation paradox. This paradox can be described as follows: if a population (capital) grows in a determinate environment and saturates that environment when it grows, the growth rate of the population also increases as saturation increases; this growth is hyperbolic (explosive) (Gryshova *et al.*, 2019). When the saturation of the system increases, the system's productivity increases. When the saturation approaches 100%, the productivity of the system starts to increase hyperbolically. The economic meaning of the saturation paradox can be defined as follows: if capital is invested in a closed (deficit) market and the financial saturation of that market increases, the profitability of the investment rises unrestrictedly.

The amount of supply to a given market cannot be infinite and depends on its capacity. The growth of supply is constrained due to the capacity limitations of the market. As the price of a particular good or service increases, producers increase their production to make more profit. However, output $Q$ can only be increased up to a certain potential limit $Q$ corresponding to the capacity of the market $Q_p$, i.e. until the market is sufficiently saturated with capital. Further quantity increases are risky because they lead to overproduction. Theoretically, if the market were of infinite capacity, such a limit would not exist. It should be noted that quantity $Q$, like the capital mentioned above, is not measured in natural units but in value terms. The existence of the potential quantity $Q_p$ has a fundamental effect on the nature of the supply curve, with the values of the supply curve rising sharply as the threshold is approached. This makes the typical (normal) supply curve adequate as a function of the increasing profitability of supply $Q$ (saturation phenomenon).

It is possible to claim that market saturation is a partial or full filling of a market of limited size, first with invested capital and then with the products themselves. Most modern markets are saturated because modern technology makes it possible to satisfy the most demanding consumers. Saturation of the market with capital at the initial stage does not cause negative consequences. On the contrary, saturation is an indicator of favourable investment outcomes, as a hot market is attractive to investors because it generates increased returns. Finally, saturation appears as a surplus of the relevant market products, turning what was initially a hidden oversupply into an open one, which results in a threat of economic recession.

The modelling of growth using saturation (general) percentages reveals that the internal rate of return increases as saturation increases (Girdzijauskas *et al*., 2012). This is particularly relevant for consumer expectations, and the ability of markets to adapt to a changing environment, namely changes in supply and demand. The internal rate of return is easily transformed into price, which is a fundamental economic category and plays a decisive role in numerous market positions.




*Source:* Girdzijauskas, 2024.

*Figure 1.* **Growth Rate Dependence on the Level of Market Saturation**

The analysis of the saturation phenomenon, which is the paradox of increasing productivity, (Gryshova *et al.*, 2019) is based on the functional dependence of the interest rate on saturation. One of the most characteristic graphs of this dependence is given in ***Error! Reference source not found.***. The graph shows the dependence of the rate of return on the degree of market saturation $Q/Q_p$. The saturation varies over the interval from 0 to 1. The initial growth rate is equal to 10%. The initial investment, under the previous conditions, was set as equal to one. The saturation is increased by changing the market capacity from infinite to close to the initial investment. The increase of saturation leads to a steadily rising curve. As the degree of saturation increases, the growth could be divided into three stages of elasticity.

The first stage represents 75% of the growth range and is characterised by a relatively slow increase. As saturation increases from 0% to 75%, profitability increases from 10% to 40%. The second stage covers the next 20% of saturation (75% to 95% saturation). It is characterised by a rapid, accelerating increase in profitability from 40% to 200% (of the initial profitability). The third stage is the final saturation increase above 95%. It is characterised by an extremely rapid and unrestricted growth, with a characteristic of explosive growth. At the beginning, a slight change in saturation, for example, by 1 percentage point (from 95% to 96%) triggers a change in profitability of around 15%. A change in saturation of the same one percentage point, from 98% to 99%, doubles the yield. It is easy to observe from the graph below that the phenomenon of increasing profitability is consistent with the well-known Pareto or 80/20 rule, although 80/20 does not imply exact proportions and is considered to be a mnemonic rule. It can be argued that the theoretical basis of the Pareto rule is a function of the percentage of saturation in profitability.

#### *4.1.3 Bubble Mechanism*

In the context of financial saturation, both theoretical and empirical explanations of the bubble formation mechanisms are possible. The theoretical explanation of the bubbles is based on the mechanism of saturated market equilibrium, in which a deficit situation develops in the market, where high demand is followed by supply.

At a theoretical level, positive feedback loops arise when economic (or other) growth becomes constrained, i.e. when there is a disproportionate investment in resource-constrained markets of limited size. Sufficiently frequent positive feedback intensifies and resonates with the cyclical investment process, with the saturation phenomenon affecting positive expectations, and the market heating up. In other words, intensively rising prices increase demand and hence profitability expectations, which are shaped by the phenomenon of rising profitability (saturation). The feedback loop further stimulates price increases, thereby accelerating investment.

If the market has unlimited productive resources (unlimited capacity), then there is no saturation, i.e. the phenomenon of increasing profitability does not work. The supply curve is at its lowest point and rises moderately. This leads to a lack of optimistic expectations and the feedback becomes negative, the price increase is minimal and the whole system is stable. It is common to consider such a market as stagnant (Girdzijauskas *et al*., 2012; Gryshova *et al.*, 2019). Overcoming stagnation requires the mobilisation of a sufficient number of investors who have optimistic (enthusiastic) expectations.

At the empirical level, positive feedback occurs when intensive investment leads to external market saturation, i.e. demand exceeds supply and a deficit market is created. In a deficit market, a rising price further increases demand, investors become optimistic, positive feedback is generated and the bubble is deflated. A slowdown in investment leads to lower yields and lower demand, the deficit disappears, the feedback loop turns negative, growth becomes rational, and prices converge to fundamental levels. To stimulate the market (to accelerate the growth of profitability), financial saturation must be increased; and demand, activated.

#### *4.1.4 Types of Bubbles: Financial Bubbles*

According to the economic historian Kindleberger (1996), the classic definition of bubbles defines a large increase in the price of an asset class in an ongoing process when the initial increase in price creates expectations of further increases and attracts new buyers, mainly speculators, who are more concerned with the profits from trading the asset than with the ability of the asset to generate income (Kindleberger, 1996). The saturation theory of economic bubbles is classified into three groups: price bubbles, financial resonance bubbles, and inflationary bubbles based on a change in the aggregate market (Girdzijauskas, 2022; Girdzijauskas *et al.*, 2022). Financial resonance bubbles tend to form in individual markets or even in individual asset classes such as real estate, oil, cryptocurrencies, etc. A key factor in the formation of a financial bubble is the deficit market resulting from financial saturation (Supply (S)<Demand (D)).

A financial bubble occurs when the market is financially saturated. This means that saturating the market turns it into a deficit market. In such a market, every investment generates a new growth impulse thanks to the saturation effect. The growth expectations that are aroused strengthen demand through feedback. The new investment repeats the previous upward price cycle. Regular investment of sufficient intensity in such a market triggers a resonance of price growth: a financial bubble (Girdzijauskas *et al.*, 2022).

*4.1.5 Bubble Anatomy and Resonance*

Market capacity, known as potential capital $K_p$, is a key determinant of bubble formation and one of the main characteristics of saturation. The measure of market capacity is market depth. Market depth is an indicator of current interest in a stock or other asset. It refers to the ability of the market to execute a large number of buy or sell orders without them having a strong impact on its market price. If financial depth is related to potential GDP, then market depth can be thought of as a measure of market capacity and is related to potential market capacity $K_p$.

Supply and demand are important for bubble formation. Feedback and cyclical demand create a quasi-resonant price rise mechanism that inflates the price bubble. The bubble is shaped by the resonating demand created by the investment and comes out in conditions of intense saturation. Investment in a given market can be compared to a swing process. A market without investment could be considered a decaying market. The intensity of the decline in market activity in the absence of investment could be considered as an individual characteristic of the market, analogous to the swing's own frequency of oscillation. The moment of investment could be likened to the push of a swing that is being swung (Girdzijauskas, 2014).

Investing is a chaotic process in the broadest sense. The existence of feedback loops gives stability to the market. Some investment impulses are likely to be consistent with the market's individual characteristics (the market's own frequency). Investment impulses that coincide with the phase of market price volatility amplify the amplitude of price fluctuations. This leads to an increase in prices or a change in the market. Due to the chaotic nature of the investment process, the resonance process is often not fully realised. Although resonance is not fully achieved, the market often reaches a state of stimulation. For this reason, we say that under heating conditions, the processes occurring in markets are quasi-resonant.

The cyclical bubble scheme (financial resonance) works as follows: when demand exceeds supply (usually in the case of well-publicised long-term technological projects), a deficit market is created. Such a market becomes saturated (closed) (Girdzijauskas, 2024). By investing in a deficit (saturated) market, the short-run market equilibrium mechanism is triggered: the Marshall scissors are twisted, and the point of convergence is shifted upwards (the price goes up). Continuous investment in a saturated market further increases the saturation of that market. The process is even accelerated when speculators enter the market and sharply increase demand, saturation, profitability, etc. The cycle closes.

The phenomenological approach shows that a bubble can only form through a cyclical process and additional stimulation (excitation). That additional stimulus is investment under saturation, i.e. the increasing returns resulting from saturation. The theory of financial saturation allows a bubble to be defined as a resonant phenomenon. Based on the above analysis, a simplified definition of a financial bubble can be formulated without reference to a market equilibrium model. A financial resonance bubble is an intense increase in asset class prices resulting from repeated and resonant investment cycles with positive feedback loops shaped by optimistic expectations, resulting from the increase in returns in a deficit market that is the consequence of financial saturation.

The following highlights of the development of a financial resonance bubble can be highlighted:

- The bubble analysis is based on a saturated market equilibrium mechanism. The distinctive feature of this mechanism is that the supply curve has a vertical asymptote at the potential market boundary. A new approach to the supply side of saturated markets, a new type of supply curve, and a new market equilibrium model allows the formation of bubbles to be understood and controlled.
- Bubbles only arise in saturated markets, and saturation leads to market shortages. A deficit market has a demand that exceeds the supply, creating a favourable environment for a bubble to grow.
- The fundamental price is essentially shaped by the unsaturated market supply. When the market is unsaturated, the supply curve has a low slope, resulting in a narrow range of prices on the price axis at the points of intersection. These are uninflated prices.
- Consumer behaviour, optimistic expectations, feedback, cyclical investing and market resonance in the bubble formation process are some of the key drivers of the formation of financial resonance bubbles.

### *4.2 Development of the Model for Green Bubble Analysis Based on the Financial Saturation Theory*

Based on financial saturation, green bubble analysis is conducted by testing the saturation level of the market with capital. The assumption is made that once a certain level of saturation is reached, the likelihood of the market overheating increases and the growth rate becomes extremely high, which affects market prices and output. The model seeks to identify the level of market saturation reached during the period of significant growth. The research also assesses how saturation and growth rate relate to stock prices in a green bubble.

The model is based on saturation (general) percentages (interest). The model is based on formula (1) (Girdzijauskas, 2002):

$$K_a = \frac{K_p \cdot K_0(1+i)^t}{K_p - K_0 + K_0(1+i)^t}, \qquad (1)$$

where $K_p$ is the market capacity or potential (maximum) value of the invested capital in the market; $K_0$ is the initial value of the investment; $K_a$ is the accumulated investment (the amount of the capital in terms of its value) over periods; $i$ is the interest rate; $t$ is the duration of the investment or the number of periods of the investment (measured in the same units of time as time in the interest rate).

Taking 1+$i$ = $r$ gives the percentage (growth rate) variant of formula (2):

$$r = \sqrt[t]{\frac{K_p - K_0}{K_0} \cdot \frac{K_a/K_p}{1 - K_a/K_p}} \,. \tag{2}$$

In the saturation percentage formula (2), the independent variable is usually time ($t$) and the dependent variable is $K_a$. In this model, the functions are solved concerning the dependent variable (the variable on the left-hand side of the equation ($r$)). The independent variable is considered to be the market saturation ($K_a/K_p$ ratio), which consists of two variables. To simplify the model, the value of $K_p$ is assumed to be constant and market saturation varies only with $K_a$.

The model assumes that $K_p$, $K_0$ and $t$ are constant and fixed. The following assumptions are made to estimate these quantities:

– $K_0$ takes the first historically available capitalisation value of the equity index under analysis for the quarter of the year, i.e. the end-of-quarter value.

– $K_p$ is calculated using the Loglet model for a given period of significant growth in quarters.

– $t$ (time) is taken to be of medium duration, i.e. $t$=1. This corresponds to the period of quarters used in the study. As will be observed later in the analysis, the logistic (saturation) growth lasts for 3–5 quarters, which also corresponds to a medium-term period.

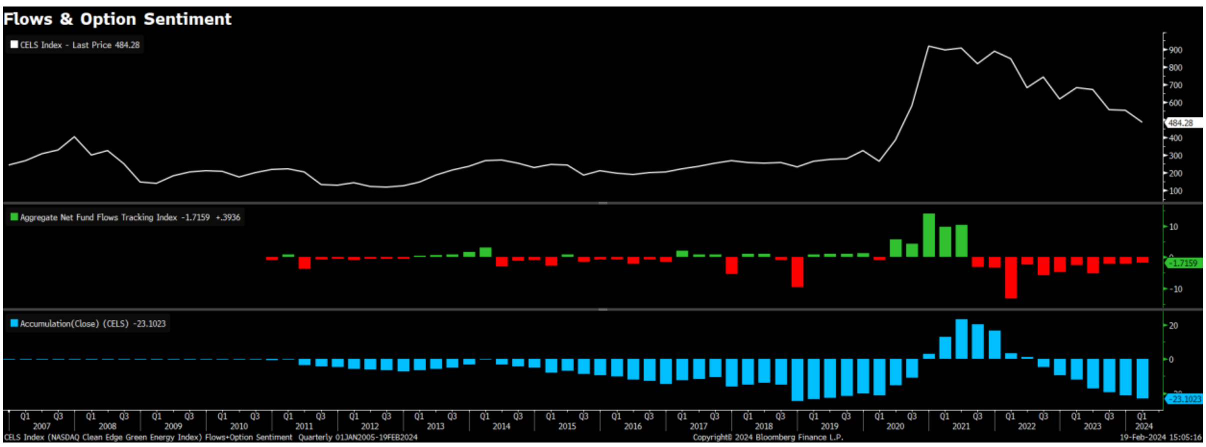
The independent variable $K_a$ is the accumulated amount of investment (capital) at the end of each period. It is calculated according to formula (3):

$$(K_a)_n = K_0 + \sum_{j=1}^{n} F_j \tag{3}$$

Aggregate Net fund flows ($F$) for the period are added to the previous period's $K_a$ to obtain the accumulated capital (investments) at the end of the period.

### *4.3 Adaption of the Developed Model for the Analysis of Green Bubbles*

The Nasdaq Clean Edge Green Energy Index (CELS) was used to study the green equity bubble. Data from the Bloomberg terminal reveals the quarterly dynamics of important indicators for the calculations. ***Error! Reference source not found.*** shows the CELS index share value, aggregate net fund flows, and accumulated capital values in quarters from Q1 of 2007 to Q1 of 2024.




*Source:* Bloomberg terminal.

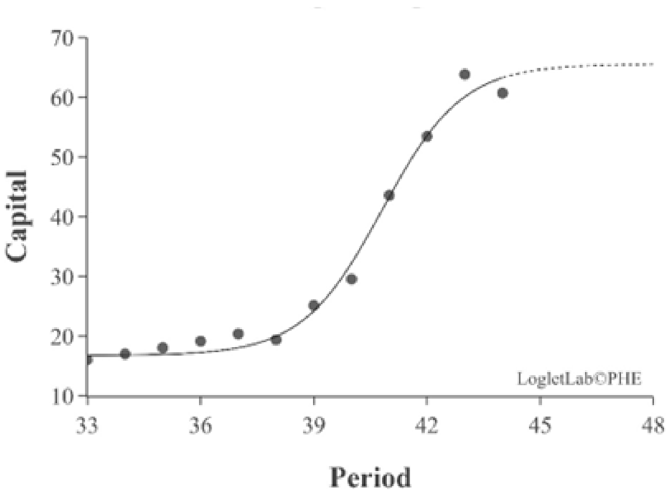
*Figure 2.* **Dynamics of the CELS Index Value and Capital Flow**

Historically, equity index capitalisations are reported from Q4 of 2012. At the end of this quarter the CELS Index had a share capitalisation of EUR 33.9 billion. After performing additional calculations based on formula (3), the dynamics of the price of the CELS Index and the accumulated capital $K_a$ during the considered period were obtained (*Figure 3*).


*Source:* created by authors.

*Figure 3.* **Dynamics of the CELS Index Price and Accumulated Capital ($K_a$)**

The capital market and the stock index price changes identified a possible bubble period when capital and price growth were particularly intense. The period between Q4 of 2018 and Q3 of 2021 was chosen and used for the analysis of the Loglet model. During this period, the value of the equity and equity index recorded the highest gains and a potential bubble formation.

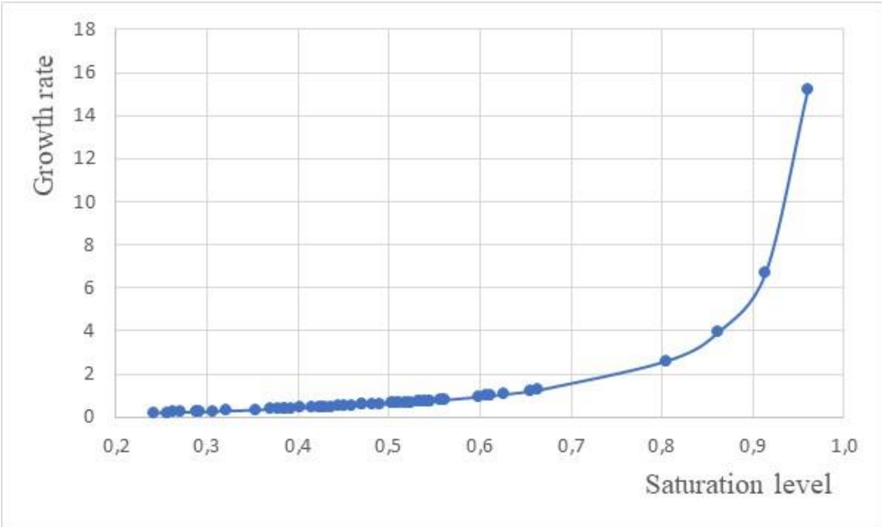



*Source:* created by authors.

*Figure 4.* **Loglet Analysis of the CELS Index Accumulated Capital $K_a$**

The 33rd period in analysis (*Figure 4*) corresponds to Q4 of 2018; and the 44th period, to Q3 of 2021. The Loglet analysis shows that in this period, the logistic growth is recorded, and the $K_p$ of this market is 66.5. This analysis reveals that in the 43rd period (Q2 of 2021), an overheating of the capital market has been reached. Meanwhile, the market capacity ($K_p$) calculated from the Loglet analysis is used for further analysis of the capital saturation ($K_a/K_p$) and the growth rate ($r$) according to formula 2.

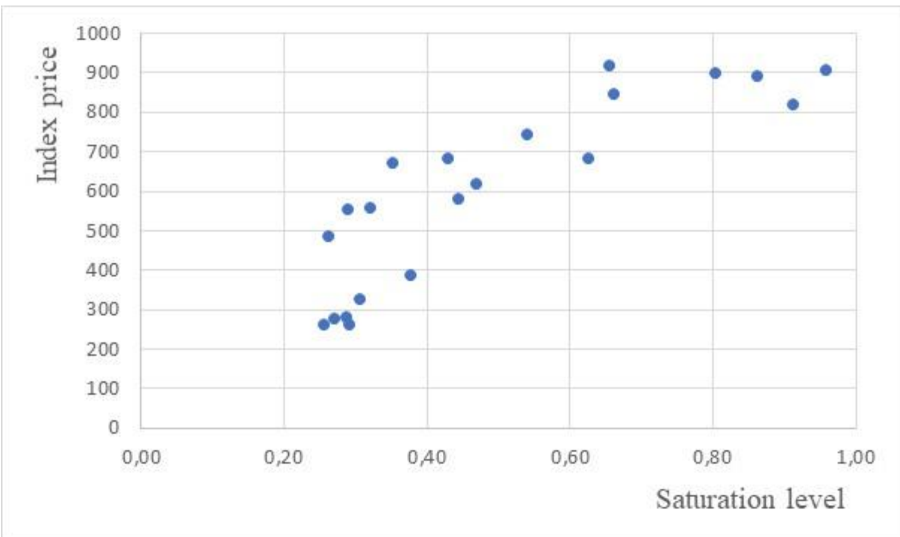
Following the calculations based on formula (2) and the mentioned assumptions in the methodology part, the curve of the growth rate of capital ($r$) according to the ranked saturation level ($K_a/K_p$) was obtained (*Figure 5*). This curve has a hyperbolic growth form, as illustrated below.




*Source:* created by authors.

*Figure 5.* **Variation of Growth/Yield Rate $r$ with Level of Saturation $K_a/K_p$**

The hyperbolic growth curve shows the distribution of the financial capital saturation and the capital growth rate $r$ for each quarter of the analysis period (from Q4 of 2012 to Q1 of 2024). The data are ranked in ascending order of the capital saturation level.




*Source:* created by authors.

*Figure 6.* **Scatter Plot of CELS Index Value and Capital Saturation Level over the Growth Period**

The distribution of the CELS Index price (value) and the capital saturation level (*Figure 6*) are measured from the period when stable capital growth started in the market ($F$>0), i.e. when the conditions for the formation of a bubble emerged. In the analysis, this corresponds to Q1 of 2019, when positive capital started flowing into the market. The analysis concludes with the last available data in Q1 of 2024 when there was a strong negative net capital flow. A scatter diagram visually depicts the relationship between the CELS Index price and capital saturation level. It provides insights into how two variables affect each other when they are plotted on a graph.

## 5. Discussion of the Results

The analysis of the green bubble is based on the theory of financial saturation. According to the theory of financial saturation, one of the key features of the formation of a bubble is the financial saturation of the market with capital as the market approaches its potential capacity. At the high end of financial saturation, there is a sharp increase in profitability and a high growth rate. A model has therefore been developed to estimate the growth rate of green equity capital and the market capital saturation. The level of saturation and the capital growth rate are key indicators in the model and show the level of green bubble formation.

The CELS Index, one of the indexes representing green stocks, has a history dating back to 2006 and is included in the analysis. This index captures the potential formation of a bubble in 2020. Looking at quarterly data, the value of this index has increased more than 3.5 times during the research period, precisely from 262 to 917. Meanwhile, aggregate net fund flows have been gradually increasing their accumulated capital since Q1 of 2019. With the slight exception of Q1 of 2020, the market capital increased until Q2 of 2021. During this period, the accumulated capital of the market increased more than 3.5 times, from 17 to 64. In 2020 alone (a period of rapid index appreciation), the accumulated capital more than doubled, from 19 to 44. The model developed analyses this period of intense growth.

Based on the theory of financial saturation and logistic growth, the model estimates the dependence of the capital growth rate (profitability) on the level of financial (capital) saturation. The level of saturation is related to the market capacity. The model estimates that some periods achieved a maximum level of saturation up to 0.96 (in the range from 0 to 1). At this highest saturation point, the growth rate of capital (profitability) $r$ is 15.25. At this and nearby points, the financial saturation of the market capital ranges from 0.86 to 0.96, and the growth rate of capital varies from 3.97 to 15.25. High financial saturation and a high growth rate led to Stage III of growth, i.e. a final saturation growth above 95%. It is characterised by extremely rapid and unrestricted growth, with an explosive upward (hyperbolic) trend.

The ranked capital growth rate ($r$) by saturation level reveals that capital gains depend strongly on the level of market saturation. When capital saturation exceeds 0.8, the rate of return increases sharply. According to the theory of financial saturation, such saturation and increased profitability reveal a bubble formation. This trend is reflected in the value dynamics of the CELS stock index.

Logistic (saturating) growth and bubble formation confirmed Loglet analysis. In a period of rapid growth in capital accumulation (Q4 of 2018– Q3 of 2021), the Loglet analysis shows a financial saturation of capital in the Q2 2021 period and thus an overheating of the market. This quarter coincides with the quarter of the developed model analysis where the highest saturation and capital growth were recorded.

Based on the model and financial saturation, the scheme of green bubble formation and the financial resonance work as follows: due to an external stimulus (the expected impact of the COVID pandemic, increased capital/money supply), when the demand for green equity investment exceeds the supply (which is what happens in the case of the realisation of intensive development and promotion of long-term technological projects, i.e. RES), a deficit market has formed. Such a market has become saturated (closed). By investing in a deficit (saturated) market, a short-term market equilibrium mechanism is triggered: the Marshall scissors have closed, and their point of convergence has moved upwards (share prices have risen). In parallel, the increase in price triggers optimistic expectations: a positive feedback loop. Investment (stock purchases) has increased as a result of rising share prices. Continuous investment in a saturated market has further increased the saturation of that market. This triggers a reaction in the supply-demand equilibrium mechanism, triggering a new upward impulse in prices. This affects the optimistic expectations of investors and in turn, increases demand. The 4–5 quarter cycle closed at the peak of capital saturation (0.96).

The transformation of the capital growth rate ($r$) into a stock price requires to estimate a time lag. Looking at the scatter of the growth rate of capital and prices, prices start to rise faster than the level of capital saturation. This is revealed by the uneven distribution of the CELS Index value and capital saturation. The opposite time trend is observed as the accumulated market capital declines, i.e. accumulated capital declines faster than the value of the equity index. This can be explained by investor confidence and the expectation that the index value will "bounce back". According to Schiller (2015), a strong jump in share prices can boost investor confidence for the next 6 months (Shiller, 2015). Investor confidence creates the effect of expecting a market rebound and further successful price appreciation as before.

**Limitations of research**. These discrepancies in the dynamics of the index price and the accumulated capital in the market over time need to be examined in more detail. This requires additional research on the time lag between the growth rate of capital (internal rate of return) and the index value. The question is whether the observed time lag between the rate of change of capital ($r$) and the index price allows for a direct simple transformation of the growth rate into a price, as suggested by the theory of financial saturation.

The model for analysing the formation of green stocks bubble consists of 5 variables, 3 of which are considered constant sizes. The aim is to simplify the calculations and to clarify the causal relationship between the dependent variable ($r$) and the independent variable ($K_a$). However, this leads to a limitation in the application of the model. It is likely that the potential capacity of the market ($K_p$) is not stable and varies over time. This leads to different saturation in different periods and affects the size of the dependent variable $r$. Further research is needed to assess how market capacity varies over time and to incorporate this into the estimation model. Changes in market capacity over time may likely explain the discrepancy between the capital growth rate $r$ and the price dynamics over time.

The analysis reveals that the increase is evident as we approach $K_p$. However, the determination of $K_p$ is more likely to be based on historical data rather than on an accurate forecast. The capital growth rate ($r$) could be used to predict that the market is approaching a growth opportunity frontier (potential level), followed by a correction/crash or market capacity change. Further research and analysis are needed to identify a dangerous growth rate that would indicate a market changing and approaching saturation.

Slight, small price/market corrections are inevitable and beneficial to the market. However, significant, large corrections are detrimental and reduce the sustainability of the market. The degree of market saturation is likely to help assess the potential magnitude of market correction, but this requires further extensive research and analysis.

## Conclusions

The energy sector is currently undergoing a rapid structural transformation. Intensive investment in the RES sector creates the conditions for potential financial saturation, market heating and the formation of financial bubbles. Some researchers have already observed in their studies the emergence of a price bubble in the green energy stock market. The saturation percentages, which are also general cases of compound percentages, are considered the most appropriate to model bubbles formation. In the general case, economic bubbles should be classified into three groups: price, financial resonance, and inflationary. The focus of the study is on financial resonance bubbles. They have been used to establish the dependence of the increasing rate of return on the level of market saturation. The theory of financial saturation allows a bubble to be defined as a resonant phenomenon: a simplified financial resonance bubble is an intense increase in asset class prices resulting from repeated and resonant investment cycles with a positive feedback loop, shaped by optimistic expectations, and driven by rising returns in a deficit, capital-saturated market. Such bubbles are characterised by certain features: the supply curve is a vertical asymptote at the potential capacity of the market; bubbles only occur in saturated markets because saturation implies a market deficit; and in an unsaturated market, there is a fundamental (non-inflated) market price. Consumer behaviour, optimistic expectations, feedback, cyclical investment, and market resonance are among the most important secondary triggers in the formation of a bubble, leading to the formation of financial resonance bubbles.

The model for analysing green stocks bubble is based on the independent fixed variables of initial capital, market (capital) potential capacity, medium-term time horizon, and a variable for accumulated capital over time. Based on these variables, the model estimates the rate of return/growth of accumulated capital according to a logistic growth formula. This growth rate-dependent variable and saturation level indicate whether the market is approaching potential market capacity and whether a bubble is forming.

The applied model shows that the CELS Green Equity Index has a market capital saturation of 0.96. At this saturation point, the capital growth rate is 15.25. A high financial saturation level and a high growth rate led to Stage III of growth, i.e. a final saturation growth above 95%. This stage is characterised by extreme and unrestricted growth and has the feature of explosive growth, i.e. a financial bubble exists due to the high level of saturation and the rate of capital growth. Loglet analysis confirms that in Q2 of 2021 there is a financial saturation with capital and thus an overheating of the market. This quarter coincides with the quarter of the analysis of the model, which shows the highest saturation and capital growth.

The model and the analysis have some limitations and shortcomings related to the time lag between the capital growth rate and the dynamics of the equity index. Fixed potential market capacity over time is another limitation. However, despite these discrepancies, the return on capital and the level of market saturation reflects the dynamics and trends of the CELS Index price and confirm the formation of a green bubble in the green stocks market.

## References

Al Mheiri, W., Nobanee, H. (2020), *Green Bonds: A Mini-Review*, Rochester, NY, available at, https://doi.org/10.2139/ssrn.3538790, referred on 05/04/2024.

Bacaër, N. (2011), "Verhulst and the logistic equation (1838)", in: N. Bacaër (ed.), *A Short History of*

*Mathematical Population Dynamics*, London: Springer, pp.35-39, available at, https://doi.org/10.1007/978-0-85729-115-8_6, referred on 28/03/2024.

Belle, R. (2007), The green bubble: waste into wealth: the new energy revolution, 1st edition, France: Editions Scali.

Boulatoff, C., Boyer, C. (2009), "Green Recovery: How Are Environmental Stocks Doing?", *The Journal of Wealth Management*, Vol. 12, No 2, pp.9-20, https://doi.org/10.3905/JWM.2009.12.2.009.

Brunnermeier, M., Rother, S., Schnabel, I. (2020), "Asset Price Bubbles and Systemic Risk", *The Review of Financial Studies*, Vol. 33, No 9, pp.4272-4317, https://doi.org/10.1093/rfs/hhaa011.

Chan, Y.T., Ji, Q., Zhang, D. (2024), "Optimal monetary policy responses to carbon and green bubbles: A two-sector DSGE analysis", *Energy Economics*, Vol. 130, February, 107281, https://doi.org/10.1016/j.eneco.2023.107281.

Criscuolo, C., Menon, C. (2015), "Environmental policies and risk finance in the green sector: Cross-country evidence", *Energy Policy*, Vol. 83, August, pp.38-56, https://doi.org/10.1016/j.enpol.2015.03.023.

Ghosh, B., Papathanasiou, S., Dar, V., Kenourgios, D. (2022), "Deconstruction of the Green Bubble during COVID-19 International Evidence", *Sustainability*, Vol. 14, No 6, 3466, https://doi.org/10.3390/su14063466.

Girdzijauskas, S. (2002), Draudimas: kiekybinė finansinė analizė, Kaunas: Naujasis lankas, [Insurance: quantitative financial analysis, *in Lithuanian*].

Girdzijauskas, S. (2014), "Mintys ekonominio rezonanso tema", *Virpesiai moksle, technikoje ir žmonijos progrese*, Kaunas: VĮ Vibroengineering, pp.51-54, [Thoughts on the topic of economic resonance, *in Lithuanian*].

Girdzijauskas, S. (2022), *Finansinio prisotinimo teorija – nauja galimybė sprendžiant ekonominių krizių problemas*, VU naujienos', SPECTRUM, available at, https://naujienos.vu.lt/spectrum-finansinio-prisotinimo-teorija-nauja-galimybe-sprendziant-ekonominiu-kriziu-problemas/, referred on 16/04/2024.

Girdzijauskas, S., Streimikiene, D., Griesiene, I., Mikalauskiene, A., Kyriakopoulos, G.L. (2022), "New Approach to Inflation Phenomena to Ensure Sustainable Economic Growth", *Sustainability*, Vol. 14, No 1, 518, https://doi.org/10.3390/su14010518.

Girdzijauskas, S. (2024), Ekonominės krizės: Finansinio prisotinimo teorijos įžvalgos, Vilnius: Vilniaus universiteto leidykla, [Economic crises: Insights from the financial saturation theory].

Girdzijauskas, S. (2024), *Prisotinimo paradigmos galimybės. Rinkos pusiausvyros modelis*, Mokslo Lietuva, available at, http://mokslolietuva.lt/2024/02/prisotinimo-paradigmos-galimybes-rinkos-pusiausvyros-modelis/, referred on 16/04/2024.

Girdzijauskas, S., Streimikiene, D., Mialik, A. (2012), "Economic Growth, Capitalism and Unknown Economic Paradoxes", *Sustainability*, Vol. 4, No 11, pp.2818-2837, https://doi.org/10.3390/su4112818.

Global energy investment in clean energy and in fossil fuels (2023), *International energy agency*, available at, https://www.iea.org/data-and-statistics/charts/global-energy-investment-in-clean-energy-and-in-fossil-fuels-2015-2023, referred on 16/04/2024.

Global Financial Development Database (2022), *World Bank*, available at, https://www.worldbank.org/en/publication/gfdr/data/global-financial-development-database, referred on 16/04/2024.

Gryshova, I., Shabatura, T., Girdzijauskas, S., Streimikiene, D., Ciegis, R., Griesiene, I. (2019), "The Paradox of Value and Economic Bubbles: New Insights for Sustainable Economic Development", *Sustainability*, Vol. 11, No 24, 6888, https://doi.org/10.3390/su11246888.

Herrero, C., Pineda, J., Villar, A., Zambrano, E. (2020), "Tracking progress towards accessible, green and efficient energy: The Inclusive Green Energy index", *Applied Energy*, Vol. 279, December, 115691, https://doi.org/10.1016/j.apenergy.2020.115691.

Kindleberger, C.P. (1996), *Manias*, Panics and Crashes: A History of Financial Crises. Macmillan.

Lehnert, T. (2023), "The Green Stock Market Bubble", *Circular Economy and Sustainability*, Vol. 3, No 3, pp.1213-1222, https://doi.org/10.1007/s43615-022-00223-4.

Marcus, A., Malen, J., Ellis, S. (2013), 'The Promise and Pitfalls of Venture Capital as an Asset Class for Clean Energy Investment: Research Questions for Organization and Natural Environment Scholars", *Organization & Environment*, Vol. 26, No 1, pp.31-60, https://doi.org/10.1177/1086026612474956.

Mrkajic, B., Murtinu, S., Scalera, V.G. (2019), "Is green the new gold? Venture capital and green entrepreneurship", *Small Business Economics*, Vol. 52, No 4, pp.929-950, https://doi.org/10.1007/s11187-017-9943-x.

Nasdaq Clean Edge Green Energy Index (CELS) (2014), *Clean Edge*, available at, https://cleanedge.com/indexes/stock-index/cels, referred 16/04/2024.

Pimonenko, T. (2018), "A conceptual framework for development of Ukraine's green stock market", Herald of

Ternopil National Economic University, Vol. 4, No 90, pp.69-80, available at, https://doi.org/10.35774/visnyk2018.04.069.

Quinn, W., Turner, J.D. (2020), *Boom and Bust: A Global History of Financial Bubbles*, Cambridge University Press.

Shapoval, Y. (2021), "Financial depth in the context of the relationship with economic growth", *Fìnansi Ukraïni*, pp.72-88, https://doi.org/10.33763/finukr2021.06.072.

Shiller, R.J. (2015), Irrational Exuberance, REV-Revised, 3, Princeton University Press, available at, https://doi.org/10.2307/j.ctt1287kz5.

Sornette, D., Cauwels, P. (2014), "Financial Bubbles: Mechanisms and Diagnostics", *SSRN Electronic Journal*, No 2, https://doi.org/10.2139/ssrn.2423790.

Srinivasan, S. (2008), "Broad-basing "green" stock market indices: A concept note", *International Journal of Green Economics*, Vol. 2, No 4, pp.372-378, https://doi.org/10.1504/IJGE.2008.022447.

Sun, W., Zhang, X., Hazarika, N. (2023), "Dilemmas of R&D investment risks and sustainability in the clean-tech economy: Evidence from Nasdaq clean edge index components", *International Journal of Green Energy*, Vol. 20, No 2, pp.139-152, https://doi.org/10.1080/15435075.2021.2023883.

Wilder, R. (2004), "Capitalizing on Solutions that can make Ecological and Economic Sense: The WilderHill Clean Energy Index (ECO)", *The Journal of Alternative Investments*, Vol. 7, No 2, pp.80-84, https://doi.org/10.3905/jai.2004.439653.

Zhong, M., Bazilian, M.D. (2018), "Contours of the energy transition: Investment by international oil and gas companies in renewable energy", *The Electricity Journal*, Vol. 31, No 1, pp.82-91, https://doi.org/10.1016/j.tej.2018.01.001.

## ŽALIŲJŲ AKCIJŲ RINKOS BURBULO ANALIZĖ FINANSINIO PRISOTINIMO TEORIJOS POŽIŪRIU

**Darius Karaša, Stasys Girdzijauskas**

**SANTRAUKA**

Šio tyrimo tikslas – išanalizuoti finansinio prisotinimo teoriją, sukurti ir pritaikyti žaliųjų burbulų susidarymo akcijų rinkose analizės modelį remiantis finansinio prisotinimo teorija. Šiame straipsnyje siūloma metodika, kurioje atsižvelgiama į finansinio prisotinimo lygį ir sukaupto kapitalo augimo dinamiką žaliųjų akcijų rinkoje. Šiuo metu vykstanti sparti struktūrinė energetikos sektoriaus transformacija, intensyvus investavimas į AEI sektorių sudaro prielaidas galimam finansiniam prisotinimui, rinkos kaitimui ir finansinių burbulų formavimuisi. Besiformuojantį kainų burbulą žaliosios energetikos akcijų rinkoje pastebėjo kai kurie mokslininkai savo tyrimuose. Parengtas *green bubble analysis* modelis, leidžiantis įvertinti kapitalo pelningumo augimo greitį. Analizė remiantis šiuo modeliu atskleidžia, kad pasiektas CELS (*Nasdaq Clean Edge Green Energy Index*) akcijų indekso rinkos talpos prisotinimas siekia 0,96, o kapitalo pelningumas r išauga iki 15,25. Aukšta augimo norma, didelis finansinis rinkos prisotinimas, viršijantis 95 proc. (trečias prisotinimo lygis), liudija, kad rinka pasižymi ypač sparčiu augimu ir turi sprogstamojo didėjimo požymių. Todėl daroma išvada, kad rinkos augimas pasiekė finansinio burbulo stadiją – susidarė žaliasis burbulas CELS akcijų rinkoje. Nors parengtas modelis ir atlikta analizė turi tam tikrų apribojimų ir trūkumų, susijusių su laiko lagu tarp kapitalo pelningumo ir akcijų indekso dinamikos, rinkos talpos pastovumu laike, tačiau gauti rezultatai atspindi CELS akcijų kainų indekso dinamiką ir tendencijas rinkoje.

*REIKŠMINIAI ŽODŽIAI:* finansinis prisotinimas; žaliasis burbulas; žaliosios akcijos; atsinaujinantys energijos ištekliai.