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RESEARCH ARTICLE

Financial constraints and sustainability in bioeconomy firms

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Abstract

In the current scenario, sustainability has become vitally important. This paper focuses on bioeconomy as it links the economic systems and sustainable development, promoting innovative and environmentally friendly solutions. The bioeconomy firms need financial resources that play a critical role in their ordinary activities and in the activities that contribute to sustainability. The relationship between firms' ESG (environmental, social and governance) factors and their financing decisions has received little attention. Therefore, the objective of this article was to analyse the relationship between financial constraints and ESG performance focusing on bioeconomy firms. To carry out the analyses we have used 227 European bioeconomy firms developing three machine learning models. The main findings highlight the importance of the profitability (return on equity—ROE and return on assets—ROA) and the indebtedness in characterising firms' constraints, and the impact of non-disclosure of ESG results. The study emphasises the economic importance of ESG practices in enhancing companies' financial conditions and access to capital, by using their corporate strategy and management: non-disclosure of ESG information is related to an increase in funding constraints for listed bio companies. Thus, improving both economic and ESG performance can enhance access to capital, guiding business decisions.

1 | A NEW ECONOMIC-FINANCIAL PARADIGMS: SUSTAINABLE DEVELOPMENT AND SUSTAINABLE FINANCE

In the current scenario, sustainability and sustainable development have become vitally important. This transformation, which is necessary to ensure the long-term value creation, is the biggest challenge facing economies, as it will have significant effects. Some of them are undesirable in the short and medium term, as certain economic sectors and business models must be reconverted, or even disinvested in certain industries, with the consequences of employment, emigration, etc.

This transition requires the combination of several elements. First, it demands a change in our intertemporal consumption and investment preferences (Lagoarde-Segot, 2019). This implies changes in the mindsets and individual and collective attitudes and behaviours that modify the way we live, consume and manage resources. Second, it also requires global collaboration at the private and public level. Third, it also needs innovation in products and processes to enable this reconversion, and finally, the financial decisions (investment and financing) to enable the transfer to sustainable activities. All these elements combined imply the emergence of new economic-financial paradigms based on sustainable development and sustainable finance (Schoenmaker, 2017).

Consequently, the companies and investors must make financial decisions aimed at sustainable practices by redefining their objectives (Schoenmaker & Schramade, 2019). It involves adding the social and environmental dimensions to the achievement of economic-financial results with a long-term vision.

This results in the fact that environmental, social and governance (ESG) considerations are becoming increasingly important, giving rise to corporate ESG policies. These policies not only help companies to address global challenges such as climate change, the resource scarcity and the social inequality, but also enable firms with sound initiatives to minimise the operational risks, to reduce the business costs and to maintain the compliance with regulatory standards. In this context of the search for sustainability, the companies incorporate into their decision-making not only the impact of the environment on their business models ('outside in') but also the impact of their activity ('inside out') on society and the planet (the so-called double materiality, i.e. the first involves the financial materiality and the second is the impact materiality) (Adams et al., 2021).

This growing interest in sustainability has led to a significant increase in theoretical and empirical research aiming to explain the relationships, implications and consequences of implementing ESG policies on economic-financial outcomes. Therefore, it contributes to identifying how to combine achieving social and environmental impact with corporate financial performance.

The academy is increasingly concerned about the impact of ESG on companies (Do & Kim, 2020). In fact, most studies have found a positive and significant relationship between ESG performance and the firm value, profitability and investment behaviour of companies and financial performance (Huang, 2021). Nevertheless, it is true that studies are still highly fragmented, indicating the need for further exploration of the relationships between sustainability and corporate financial performance.

The relationship between ESG factors and firm performance has been extensively studied. However, the relationship between firms' ESG factors and their financing decisions, in particular financial constraints (and financial flexibility), has received little attention in the literature and needs to be explored further. In fact, the prior academic literature argued that ESG performance and financial constraints display a significant negative relation between them (Zhang et al., 2023; Zhang & Lucey, 2022).

Bearing all this in mind, this article is motivated by several reasons. First, the lack of scholarly attention to the relationships between ESG factors and firms' financing, considering that the transition towards more sustainable economic models requires a significant investment effort and hence, a significant flow of funds towards sustainable economic activities.

Second, we will delve into this analysis by studying the relationship between ESG and financial constraints in European companies. It is an acknowledged fact that Europe plays a key role in this transition as a strategic hub for sustainable development and is a region of the world with a growing concern for sustainability. Consequently, our findings can offer a deeper insight into how sustainability influences the European financial market. It is worth noting that several recent studies addressing the relationship between ESG factors and the financial constraints have been focused on Chinese listed companies[i] This fact reflects the special emphasis on this topic,

Policy Implications

- Encouraging ESG disclosure: Governments must continue to facilitate and encourage ESG disclosure for bioeconomy companies, which would increase the efficiency of capital allocation. Enhanced transparency in ESG practices can help reduce information asymmetry and improve access to financing.
- Promoting ESG integration: Policy makers should consider the link between ESG performance and the financial constraints to design supportive frameworks that incentivise companies to adopt sustainable practices and attract investment, thereby fostering a more flexible and sustainable financial ecosystem. This integration can help companies address global challenges and enhance their operational resilience.
- Supporting sustainable finance: Policymakers should develop frameworks that support sustainable finance initiatives. This can include mechanisms to facilitate green financing for bioeconomy companies, thereby promoting both financial stability and environmental sustainability.
- Enhancing investor awareness: Policies aimed at increasing investor awareness of the impact of ESG practices on financing constraints can help investors make more informed decisions. This can lead to greater investment in bioeconomy firms with strong ESG performance.
- Supporting young bioeconomy firms: Policymakers should provide financial support for younger bioeconomy firms. This could include grants, low-interest loans and guarantees to encourage investment in sustainable practices.
- Facilitating consumer awareness: Policymakers must design frameworks that facilitate the consumer awareness to improve the economic prospects of bio-based businesses leading to increase their customer loyalty, enhance their brand value and improve their stakeholder relations.

the growing interest and importance of China in the global economic and academic sphere, as well as the specific challenges facing the country in terms of corporate sustainability (Liang & Chen, 2024). Therefore, further research must also be conducted, especially in other regions.

Third, due to the scarcity of empirical studies in the bioeconomy (Ferraz & Pyka, 2023), this paper goes deeper into these relationships. This way, we will focus on the economic sectors that link the economic systems and the sustainable and balanced development that promote the development of innovative and environmentally friendly solutions (Aguilar et al., 2019), analysing companies belonging to the Bioeconomy. These are the companies that will lead the transition process, and therefore, it will be possible to improve knowledge to determine whether the financial resources enabling this transition are being directed towards those companies that are the pillar of sustainable development.

Finally, to make the results robust, we will apply various machine learning methodologies (logit regression, a decision tree and a rule induction algorithm) so that the results can be understood by end users (financial institutions, investors, policy makers, etc.) and address their analysis from other methodological approaches. It is worth mentioning that most studies have analysed the problem under study just by means of regressions. Therefore, another contribution of our paper is the combination of several machine learning methodologies that can achieve the generalisation of the results or give another view of them.

This article is structured as follows: Section 2 outlines the relationships between the bioeconomy, sustainability and financial constraints and their importance in the financial decision-making. Next, we present the data and the methodology used to delve into these relationships with another methodological approach. Finally, we analyse the results obtained and their main implications.

2 | THEORETICAL FRAMEWORK: BIOECONOMY, SUSTAINABILITY AND FINANCIAL CONSTRAINTS

2.1 | The 'sustainable' bioeconomy

Advancing towards sustainable development requires the involvement of business models capable of addressing the dual challenge of climate change and the increasing depletion of natural resources. One of these models may be the bioeconomy or bio-based economy (Luoma et al., 2011). However, despite the key role attributed to the bioeconomy in addressing these major challenges, there seems to be little consensus on its definition (Bugge et al., 2019), with some paradoxes arising.

The concept of bioeconomy was introduced in the 1970s when discussions about the ecological economics began with Georgescu-Roegen emphasising the need to reconcile the economics with ecology. In this sense, economics can be understood as an extension of biological evolution and subject to various interpretations and visions, linked to three types of activities (Bugge et al., 2019): the bio-technology vision, which emphasises the importance of biotechnology, for example, used by the OECD; the bio-resource vision, which focuses on the use of biological materials (approach used in the EU); and finally, the bio-ecology vision, centred on sustainability, the ecological processes and the preservation of biodiversity and ecosystems. Thus, these three visions—bio-technology, bio-resource and bio-ecology—offer different viewpoints on the bioeconomy, reflecting a blend of the technological innovation, resource utilisation and ecological sustainability.

However, these complementary interpretations are based on the utilisation of renewable resources and the integration of biotechnology within production processes (D'Amato et al., 2017). Consequently, this has led to the concept of bioeconomy being associated as a means to foster sustainable development (Sanz-Hernández et al., 2019) and with promising potential due to its significant contribution to the SDGs (Ronzon & Sanjuán, 2020).

This contribution is attributed to its 'potential' by offering solutions to environmental, social and economic grand challenges (e.g. climate change, food security, health, industrial restructuring and energy security), as well as its capacity to create value and employment opportunities in sectors such as biotechnology, bioenergy and sustainable agriculture (Mougenot & Doussoulin, 2022). This can stimulate economic growth while supporting a transition towards a more sustainable and resource-efficient economy.

The bioeconomy has garnered increasing political attention, prompting calls for the implementation of effective economic policies focused on sustainability, which facilitate the policy development. Furthermore, as bioeconomy-based strategies are being adopted by countries like Brazil, Russia, India, China, the United States and the European countries, this shift towards the bioeconomy can enhance the international cooperation, particularly in the realm of biodiplomacy. On the other hand, the bioeconomy fosters innovation and research in areas such as biorefineries, biomass utilisation and biotechnology (McCormick & Kautto, 2013).

Despite all the possibilities offered, the bioeconomy is not per se sustainable (Gawel et al., 2019) and requires special attention from policymakers, practitioners and academics. Regarding the first issue, there is a paradoxical situation where the sustainability aspect of the bioeconomy receives limited attention from policymakers despite its potential positive impacts. The integration of sustainability aspects in bioeconomy

policies is weak, even though academics often question the sustainability effects of the bioeconomy (Bugge et al., 2019).

As for the second issue, there is limited insight into sustainability as historical bioeconomy studies do not provide sufficient information to assess the sustainability of the bioeconomy, lacking a holistic view and neglecting important sustainability aspects (Talwar & Holden, 2022). While technological aspects linked to the bioeconomy have been more studied, the theoretical and empirical research from social sciences analysing the social impact, economic quantification or political developments are scarce and several studies have pointed out the need to broaden and deepen this knowledge (Bugge et al., 2019; Ferraz & Pyka, 2023; Wesseler & von Braun, 2017), on issues related to the contribution of the bioeconomy to rural development, increasing the quality of life, consumer behaviour or policy cooperation, among others.

One way to assess the sustainability of the bioeconomy is through the development of ESG policies and strategies. In this research, we will seek to combine both elements, thereby contributing to reducing the previously mentioned gap. Additionally, we will do so in a novel manner by analysing the relationship between sustainability and the financial constraints faced by these types of companies. It should be noted the obstacles hindering the bioeconomy (Guo & Song, 2019) related to inputs and production processes such as the lack of cheap and sustainable raw materials, inefficient technologies, scarcity of alternatives to petroleum-derived products, uncertainty surrounding the bioenergy and bioproducts market, insufficient societal readiness for the adoption of biofuels and bioproducts. These obstacles, together with the lack of consistency in bioeconomy policies from a financial standpoint, pose significant challenges.

These financial challenges are related to several key elements (European Regional Development Fund, 2021; Leoussis & Brzezicka, 2017): (i) the bioeconomy requires substantial, high-risk capital investment in infrastructure and facilities, particularly within a risk-averse financial landscape; (ii) the market and demand risks rank as the highest business risk factor for investments in the bioeconomy; (iii) the operational and technological risks related to the lack of developed markets and insufficient demand for products, largely affected by regulation; (iv) the high financial risks primarily refer to the risks that bioeconomy-related activities show low or volatile profitability and the cash flow generation, driven by volatilities in the volumes and prices of inputs/raw materials as well as outputs/products; (v) finally, the long period required to recover the investment as well as difficulties in accessing private financing.

Thus, the analysis of these financial constraints and obstacles can contribute to implementing and expanding the sustainable bioeconomy.

2.2 | ESG and financial constraints

At present, there has been a growing interest among companies in integrating the ESG considerations into their business management. The incorporation of these elements into business decisions has led to an increase in research on relationships between the ESG factors and economic-financial performance, generally finding a positive and significant relationship. Theoretical foundations such as institutional theory, stakeholder theory, agency theory and signal transmission theory support these results (Chen et al., 2023; Chouaibi et al., 2022).

From these perspectives, it is explained how companies with high ESG ratings often attract more investment and can be a key to creating long-term value by addressing the sustainability challenges, attracting socially conscious investors and improving operational efficiency. Additionally, ESG practices can contribute to improving financial performance by reducing the agency costs and strengthening the corporate governance.

The institutional theory posits that firms aligning with societal norms and expectations regarding ESG factors are more likely to gain legitimacy, trust and support from stakeholders, ultimately leading to enhance the financial performance. According to stakeholder theory and signal transmission theory, the firms that incorporate ESG factors tend to create value for all stakeholders, including investors, employees, customers and society at large. Stakeholder theory argues that minimising the agency costs acts as a value-enhancing mechanism. This value creation can positively impact the financial performance as ESG efforts help to eliminate the information asymmetry thereby, enhancing corporate reputation and increasing investor confidence. Furthermore, according to stakeholder theory and signal transmission theory, the more stakeholders value a company's ESG during a crisis, the more important it becomes to them (Whelan et al., 2021). In fact, the research results indicate that companies with good ESG performance are more resilient in crises (Gao & Geng, 2024).

Despite the increasing number of studies that show these relationships, the study of sustainability (assessed by ESG criteria) and financial constraints (understood as the difficulty of companies in accessing external funding), has been more limited (Chen, 2016). However, we consider this issue to be of vital importance for sustainable development, especially in an environment of imperfect financial markets where there are frictions for companies to obtain capital (Lamont et al., 2001).

The financial constraints of a company in general, and those belonging to the bioeconomy in particular, can affect its ability to implement ESG policies as it often requires significant investments in technology,

infrastructure, human resources and production processes. If a company faces severe financial constraints, it may have difficulty in allocating resources to these initiatives and prioritise the short-term activities over the long-term goals. Moreover, if companies adopt ESG strategies precisely to improve their long-term financial performance, it can also affect their ability to raise funds and the conditions under which they do so by reducing the cost of capital, financing risk or credit rating, or the cost of equity (Gao & Geng, 2024; Hao & Wu, 2024).

The different studies have used various measures of the degree of financial constraints (usually indices), as these are not directly observable, without reaching a consensus on which one best reflects the company constraints (Farre-Mensa & Ljungqvist, 2016). Table 1 summarises the main approaches to measure financial constraints (Miranda-Garcia et al., 2019).

The asymmetric information between investors and companies and the agency conflicts are among the main causes of financial constraints, thus leading to a situation where a higher degree of asymmetric information generates greater difficulties in accessing financing (Zhang et al., 2023). Such limitations can manifest as credit constraints, inability to obtain loans, incapacity to issue equity, reliance on bank loans or lack of asset liquidity (Lamont et al., 2001). Therefore, the factors that reduce market imperfections would ultimately decrease the likelihood of financial constraints. One of these mechanisms for mitigating market frictions is precisely the ESG policies implemented by companies

TABLE 1 Models of financial constraints.

Study	Model	Variables
Kaplan & Zingales, 1997 (first approach). Lamont et al. (2001) (index creation).	*KZ index* KZ Index = −1.001909 × CF/K + 0.2826389 × Q + 3.139193 × D/TotCap + −39.3678 x Div/ K + −1.314759 × Cash/K	K: property, plant and equipment (year-1) CF: the cash flow variable Q: is the Tobin's Q D: the debt variable TotCap: the total capital (sum of debt plus stockholders' equity) Div: dividends Cash: is the cash (cash plus short-term investments).
Whited and Wu (2006)	*WW index* WW index = −0.091CF − 0.062DIVPOS + 0.021 × TLTD − 0.044 × LNTA +0.102 × ISG − 0.035 × SG	TLTD: ratio of the long-term debt to total assets DIVPOS: an indicator that takes the value of one if the firm pays cash dividends and zero otherwise SG: firm sales growth LNTA: the natural log of total assets ISG: the firm's three-digit industry sales growth CASH: the ratio of liquid assets to total assets CF: the ratio of cash flow to total assets
Musso and Schiavo (2008) (Bellone et al.'s, 2010 contributions are based on this method)		Size (total assets) Profitability (return on total assets) Liquidity (current asset over current liabilities) Cash flow generating ability Solvency (own funds over total liabilities) Trade credit over total assets Repaying ability (financial debt over cash flow)
Hadlock and Pierce (2010)	*Size-age (SA) methodology*: SA index = −0.737 × $Size + 0.034 × $Size^2 − 0.040 × $Age	Size (natural log of total assets) Age: firm's age
Stiebale (2011)		Liquidity ratio Leverage Short-term Leverage Coverage Ratio Cash-flow ratio Size Productivity Total factor productivity Reports intangible assets (yes/no) Intangible assets Tangible fixed assets Export sales/total sales Number of employees Value added per employee Sales per employee Personal costs per employee

Source: Own elaboration.

and their disclosure (Garcia-Sanchez et al., 2019; Li et al., 2023; Samet et al., 2018). Several studies have explored the relationship between ESG performance and financial constraints, mostly arguing that ESG performance and financial constraints display a significant negative relation. Evidence suggests that a higher ESG rating relates to lower asymmetric information and agency conflicts (Banerjee et al., 2020; Li et al., 2023; Samet et al., 2018; Xiaoyu, 2023; Zhang et al., 2023).

The importance of ESG on financial constraints is based on several theories and empirical findings in the field of corporate finance and sustainability. These ESG activities and their disclosure can enhance the assessment of a company's strengths and risk management, assisting investors in a better evaluating and, thus, facilitating financing, which would alleviate financial constraints (Banerjee et al., 2020). By enhancing transparency through ESG disclosure, the companies can reduce information asymmetry, leading to improve relationships, to strengthen trust with investors and to access to capital what would reduce the financial constraints (Xiaoyu, 2023). A strong ESG performance can be a signal for the shareholders that the management is acting in the best interests of the company, thereby reducing the agency costs and potentially lowering financing constraints (Raimo et al., 2021).

Furthermore, in the third-party ESG evaluations where the company does not intervene during the assessment, there is greater credibility of its information. Thus, the promotion of the ESG development of the companies helps to improve the information disclosure, increase the operational efficiency and reduce the financial limitations (Gu et al., 2020).

By integrating these theoretical perspectives, this research aims to contribute to the existing literature by examining the interaction between ESG activities, the financial constraints and the firm performance in the European market context. Consequently, it contributes to a deeper understanding of the relationship between sustainability practices and financial outcomes and ultimately to their value-creation processes.

3 | METHODOLOGY

3.1 | Data

We have used data from European listed firms in 2022. Despite the lack of consensus on which economic sectors belong to the bioeconomy (Pender et al., 2024), this research aims to employ a broad approach that encompasses a representation from the primary, secondary and tertiary sectors (Kuosmanen et al., 2020). The primary bio-based production sector involves interactions with biological processes of nature; the secondary bio-based production sector entails the manufacturing of goods using bio-based raw materials in the production process or as ingredients of final products, such as bio-based industries; and the tertiary bio-based production sector involves further refining manufactured bio-based products or services to facilitate the final consumption of bio-based goods.

Thus, utilising the EIKON REFINITIV database, a search for companies was conducted using the Refinitiv Business Classification TRBC Activity Description. This code classifies companies with increasing granularity by Economics Sector, Business Sector, Industry Group, Industry and Activity, resulting in the following sectors:

- Agricultural Biotechnology.
- Bio Diagnostics & Testing.
- Bio Medical Devices.
- Bio Therapeutic Drugs.
- Biodiesel.
- Biomass & Waste to Energy Electric Utilities.
- Biopharmaceuticals.
- Biotechnology & Medical Research (NEC).
- Industrial Biotechnology Chemicals.
- Environmental R&D Services & Biotechnology.

Consequently, an intersectoral analysis is conducted to assess the impact of ESG factors, following the bioeconomy policies adopted in Europe (European Commission, 2022), resulting initially in 227 listed companies from Belgium, Denmark, Finland, France, Germany, Republic of Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Spain, Sweden, Switzerland and the United Kingdom. The process of selection and cleaning of the selected variables has led that the final dataset consisting of 146 companies from Belgium, Denmark, Finland, France, Germany, Republic of Ireland, Italy, Netherlands, Norway, Poland, Spain, Sweden, Switzerland and the United Kingdom, with representation from all the aforementioned sectors.

It is worth noting that 10 EU Member States plus Norway have developed national bioeconomy strategies to date, including Finland, Germany, France and Spain, while seven others are in the development phase, including Sweden, Poland and Switzerland (European Commission, 2022).

3.2 | Variables

3.2.1 | Dependent variable

Among all the indices explained in the literature review, we have used the KZ index. This index was proposed by Kaplan and Zingales (1997) implemented by Lamont et al. (2001). Their model is as follows:

$$\text{KZ index} = -1.002 \times \left(\frac{CashFlows}{K_{-1}}\right) + 0.283 \times Q + 3.139 \times \left(\frac{Debt}{CapitaL}\right) - 39.368 \times \left(\frac{Dividends}{K_{-1}}\right) - 1.315 \times \left(\frac{Cash}{K_{-1}}\right)$$

where Q represents Tobin's Q and K represents the property, plant and equipment (year-1).

This measure is one of the most widely used from its formulation to the present day (e.g. Chen & Xie, 2022; Hao & Wu, 2024). The KZ index indicates that a higher score on the index represents a higher level of constraints. To further examine the association between financial constraints and ESG performance, we have created two dummy variables for two constraint thresholds: above 20% and 33% of the KZ score. Therefore, the 20% firms for the first dummy variable on the top are classified as constrained and the rest as non-constrained, while in the other case, the 33% firms on the top are classified as constrained and the rest as non-constrained.

The use of the 20% and 33% thresholds to classify financially constrained firms using the Kaplan–Zingales (KZ) index is well supported in the academic literature. Originally, in the paper that provides the background for the KZ-index (Kaplan & Zingales, 1997), the companies are classified into five groups, defining the more financially constrained firms as those that fall around the top 20% of the KZ index. This threshold has been used in research on various aspects of corporate finance, such as the relationship between financial constraints and corporate social responsibility, investment behaviour and financial policies (Baker et al., 2003; Chen et al., 2007; Chen & Wang, 2012; Chang et al., 2017). Later, Lamont et al. (2001) developed the KZ index in its current formulation, classifying the most financially constrained firms as those in the top tercile while the remaining firms are classified as medium constrained and non-financially constrained. Therefore, the consistent application of the 20% and 33% thresholds across studies demonstrates their validity and usefulness in distinguishing constrained from unconstrained firms.

Consequently, the dependent variable is the KZ index and represents a dichotomous status of the firms (1—constrained or 0—non-constrained). The number of constrained firms is 29 and non-constrained 116 when the threshold is 20% and, when the threshold is situated at 33% the constrained firms are 48 and the non-constrained are 97. As can be seen, the dataset is unbalanced. This fact could introduce certain limitations to the model and may affect the reliability of the statistical tests performed on this dataset. These include the bias in the classification towards the majority class which may make it difficult to identify the minority class, the difficulty in generalising the model to new data which may lead to poor generalisation in unseen data situations or the decreased reliability of statistical tests (Chawla, 2010). To deal with these limitations and improve the reliability of the model, there are several strategies that can be considered. A first strategy would be to rebalance the data using resampling techniques that mitigate the model's bias towards the majority class and improve the model's ability to capture patterns in the minority class. Another possibility is to specify weights for each class that would compensate for class imbalance during model training. These weights assign greater importance to the minority class during the model optimisation process. Finally, another possibility is to evaluate the model with appropriate metrics. Thus, instead of evaluating the model just with the accuracy, it is necessary to evaluate the model performance using metrics that consider the class imbalance such as sensitivity (Se), specificity (Sp), the area under the receiver operating characteristic (ROC) curve, among others (He & Garcia, 2009). Therefore, in the results section, given that we have the population of European listed bioeconomy companies, we have included the evaluation of the models according to different metrics (see Table 4).

3.2.2 | Independent and control variables

The independent variables involve either qualitative or quantitative attributes. The list of the independent variables is shown in Table 2.

We have introduced the ESG performance in two ways. The first relevant information is whether the company provides a sustainability report or not. So, it is a dummy variable, 0—no disclosure and 1 for the rest (Zhongfei & Guanxia, 2022). In our dataset, there are 87 companies that do not report on ESG issues and 58 that do. On the other hand, this paper selects the ESG score which is an overall company score based on the self-reported information in the environmental, social and corporate governance pillars reported by Refinitiv EIKON (Demers et al., 2021). The rating can take 12 values and ranges from A+ (highest rating) to D– (lowest rating). There are five companies with an A rating (grouping the three modalities), 14 with a B rating, 24 with a C rating and 15 with a D rating.

Among the firm's characteristics, the firm's age and size are selected to control for differences in firm establishment and size. The literature shows that older and larger firms have more experience about survival, hold a larger market share and have greater financing ability what involves an important impact on financing constraints reduction (Kong, 2023).

On the other hand, according to the most classical studies, the profitability, the liquidity, the leverage and the efficiency ratios are the most used to describe the economic-financial situation of a firm. We have followed this approach to select the rest of the variables.

TABLE 2 Independent variables.

ID	Variables	Definition	Research
ESG_disclo ESG_DISC	Environmental, social and governance sustainability	ESG_disclo. Dummy variable, 0 no disclosure and 1 disclosure about ESG issues ESG_DISC. ESG Score reported by EIKON (0-no report-, A+, A, A–, B+, B, B–, C+, C, C–, D+, D, D–)	Garcia-Sanchez et al. (2019); Gu et al. (2020); Do and Kim (2020); Zhang and Lucey (2022); Zhongfei and Guanxia (2022); Chen and Xie (2022); Li et al. (2023); Hao and Wu (2024); Liang and Chen (2024)
Control variables			
AGE	Age	The number of years since its initial public offering	Hadlock and Pierce (2010); Liu and Cao (2015); Farre-Mensa and Ljungqvist (2016); Bolin and Rana (2021); Kong (2023)
LNTA	Size	Firm size, the natural logarithm of the firm's total assets at the end of the year.	Whited and Wu (2006); Hadlock and Pierce (2010); Samet et al. (2018); Kong (2023)
CURRENT	Current ratio	Current assets/current liability	Chen (2016); Garcia-Sanchez et al. (2019): Demers et al. (2021); Li et al., 2023; Liang and Chen (2024); Gao and Geng (2024); Hao and Wu (2024).
DEBT_EQUITY	Indebtedness	Total liabilities/total equity	Stiebale (2011); Chen (2016); Demers et al. (2021); Bai et al. (2022); Samet et al. (2018); Gao and Geng (2024); Kong (2023); Li et al. (2023); Hao and Wu (2024).
DEBT_ CAPITAL	Solvency ratio	Total liabilities/Total assets	Whited and Wu (2006); Samet et al. (2018); Chen and Xie (2022); Li et al. (2023); Kong, W. (2023); Hao and Wu (2024)
ROA	Return on assets	Net profit/Total assets	Liu and Cao (2015); Farre-Mensa and Ljungqvist (2016); Chan et al. (2017); Samet et al. (2018); Gu et al. (2020); Huang (2021); Zhang et al. (2023); Chen et al. (2023); Kong (2023); Hao and Wu (2024)
ROE	Return on equity	Net profit/Total equity	Liu and Cao (2015); Chan et al. (2017); Gu et al. (2020); Do and Kim (2020); Huang (2021); Zhang et al. (2023); Chen et al. (2023); Kong (2023); Hao and Wu (2024)
SALES	Sales growth	Sales t –sales t-1/sales t-1	Kong (2023); Bai et al. (2022); Liu and Cao (2015): Whited and Wu (2006)

Source: Own elaboration.

This way, the current ratio shows the firm's performance from the perspective of inflow and outflow of funds (so, a higher value can indicate that the firm is facing fewer financial difficulties). The indebtedness and solvency ratios show that companies with low financial constraints may have better loan positions and it may be easier for them to get funds. Regarding profitability (ROA-ROE), the positive values imply a better performance that involves a significant impact on its financing needs and on financing constraints. Finally, sales growth reflects a firm's growth potential in the market and is positive when the firm gains market share. It is a key variable for investors and has an important impact on financing constraints. (Zhang et al., 2023: Kong, 2023; Bai et al., 2022; Liu & Cao, 2015). Summary statistics for the control variables are provided in Table 3.

3.3 | Machine learning techniques

To develop the empirical analyses, we have carried out three models implementing different well-known machine learning techniques: A logistic regression model, a decision tree (specifically, C4.5) and a rule induction algorithm (in particular, the PART). All the selected methods have demonstrated their good performance for solving classification problems as well as their explicative nature (e.g. Golbayani et al., 2020; Muñoz-Izquierdo et al., 2022). The statistical methods have been the most widely used for the problem we face (e.g. Hao & Wu, 2024: Xiaoyu, 2023). Therefore, we have introduced a new factor in the prediction model of financial constraints considering the ESG variable: the use of a statistical technique (logistic regression) together with two artificial intelligence methods (C4.5

TABLE 3 Statistics for the control variables.

	Minimum	Maximum	Mean	Standard deviation
LNTA	14.21	23.72	18.23	2.04
AGE	1.27	118.84	12.31	11.73
CURRENT	0.1	68.03	4.69	6.43
DEBT_EQUITY	0	17.42	0.63	1.816
DEBT_CAPITAL	0	1.24	0.21	0.25
ROA	–1.73	0.46	–0.33	0.40
ROE	–13.63	0.65	–0.78	1.57
SALES	–1	18.44	0.89	2.55

Source: own elaboration.

TABLE 4 Summary of the metrics.

Model	Metric	KZ-20	KZ-33
C4.5	Sp	0.82	0.82
	Se	0.83	0.82
	Acc	83.45%	82.07%
	AUC	0.62	0.80
PART	Sp	0.82	0.79
	Se	0.83	0.79
	Acc	83.45%	78.62%
	AUC	0.61	0.80
Logistic regression	Sp	0.83	0.81
	Se	0.92	0.87
	Acc	91.03%	85.52%
	AUC	0.92	0.91

Source: Own elaboration.

and PART). With the combination of several machine learning methodologies, we can achieve two things: on the one hand, to give robustness to the results (the generalisation of the results) and, on the other hand, to see the most relevant variables in the prediction of financial constraints.

To evaluate the performance of the different models and to compare them, we will use a well-known measure, the area under the ROC curve (AUC—the maximum accuracy would correspond to an AUC value closer to 1). Additionally, we analysed the performance using three metrics: accuracy (Acc), specificity (Sp) and sensitivity (Se) These measures can be obtained from the confusion matrix, in which the diagonal represents the correctly classified examples and the off-diagonal represents the classification errors. The accuracy is the rate of correctly classified observations. The specificity and the sensitivity identify the two possible error types in a binary classification problem: type I errors and type II errors. A type I error is associated with the specificity of the model (Type I error = 1 – Sp). A higher Sp indicates a lower probability of type I misclassifications. In contrast, a type II error is related to the sensitivity (Se) of the model (Type II error = 1 – Se). A higher Se implies a lower probability of type II misclassifications (Drzewiecki, 2017; Gu et al., 2009; Lukason et al., 2021).

We must mention that, unlike statistical techniques, the other two methods may suffer from the overfitting problem. To avoid it, k-fold cross-validation is applied. This validation implies that the dataset is divided into k subsamples (10 in this paper) so that k-1 are used to estimate the model and the remaining one is the test subsample, while the process is repeated k times. The result of the model will be averaged over the different k-folds.

Due to the well-known nature of these methods, we will provide just a brief overview of them. The logistic regression has become a widely used statistical technique and accepted method of analysing binary classification problems due to its flexibility. A logistic regression model is developed using as dependent variables the dichotomous status of the firms (1—constrained or 0—non-constrained), whereas the independent variables involve either qualitative or quantitative variables. The general equation is based on a conditional probability (i.e., the probability of *y*-occurrence known the values of *x*-variables) and the constant term and the regression coefficients for the independent variables are developed by the model (Kosmidou et al., 2006).

C4.5 is probably the most popular of all decision tree algorithms. It was developed by Quinlan (1993) and the criterion used to make the partitions is based on several Information Theory concepts and has introduced various improvements over time. Unlike the regression, in which we can only identify the causes that explain the financial constraints, a decision tree contributes more to the interpretation of the results as it shows the financial constraint processes, that is, the ways or 'paths' that cause the financial constraints. After the decision tree is 'pruned' (all branches of specific cases are eliminated as the results cannot be generalised), the C4.5 obtains a simple, accurate and robust tree that shows (in the form of 'branches') the most common causes of financial constraints in the sample (Diaz-Martinez et al., 2011).

Finally, the PART algorithm is a rule induction classifier developed by Frank and Witten (1998). This algorithm builds partial decision trees and then, the tree-building stops generating a rule that represents the greatest number of situations. Since it is based on partial decision trees, the main advantage of this algorithm is its simplicity without losing accuracy. The results are easier to interpret when compared to other classifiers as the rules are expressed in logical statements with the following form: IF < conditions are fulfilled > THEN < the object belongs to a given decision class >. In our paper, the objects are the bioeconomy firms, the two decision classes were constrained and non-constrained, and the conditions are the independent variables.

Of the three methods, logistic regression is an explanatory analysis technique. Although decision trees and rule-inducing algorithms are not inherently designed to provide an explicit understanding of causal relationships between variables, they can provide valuable information in an explanatory context due to its interpretable nature. Some ways to conduct an explanatory analysis using decision trees and rule induction algorithms are the following. First, the analysis of important features: decision trees and rule induction algorithms can reveal which features are the most important for prediction; so, by examining the tree or the generated rules, it is possible to identify which variables have the greatest impact on classification or prediction. This can provide insights into which explanatory variables are most relevant in the model. Second, the analysis of the results (the tree and the rules): Both methods are easily interpretable, and their results can be examined to understand how the variables interact with each other and contribute to classification or prediction, so they can provide information on the complex relationships between the variables and the target variable. Third, the hypothesis validation: although decision trees and rule induction algorithms do not conduct hypothesis testing as parametric models do, hypotheses can still be informally validated by examining the consistency of the generated rules with respect to a theory or a domain knowledge (Hastie et al., 2009; Kuhn & Johnson, 2013; Witten et al., 2005).

4 | RESULTS AND DISCUSSION

We have used the firm dataset described in Section 3.1 to apply the proposed machine learning techniques. Our main results are presented in Table 5 for the 20% KZ index threshold and in Table 6 for the 33%. To interpret the models, the first step is to test their suitability. In our case, the accuracy (percentage of correct classifications) is around 84% on average (with a maximum of 91% for the logistic regression KZ-20 and a minimum of 78% for the PART KZ-33), so these levels are quite high. Regarding the AUC value, their values show a good performance except for the KZ-20 index C4.5 and PART models which show acceptable values. Finally, in terms of specificity and sensitivity, the models show good results with these metrics at 80% or above. In fact, for the KZ-20 threshold, logistic regression exhibits significantly superior performance across all metrics. For the KZ-33 threshold, although logistic regression remains superior, the performance difference is smaller compared to the KZ-20 threshold. As we have noted previously, these differences may be due to the fact that increasing the threshold value to 33% incorporates into the classification of constrained companies certain firms that present moderate financial constraints, making the characterisation of the truly financially constrained companies less precise.

Therefore, the C4.5 and PART models have comparable sensitivity and specificity, but logistic regression excels in terms of accuracy, sensitivity and AUC values demonstrating. A superior ability to identify patterns both constrained and unconstrained companies. So, although all models show good overall performance, logistic regression stands out as the most effective technique for predicting financial constraints in our bioeconomy companies' dataset, particularly when high precision and discrimination capability are required.

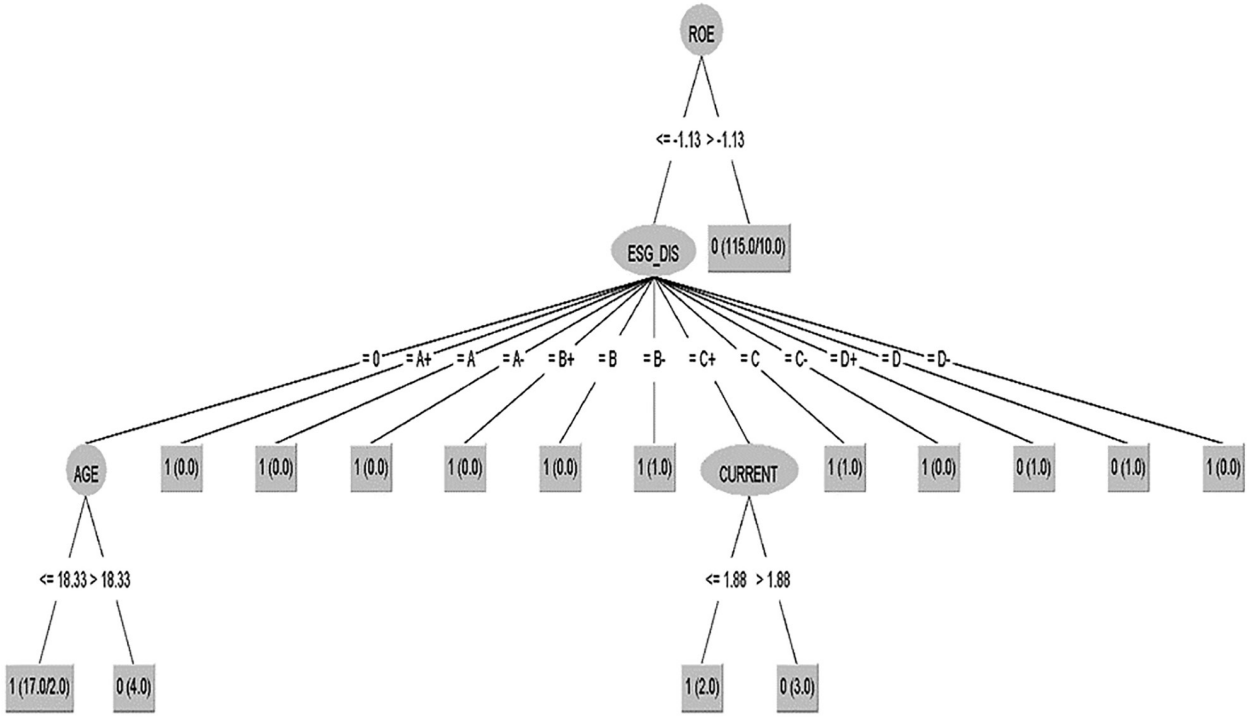
First, we will analyse the results for the C4. 5 decision tree and PART algorithm for both levels, 20 and 33 (Tables 5 and 6, panels A and B).

The KZ-20 tree (Table 5, panel A) is presented in a tree-shaped figure with 16 leaves using the variables ROE (return on equity), ESG_DISC (disclosure of environmental, social and governance performance) and AGE (company age) (see also Table 7). The results show that the main indicator for classifying bioeconomy firms is the profitability by means of ROE indicator. The cut-off point is –1.13 (very close to 0, and from this point onwards, positive profitability values). Thus, all firms with a value above this cut-off point are financially unconstrained firms. This branch is verified by 115 companies (with 10 errors). Given that there are 116 unconstrained firms in the dataset, 90% of unconstrained firms would be characterised by this branch. This branch underscores the importance of profitability in a company's financial health. On the other hand, to identify financially constrained companies, not only the ROE is needed but also the sustainability score. Thus, the most relevant branch of the tree shows that if the company does not report sustainability information and its age is less than 18 years, the company is financially constrained. This branch of the tree is verified by 17 companies (with two errors) which represents 52% of constrained firms.

The KZ-20 PART algorithm (Table 5, Panel B) generates three rules to explain the constrained index. The rules are like the branches obtained using the C4.5 decision tree, complementing the evidence from this initial technique. The evidence provided by this algorithm

TABLE 5 Models C4.5, PART and logistic regression KZ 20%.

Panel A. Decision tree results: C4.5



Number of leaves: 16

Panel B. PART results: PART decision list

ROE > –1.13: 0 (115.0/10.0)

ESG_DIS = 0 AND AGE < = 18.33: 1 (17.0/2.0)

DEBT_EQUITY < = 4.27: 0 (10.0/1.0)

Number of rules: 3

Panel C logistic regression results: Logistic coefficients of the function

	b	*s.e.*	*p-value*	*Exp(b)*
Intercept	96.558	4.58	0.035*	15,611.65
ESG	0.1145	0.04	0.007*	1.12
ESG_disclo	−4358	2.06	0.034*	0.01
LNTA	−0.722	0.29	0.011*	0.49
AGE	−0.081	0.06	0.181	0.92
CURRENT	−0.019	0.11	0.870	0.98
DEBT_EQUITY	14.793	0.58	0.011*	4.39
DEBT_CAPITAL	26.771	1.75	0.126	14.54
ROA	−3808	1.12	0.001*	0.02
ROE	0.7422	0.38	0.054	2.10
SALES	−0.323	0.24	0.173	0.72

Note: *R*-squared Cox-Snell: 0.384; *R*-squared Nagelkerke: 0.608; χ^2: 70.315; *p*-value: 0.000.

Abbreviations: b, coefficient; exp(b), exponential of b; s.e., standard error.

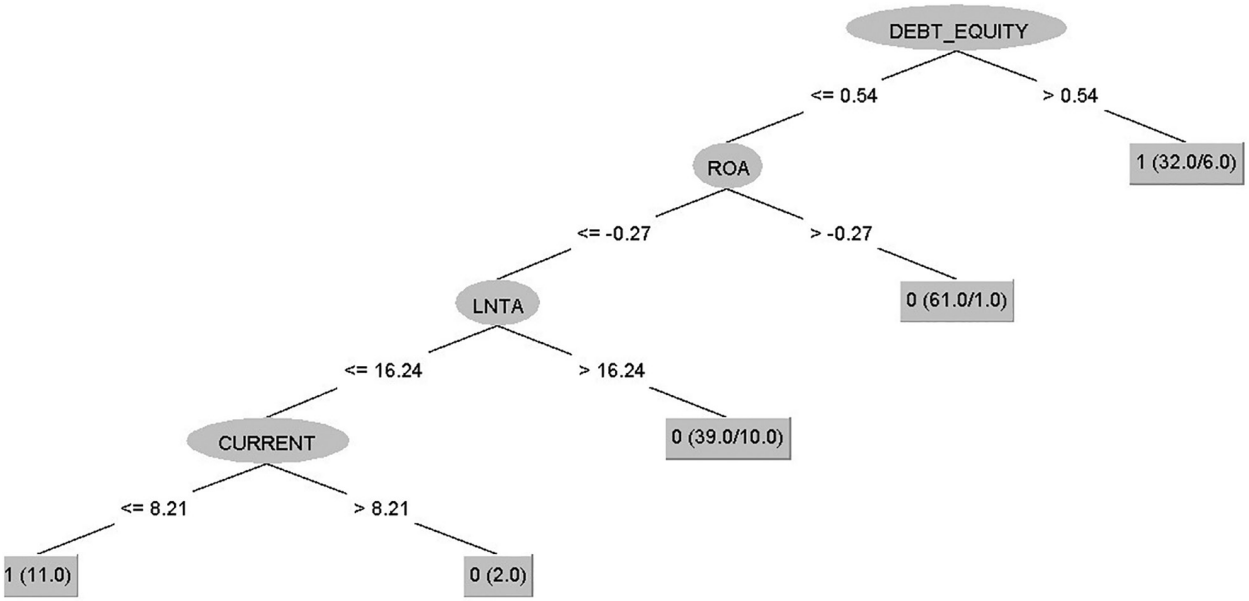
*Denote statistical significance at the 5%.

Source: Own elaboration.

suggests that the most important variable to classify unconstrained firms is ROE, establishing that all companies with a profitability above –1.13 are unconstrained. This rule is verified by 115 companies (with two errors) which represents 90% of unconstrained firms would be characterised by this rule. For constrained firms, the

TABLE 6 Models C4.5, PART and logistic regression KZ 33%.

Panel A. Decision tree results: C4.5



Number of leaves: 5

Panel B. PART results: PART decision list

DEBT_EQUITY < = 0.54 AND ROA > −0.27: 0 (61.0/1.0)

DEBT_EQUITY < = 0.04 AND AGE >5.35: 0 (14.0)

CURRENT < = 1.92: 1 (30.0/3.0)

Number of rules: 3

Panel C logistic regression results: Logistic coefficients of the function

	b	*s.e.*	*p*-value	*Exp(b)*
Intercept	7.6148	3.69	0.039*	2027.98
ESG	0.0289	0.02	0.239	1.03
ESG_disclo	−0.259	0.95	0.785	0.77
LNTA	−0.54	0.22	0.013*	0.58
AGE	−0.007	0.03	0.774	0.99
CURRENT	−0.3	0.13	0.019*	0.74
DEBT_EQUITY	2.2409	0.73	0.002*	9.40
DEBT_CAPITAL	2.2438	1.71	0.190	9.43
ROA	−4.43	1.13	0.000*	0.01
ROE	1.2709	0.41	0.002*	3.56
SALES	−0.075	0.18	0.670	0.93

Note: *R*-squared Cox-Snell: 0.434; *R*-squared Nagelkerke: 0.603.

χ^2: 82.510; *p*-value: 0.000.

Abbreviations: b, coefficient; exp(b), exponential of b; s.e., standard error.

*Denote statistical significance at the 5%.

Source: Own elaboration.

rule points out that the ESG variable takes a value of zero, that is, they do not report on sustainability issues, and, in addition, their age is less than 18 years (verified by 17 companies with two errors, 52% of constrained firms).

So, we can conclude that for the KZ-20 threshold, both methodologies show that the disclosure of ESG information and ESG ratings have an important impact on financial constraints, highlighting the relevance of sustainability and transparency in improving access to

TABLE 7 Summary of variables in the models.

	KZ 20%			KZ 33%			
MODEL	C4.5	PART.	Log. Reg.	C4.5	PART	Log. Reg.	Count
ESG			✓				1
ESG_disclo	✓	✓	✓				3
LNTA			✓	✓		✓	3
AGE	✓	✓			✓		3
CURRENT					✓	✓	2
DEBT_EQUITY			✓	✓	✓	✓	4
DEBT_CAPITAL							0
ROA			✓	✓	✓	✓	4
ROE	✓	✓				✓	3
SALES							0

Source: Own elaboration.

financing. Consequently, the firms that optimise these factors can improve their access to financing and their financial stability. Business policies and strategies should align to promote sustainable practices and enhance transparency, thereby supporting growth and resilience in the bioeconomy sector.

As for the KZ-33 tree (Table 6, panel A), the decision tree shows five leaves that use the following variables (see also Table 7): DEBT_EQUITY, ROA and LNTA (natural logarithm of total assets). The main indicator for classifying bioeconomy firms is the indebtedness (DEBT_EQUITY). The cut-off point is 0.54. Thus, all firms with a value above this cut-off point are financially constrained firms. This branch is verified by 32 companies (with 6 errors). Given that there are 47 unconstrained firms, 56% of constrained firms would be characterised by this branch. On the other hand, to identify financially unconstrained companies, not only the indebtedness (values lower than 0.54) is needed, but also the ROA (cut-off point above −0.27) and the size (for companies with ROA values lower than −0.27), measured through assets, LNTA (cut-off point above 16.24). Nearly 92% of unconstrained firms can be characterised using this pattern. Regarding the KZ-33 PART algorithms, the main indicator for classifying unconstrained bioeconomy firms is the indebtedness (DEBT_EQUITY) with values above 0.54 and the ROA, with values above −0.27 (very close to 0, and from this point onwards, positive profitability values). This pattern is verified by 62% of firms. On the contrary, the most relevant variable to characterise constrained firms is the CURRENT ratio with a cut-off point lower than 1.92. This pattern characterises the 63% of these firms.

The PART and C4.5 results are very interesting because we have patterns for both constrained and unconstrained firms even if the dataset is unbalanced for the two KZ thresholds.

Regarding the KZ-20, the results from the C4.5 decision tree and the PART algorithm are consistent in key aspects, particularly in the importance of ROE and the combination of ESG disclosure with the company age (AGE). These models show the need to improve profitability, promote transparency in ESG disclosure and adequately manage the debt to reduce financial constraints, as well as the importance of company age.

Thus, these two methodologies highlight the first relevant finding in this research: the differentiating factor between biofirms with and without financial constraints is ROE (Chan et al., 2017). So, in line with other research, return on equity (ROE) can affect these constraints in several ways. A strong ROE can positively influence a company's financial situation by increasing profitability, improving access to external finance, managing the risk effectively and providing a competitive advantage. However, it is worth noting that in our dataset the ROE cut-off value is close to 0, which seems to indicate that the external investors have confidence in this type of companies without the need that their financial results were not very significant yet. In other words, they find their potential attractive, which in turn translates into less financial constraints as access to external capital increases. Huang (2021) shows a significant positive relationship between ROE and reduced financial constraints, which is consistent with the findings of this study. Farre-Mensa and Ljungqvist (2016) also found that firms with higher levels of profitability face fewer financial constraints, supporting the importance of ROE. A second result offers us possible lines of action. That is, the evidence that bio companies with financial restrictions not only have insufficient financial profitability but also do not disclose information on ESG activities and are companies that, despite having a certain track record in the financial markets (<18 years since their first initial public offering), have difficulties in accessing external funds. Therefore, it is highlighted that for bio companies without financial constraints, regardless of their ESG rating, disclosing

their ESG activities leads to attracting certain positive signals from the market. Chen and Xie (2022) find that ESG disclosure significantly reduces financial constraints, aligning with the results of this study. Garcia-Sanchez et al. (2019) indicate that transparency in ESG information improves access to financing, thereby reducing financial constraints. This aligns with Zhang and Lucey (2022) and Hao and Wu (2024), who also found a negative relationship between ESG performance and financial constraints, suggesting that good ESG practices help mitigate financing difficulties. The results linking company age to financial constraints have also been consistent, with previous research such as Kong (2023) indicating that younger companies tend to face more financial difficulties due to their shorter track record and experience, and Liu and Cao (2015) who also found that company age is a relevant factor in determining financial constraints.

In the case of increasing the threshold value of the KZ index to 33%, we have found the indebtedness (DEBT_EQUITY) to be a crucial factor in determining financial constraints. Additionally, the Profitability (ROA), is a relevant predictor of financial constraints in both models, as well as size (LNTA) and liquidity management (CURRENT). Consequently, proper debt management, improving profitability, strategies for company size growth and optimising liquidity are key strategies that can help companies overcome financial barriers and ensure continuous and efficient access to financing. In fact, Whited and Wu (2006) in their research conclude that high levels of debt increase financial constraints due to the higher perceived risk by lenders and investors. Moreover, Bai et al. (2022) also find a negative relationship between high debt and ease of access to financing. Additionally, the findings of Huang (2021) and Farre-Mensa and Ljungqvist (2016) support the importance of the profitability as a key factor in improving access to financing. Regarding the other two factors, the studies of Liu and Cao (2015) and Kong (2023) validate the importance of company size in improving access to financing and Li et al. (2023) and Garcia-Sanchez et al. (2019) confirm that maintaining a healthy current ratio is essential to avoid financial constraints. These conclusions and recommendations are consistent with existing literature and provide clear guidance for improving the financial health of companies in this crucial sector for sustainable development.

On the other hand, these methodologies can be complemented by approaches such as logistic regression. The Logistic regression functions to explain the constrained index, are set out in Tables 5 and 6 Panel C. According to these functions, for the KZ-20 model, the significant variables for predicting financial constraints are ESG (rating ESG), ESG_DISCLO (whether or not to disclose ESG), size (measured through assets, LNTA), profitability (ROA) and indebtedness (DEBT_EQUITY). As can be seen, the coefficients of ESG_DISCLO, profitability and size are negative, which would imply that reporting and higher values of the other variables decrease the financial constraint, while ESG and indebtedness are positive (the opposite). Therefore, companies with high DEBT_EQUITY ratios may face greater financial constraints due to concerns about their ability to manage debt obligations and financial risks. The analysis of the model suggests that, in the absence of other factors, the probability of facing financial constraints is high. This may reflect the inherent difficulty in raising funds for bioeconomy companies, possibly due to high start-up costs, regulatory uncertainties and the long-term nature of investment returns. We can see that ESG rating is positively associated with slight restrictions in this model, which may reflect the initial costs of implementing ESG practices. Although a good ESG rating generally improves access to capital and reduces financing costs, it may also be associated with temporary financial constraints (Chan et al., 2017; Farre-Mensa & Ljungqvist, 2016; Gao & Geng, 2024).

However, as in the case of C4.5 and PART, disclosure of ESG practices significantly reduces these restrictions, thereby improving access to finance. This result is consistent with that found in the previous models and explained above. In addition, company size and profitability (ROA) are again critical determinants: larger and more profitable companies are less likely to face financial constraints, while higher levels of debt increase this probability. Hadlock and Pierce (2010) developed the size-age index, which uses firm size as a critical determinant of financial constraint, finding that larger firms face fewer financial constraints. Chan et al. (2017) also support that size and profitability are critical determinants of mitigating financial constraints, suggesting that corporate policies should focus on improving these aspects to alleviate financing constraints. Additionally, Gao and Geng (2024) show that larger and more profitable firms have less difficulty in accessing financing during times of crisis, underscoring the importance of these factors in reducing financial constraints. On the other hand, Luo and Wei (2023) and Bai et al. (2022) confirm the effect of leverage, finding that firms with high levels of debt face greater financial constraints due to higher debt servicing obligations and increased risk perception by lenders.

Finally, regarding the other function (KZ-33), the significant variables for predicting financial constraints are size (measured through assets, LNTA), liquidity (CURRENT), indebtedness (DEBT_EQUITY) and profitability (ROA and ROE). As can be seen, the coefficients of the liquidity, SIZE and ROA are negative, which would imply that higher values of the other variables decrease the financial constraint, while ROE and indebtedness are positive (the opposite). The regression analysis for the 33% threshold shows that

there are three variables that also appeared in the 20% threshold model. These variables are the indebtedness (DEBT_EQUITY), the size and the ROA and confirms the previous patterns Hadlock and Pierce (2010; Chen, 2016). LNTA indicates that, regardless of the level of financial constraints, larger companies have significant advantages in terms of access to financing due to their ability to provide collateral and their perceived financial stability Whited and Wu (2006). In addition, a higher profitability (ROA) reduces the likelihood of facing financial constraints. More profitable companies are seen as safer and more reliable by investors. Profitability demonstrates a company's ability to generate income and meet its financial obligations, which is crucial for maintaining investor and lender confidence. A high debt-to-equity ratio is consistently a critical factor that increases the likelihood of financial constraints. This reflects the risk associated with high debt levels. The two variables that appear at this 33% level but do not appear at the 20% level are liquidity and ROE. Therefore, the liquidity is more important at the 33% threshold, where financial constraints are less severe. Companies with better liquidity management are less likely to face moderate constraints, while at the 20% threshold, other factors may be more determinant due to the severity of the constraints. However, a high ROE can be a sign of profitability, although its positive relationship with financial constraints in the latest model may be due to the volatility of returns and investor expectations regarding the sustainability of these returns so it is necessary a deeper review of the context of volatility and risk. Whited and Wu (2006) find that more financially constrained firms earn higher stock returns on average.

Additionally, ESG disclosure does not show statistical significance at the 33% threshold: nevertheless, the significance of ESG performance and its disclosure at the 20% threshold suggests that in situations of extreme financial constraints, sustainable practices and their transparency can be crucial for improving access to financing. At the 33% threshold, where constraints are more moderate, these factors are not as determinant.

These conclusions and recommendations are not only consistent with the findings of previous studies but also provide practical guidance for bioeconomy companies seeking to improve their financial situation and reduce constraints on access to financing.

The following conclusions can be made about the useful predictors (see Table 7) for a financial constraint status: in high-restriction contexts (20%), the ESG disclosure is a critical variable showing that the transparency in ESG improves investor confidence. With less severe financial constraints, the indebtedness and the profitability become the dominant factors showing that firms. with good profitability and low debt face fewer financial constraints.

Summarising, the most relevant factors are the indebtedness (DEBT_EQUITY) and the ROA, (in 4 out of 6 models). The indebtedness shows that higher debt levels increase financial constraints due to the perceived risk. Next variable to reduce financial constraints is the ROA indicating that more profitable companies are seen as safer and more reliable. Finally, the variables ESG_disclo, LNTA, AGE and ROE appear in three out of six models, suggesting: the importance of transparency in ESG practices for improving access to financing; larger and older companies have greater financial stability and experience; the efficiency of the financial sources (ROE) is crucial for meeting short-term obligations.

5 | CONCLUSIONS

This study has examined the financial constraints in bioeconomy firms using various machine learning methodologies, such as C4.5 decision tree, PART algorithm and logistic regression, applying two KZ index thresholds of 20% and 33%. From these analyses, several key predictors have been identified and important findings have been obtained.

This way, in highly constrained contexts the ROE, ESG disclosure, age of the company are critical factors. So, the main findings of the study emphasise the importance of ROE as a measure that characterises more or less constrained bio firms and the impact of not disclosing ESG results on firms' financing constraints. Therefore, it highlights the economic importance of ESG practices in improving companies' financial conditions and access to capital. This result is supported by recent research (Li et al., 2023). With less severe financial constraints, indebtedness becomes the dominant factor as in other studies (Chen, 2016). The ROA, firm size, liquidity and ESG disclosure are also essential, underlining the importance of transparency in ESG practices, the financial stability associated with firm size and age, the liquidity management and profitability (Liang & Chen, 2024).

The results of this research may have implications for corporate strategy and management, policy development and academic research. First, the results obtained from the empirical analysis provide some guidance for the business decisions of the departments and companies involved. The study suggests that listed bio companies that do not disclose ESG information and therefore do not have an ESG score face more funding constraints. This implies that firms that focus on improving not only their economic performance (ROA and ROE) but also their ESG performance may benefit from improving the access to capital. In this way, enhancing the disclosure can help investors to understand the impact of ESG practices on financing constraints and thus help investors to make more informed decisions

when selecting companies (Xiaoyu, 2023; Zhang & Lucey, 2022).

Second, we want to highlight the contribution to the academic literature. It extends the literature on ESG performance and financial results with the use of machine learning analyses to examine ESG ratings in the context of biofirm profiles. Thus, this research contributes to a deeper understanding of the relationship between sustainability practices and financial performance, especially for financially constrained companies. Consequently, the ESG performance can be an important factor in improving companies' access to finance. Those companies that optimise these factors can significantly improve their access to finance and their financial stability. Thus, based on these findings, there are certain strategic recommendations for biobusinesses to ensure liquidity and reduce financial constraints, especially for smaller companies. That is, in general, they should carefully manage their debt levels and promote strategies that improve ROA. Specifically, the smaller companies should consider expansion strategies to increase their size and maintain a healthy current ratio. So, the business policies and strategies should be aligned to encourage sustainable practices and improve transparency, thus supporting growth and resilience in the bioeconomy sector.

Finally, the policy implications are also remarkable. Government regulators and policy makers can facilitate, promote and encourage ESG disclosure, which would increase the efficiency of capital allocation. In fact, the European Commission adopted the CSRD (the Corporate Sustainability Reporting Directive) in late 2022 and the rules will start to apply between 2024 and 2028. In addition, by recognising the link between ESG performance and the financial constraints, the policy makers can design supportive frameworks that incentivise companies to adopt sustainable practices and attract investment, thereby fostering a more resilient and sustainable financial ecosystem. In addition, such support frameworks can also facilitate consumer awareness, which could improve the economic prospects of bio-based businesses. In addition, the positive ESG results can enhance a company's reputation in the marketplace. This can increase the customer loyalty, enhance the brand value and improve the stakeholder relations. A strong reputation in the marketplace can lead to an improvement in the financial performance and to reduce financial constraints for the company.

These findings and recommendations provide practical guidance for bioeconomy companies seeking to improve their financial situation and reduce barriers in accessing finance. The proposed strategies will not only improve the financial stability of these companies but will also support the sustainable development in the bioeconomy sector, promoting responsible and efficient practices that benefit both companies and society at large (Leoussis & Brzezicka, 2017). The results obtained are consistent with existing literature, providing a solid basis for the formulation of business policies and strategies focused on sustainability and financial efficiency (Do & Kim, 2020).

Some limitations of this paper should be noted, such as the geographical scope. The results have been obtained for the European market and the conclusions should be corroborated for other global financial markets. In addition, we have used the ESG rating obtained from EIKON Refinitiv. It should be clarified that the quality and consistency of ESG reports from different providers may vary. In addition, further research is needed to explore correlations in other financial markets and to investigate additional measures for financial constraints among others. These limitations highlight some areas for future research and suggest the need of additional studies to generalise the findings beyond the specific context of the study.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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ENDNOTE

[i] Gao & Geng, 2024; Hao & Wu, 2024; Liang & Chen, 2024; Li et al., 2023; Zhang et al., 2023; Li et al., 2023; Bai et al., 2022; Chen & Xie, 2022.

REFERENCES

Adams, C.A., Alhamood, A., He, X., Tian, J., Wang, L. & Wang, Y. (2021) *The double materiality concept; application and issues*. Amsterdam: Global Reporting Initiative.

Aguilar, A., Twardowski, T. & Wohlgemuth, R. (2019) Bioeconomy for sustainable development. *Biotechnology Journal*, 14(8), 1800638.

Bai, X., Han, J., Ma, Y. & Zhang, W. (2022) ESG performance, institutional investors' preference and financing constraints: empirical evidence from China. *Borsa Istanbul Review*, 22(2), 157–168.

Baker, M., Stein, J.C. & Wurgler, J. (2003) When does the market matter? Stock prices and the investment of equity-dependent firms. *The Quarterly Journal of Economics*, 118(3), 969–1005.

Banerjee, R., Gupta, K. & Mudalige, P. (2020) Do environmentally sustainable practices lead to financially less constrained firms? International evidence. *International Review of Financial Analysis*, 68, 101337. Available from: https://doi.org/10.1016/j.irfa.2019.03.009

Bellone, F., Musso, P., Nesta, L. & Schiavo, S. (2010) Financial constraints and firm export behaviour. *The World Economy*, 33, 347–373.

Bolin, M. & Rana, O.S. (2021) *What is the relationship between ESG performance and financial constraints? Evidence from Europe*. Unpublished PhD thesis, Master's thesis, Handelshøyskolen BI.

Bugge, M.M., Hansen, T. & Klitkou, A. (2019) What is the bioeconomy? In: *From waste to value*. London: Routledge, pp. 19–50.

Chang, C.Y., Chou, D.W. & Lo, H.C. (2017) Do financial constraints matter when firms engage in CSR? *The North American Journal of Economics and Finance*, 39, 241–259.

Chawla, N.V. (2010) 'Data mining for imbalanced datasets: an overview. In: *Data mining and knowledge discovery handbook*. Berlin: Springer, pp. 875–886.

Chen, I. (2016) *Literature review for firm's financial constraints*. Available from: http://asiair.asia.edu.tw/ir/handle/310904400/96954 [Accessed: 12 May 2024].

Chen, Q., Goldstein, I. & Jiang, W. (2007) Price informativeness and investment sensitivity to stock price. *The Review of Financial Studies*, 20(3), 619–650.

Chen, S., Song, Y. & Gao, P. (2023) Environmental, social, and governance (ESG) performance and financial outcomes: analyzing the impact of ESG on financial performance. *Journal of Environmental Management*, 345, 118829.

Chen, S.S. & Wang, Y. (2012) Financial constraints and share repurchases. *Journal of Financial Economics*, 105(2), 311–331.

Chen, Z. & Xie, G. (2022) ESG disclosure and financial performance: moderating role of ESG investors. *International Review of Financial Analysis*, 83, 102291.

Chouaibi, S., Chouaibi, J. & Rossi, M. (2022) ESG and corporate financial performance: the mediating role of green innovation: UK common law versus Germany civil law. *EuroMed Journal of Business*, 17(1), 46–71.

D'Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J. et al. (2017) Green, circular, bio economy: a comparative analysis of sustainability avenues. *Journal of Cleaner Production*, 168, 716–734.

Demers, E., Hendrikse, J., Joos, P. & Lev, B. (2021) ESG did not immunize stocks during the COVID-19 crisis, but investments in intangible assets did. *Journal of Business Finance & Accounting*, 48(3–4), 433–462.

Díaz-Martínez, Z., Sánchez-Arellano, A. & Segovia-Vargas, M.J. (2011) Prediction of financial crises by means of rough sets and decision trees. *Innovar*, 21(39), 83–100.

Do, Y. & Kim, S. (2020) Do higher-rated or enhancing ESG of firms enhance their long–term sustainability? Evidence from market returns in Korea. *Sustainability*, 12, 2664. Available from: https://doi.org/10.3390/su12072664

Drzewiecki, W. (2017) Thorough statistical comparison of machine learning regression models and their ensembles for subpixel imperviousness and imperviousness change mapping. *Geodesy and Cartography*, 66(2), 171–209.

European Commission. (2022) Progress report on the EU bioeconomy strategy European bioeconomy policy: stocktaking and future developments.Com(2022) 283.

European Regional Development Fund. (2021) *Needs and challenges of companies in the bioeconomy in NW Europe*. London, UK: European Regional Development Fund.

Farre-Mensa, J. & Ljungqvist, A. (2016) Do measures of financial constraints measure financial constraints? *The Review of Financial Studies*, 29(2), 271–308.

Ferraz, D. & Pyka, A. (2023) Circular economy, bioeconomy, and sustainable development goals: a systematic literature review. *Environmental Science and Pollution Research*, https://doi.org/https://doi.org/10.1007/s11356-023-29632-0

Frank, E. & Witten, I.H. (1998) Generating accurate rule sets without global optimization.

Gao, M. & Geng, X. (2024) The role of ESG performance during times of COVID-19 pandemic. *Scientific Reports*, 14(1), 2553.

Garcia-Sanchez, I., Hussain, N., Martinez-Ferrero, J. & Ruiz-Barbadillo, E. (2019) Impact of disclosure and assurance quality of corporate sustainability reports on access to finance. *Corporate Social Responsibility and Environmental Management*, 26(4), 832–848. Available from: https://doi.org/10.1002/csr.1724

Gawel, E., Pannicke, N. & Hagemann, N. (2019) A path transition towards a bioeconomy—the crucial role of sustainability. *Sustainability*, 11(11), 3005.

Golbayani, P., Florescu, I. & Chatterjee, R. (2020) A comparative study of forecasting corporate credit ratings using neural networks, support vector machines, and decision trees. *The North American Journal of Economics and Finance*, 54, 101251.

Gu, L., Guo, J. & Wang, H. (2020) Corporate social responsibility, financing constraints, and the financialization of enterprises. *Journal of Financial Research*, 476(2), 109–127.

Gu, Q., Zhu, L. & Cai, Z. (2009) Evaluation measures of the classification performance of imbalanced data sets. In: *Proceedings of ISICA 2009: Computational intelligence and intelligent systems*. Berlin: Springer, pp. 461–471.

Guo, M. & Song, W. (2019) The growing US bioeconomy: drivers, development and constraints. *New Biotechnology*, 49, 48–57.

Hadlock, C.J. & Pierce, J.R. (2010) New evidence on measuring financial constraints: moving beyond the KZ index. *The Review of Financial Studies*, 23(5), 1909–1940.

Hao, Y. & Wu, W. (2024) Environment, social, and governance performance and corporate financing constraints. *Finance Research Letters*, 62, 105083.

Hastie, T., Tibshirani, R., Friedman, J.H. & Friedman, J.H. (2009) *The elements of statistical learning: data mining, inference, and prediction, 2*. New York: Springer.

He, H. & Garcia, E.A. (2009) Learning from imbalanced data. *IEEE Transactions on Knowledge and Data Engineering*, 21(9), 1263–1284.

Huang, D.Z. (2021) Environmental, social and governance (ESG) activity and firm performance: a review and consolidation. *Accounting and Finance*, 61(1), 335–360.

Kaplan, S.N. & Zingales, L. (1997) Do investment-cash flow sensitivities provide useful measures of financing constraints? *The Quarterly Journal of Economics*, 112(1), 169–215.

Kong, W. (2023) The impact of ESG performance on debt financing costs: evidence from Chinese family business. *Finance Research Letters*, 55, 103949.

Kosmidou, K., Pasiouras, F., Zopounidis, C. & Doumpos, M. (2006) A multivariate analysis of the financial characteristics of foreign and domestic banks in the UK. *Omega*, 34(2), 189–195.

Kuhn, M. & Johnson, K. (2013) *Applied predictive modeling, 26*. New York: Springer.

Kuosmanen, T., Kuosmanen, N., El'Meligi, A., Ronzon, T., Gurria, P., Iost, S. et al. (2020) *How big is the bioeconomy?: reflections from an economic perspective*. European Commission.

Lagoarde-Segot, T. (2019) Sustainable finance. A critical realist perspective. *Research in International Business and Finance*, 47, 1–9.

Lamont, O., Polk, C. & Saaá-Requejo, J. (2001) Financial constraints and stock returns. *The Review of Financial Studies*, 14(2), 529–554.

Leoussis, J. & Brzezicka, P. (2017) *Access-to-finance conditions for investments in biobased industries and the blue economy*. Luxembourg: European Investment Bank.

Li, K., Huang, L., Zhang, J., Huang, Z. & Fang, L. (2023) Can ESG performance alleviate the constraints of green financing for Chinese enterprises: empirical evidence from China's A-share manufacturing companies. *Sustainability*, 15(14), 10970.
Liang, X. & Chen, X.C. (2024) Mandatory corporate social responsibility disclosure and financial constraints: evidence from China. *International Review of Economics and Finance*, 89, 954–974.
Liu, H. & Cao, T. (2015) Advertising, information asymmetry and cost of debt. *Journal of Audit & Economics*, 30, 80–87.
Lukason, O., Vissak, T. & Segovia-Vargas, M.J. (2021) How does managerial experience predict the internationalization type of a young firm? *IEEE Access*, 9, 18148–18166.
Luo, C. & Wei, D. (2023) Corporate ESG performance and trade credit financing–evidence from China. *International Review of Economics and Finance*, 85, 337–351.
Luoma, P., Vanhanen, J. & Tommila, P. (2011) *Distributed bio-based economy: driving sustainable growth*. Finnish Innovation Fund (SITRA): Helsinki, Finland.
McCormick, K. & Kautto, N. (2013) The bioeconomy in Europe: an overview. *Sustainability*, 5(6), 2589–2608.
Miranda-Garcia, M., Segovia-Vargas, M.J., Lukason, O. & Vissak, T. (2019) Financial capacities and export success: evidence from small and medium-sized Estonian firms. *ECORFAN Journal-Mexico*, 10(22), 39–54.
Mougenot, B. & Doussoulin, J.P. (2022) Conceptual evolution of the bioeconomy: a bibliometric analysis. *Environment, Development and Sustainability*, 24(1), 1031–1047.
Muñoz-Izquierdo, N., Segovia-Vargas, M.J., Camacho-Miñano, M.D.M. & Pérez-Pérez, Y. (2022) Machine learning in corporate credit rating assessment using the expanded audit report. *Machine Learning*, 111(11), 4183–4215.
Musso, P. & Schiavo, S. (2008) The impact of financial constraints on firm survival and growth. *Journal of Evolutionary Economics*, 18(2), 135–149.
Pender, A., Kelleher, L. & O'Neill, E. (2024) Regulation of the bioeconomy: barriers, drivers and potential for innovation in the case of Ireland. *Cleaner and Circular Bioeconomy*, 7, 100070.
Quinlan, J.R. (1993) *C4.5: programs for machine learning*. San Mateo, CA: Morgan Kaufmann.
Raimo, N., Caragnano, A., Zito, M., Vitolla, F. & Mariani, M. (2021) Extending the benefits of ESG disclosure: the effect on the cost of debt financing. *Corporate Social Responsibility and Environmental Management*, 28(4), 1412–1421.
Ronzon, T. & Sanjuán, A.I. (2020) Friends or foes? A compatibility assessment of bioeconomy-related sustainable development goals for European policy coherence. *Journal of Cleaner Production*, 254, 119832.
Samet, M., Mouakhar, K. & Jourboui, A. (2018) Exploring the relationship between CSR performance and financial constraints: empirical evidence from European firms. *Review of Social Economy*, 76(4), 480–508. Available from: https://doi.org/10.1080/00346764.2018.1480795
Sanz-Hernández, A., Sanagustín-Fons, M.V. & López-Rodríguez, M.E. (2019) 'A transition to an innovative and inclusive bioeconomy in Aragon, Spain. *Environmental Innovation and Societal Transitions*, 33, 301–316.
Schoenmaker, D. (2017) *Investing for the common good: a sustainable finance framework*. Brussels: Bruegel.
Schoenmaker, D. & Schramade, W. (2019) Investing for long-term value creation. *Journal of Sustainable Finance & Investment*, 9(4), 356–377.
Stiebale, J. (2011) Do financial constraints matter for foreign market entry? A firm-level examination. *The World Economy*, 34(1), 123–153.
Talwar, N. & Holden, N.M. (2022) The limitations of bioeconomy LCA studies for understanding the transition to sustainable bioeconomy. *The International Journal of Life Cycle Assessment*, 27(5), 680–703.
Wesseler, J. & von Braun, J. (2017) Measuring the bioeconomy: economics and policies. *Annual Review of Resource Economics*, 9, 275–298.
Whelan, T., Atz, U., Van Holt, T. & Clark, C. (2021) *ESG and financial performance: uncovering the relationship by aggregating evidence from 1,000 plus studies published between 2015–2020*. New York: NYU STERN Center for Sustainable Business.
Whited, T.M. & Wu, G. (2006) Financial constraints risk. *Review of Financial Studies*, 19, 531–559. Available from: https://doi.org/10.1093/rfs/hhj012
Witten, I.H., Frank, E., Hall, M.A., Pal, C.J. & Data, M. (2005) Practical machine learning tools and techniques. *Data Mining*, 2(4), 403–413.
Xiaoyu, H. (2023) Corporate ESG performance and financing constraints: empirical evidence from Chinese listed companies. *Journal of Applied Finance and Banking*, 13(5), 77-96.
Zhang, D. & Lucey, B.M. (2022) Sustainable behaviors and firm performance: the role of financial constraints' alleviation. *Economic Analysis and Policy*, 74, 220–233.
Zhang, D., Wang, C. & Dong, Y. (2023) How does firm ESG performance impact financial constraints? An experimental exploration of the COVID-19 pandemic. *The European Journal of Development Research*, 35(1), 219–239.
Zhongfei, C. & Guanxia, X. (2022) ESG disclosure and financial performance: moderating role of ESG investors. *International Review of Financial Analysis*, 83, 102291.

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