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Article

Does green mean paying? Environmental innovations and financial performance: Meta-Analytical insights/approach

Anastasia Semenova[1,*], Konstantin Semenov[2]

[1] National Research University Higher School of Economics, Moscow 101000, Russia
[2] Peter the Great St. Petersburg Polytechnic University, St Petersburg 195251, Russia
*** Corresponding author:** Anastasia Semenova, assemenova@hse.ru

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Abstract: Interest in the impact of environmental innovations on firms' financial performance has surged over the past two decades, but studies show inconsistent results. This paper addresses these divergences by analyzing 74 studies from 1996 to 2022, encompassing 4,390,754 firm-year observations. We developed a probability-based meta-analysis approach to synthesize existing knowledge and found a generally positive impact of environmental innovations on financial performance, with a probability range of 0.85 to 0.97. Manufacturing firms benefit more from environmental innovations than firms in other industries, and survey-based studies report a more favorable relationship than those using secondary data. This study contributes to existing knowledge by providing a comprehensive aggregation of data, supporting the resource-based view (RBV) and the Porter hypothesis. The findings suggest significant policy implications, highlighting the need for tailored incentives and information-sharing mechanisms, and underscore the importance of diverse data sources in research to ensure robust results.

Keywords: environmental innovations; eco-innovations; financial performance; sustainable development; green innovations; economic performance
JEL Classification: G3; O31

1. Introduction

Adoption of the concept of sustainable development, the aggravation of environmental problems, and the growth of consumer awareness of environmental issues encourage companies to implement environmental innovations. Given the constantly growing competition in a tightly regulated environment, companies need to be able to predict how the implementation of environmental innovations will impact their financial performance to successfully combine environmental and economic gains and remain lucrative for shareholders and investors.

The interest in the topic of how environmental innovations affect financial performance has been spinning up throughout the past two decades and was substantially reflected in the academic literature. Different studies investigate the effects of 'green', 'environmental', 'eco, sustainable' innovations, therefore, to be able to analyze the results of these studies, it is important to well-frame the concept of environmental innovations. The terms 'environmental', 'green', and 'eco', and 'sustainability innovation' are often used in describing innovations that reduce a firm's negative impact on the environment and society (Diaz-García et al., 2015).

Environmental innovations are defined by Angelo et al. (2012) as organizational implementations and changes focusing on the environment, with implications for companies' products, manufacturing processes, and marketing, with different degrees of novelty. Eco-innovation can be defined as 'the production, assimilation or exploitation of a product, production process, service or management or business methods that are novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources used (including energy use) compared to relevant alternatives' (Kemp et al., 2008). Boons et al. (2013) define sustainable innovation as 'innovation that improves sustainability performance', where performance includes all three dimensions of sustainability—environmental, economic, and social.

Generally, sustainability focuses on equity and efficiency across generations, while eco-innovation addresses current economic and environmental balance. Green innovation encompasses both, creating new value and using fewer resources than traditional methods. Thus, green innovation is a broad concept that includes various aspects of environmental and sustainability concerns.

Although each term has its own distinction and highlights different aspects of the phenomena, in practice, the terms 'environmental', 'green', 'sustainable' and 'eco-innovation' are, to a large extent, used synonymously in the literature (Ben Arfi et al., 2018; Forsman, 2013; Hojnik et al., 2016; Karakaya et al., 2014). Recent literature reviews stated that there are only subtle differences between the terms and that they are often used as equivalents (Hermundsdottir et al., 2020; Schiederig et al., 2012; Tariq et al., 2017).

Although, the topic of how environmental or green innovations affect financial performance has been actively researched recently, and, for many firms, worldwide green innovation is becoming a common environmental strategy, 'there seems to be no consensus in the relevant literature' (Przychodzen et al., 2015) and the studies dedicated to this question show divergent results.

While a great part of the studies refers to the positive impact of environmental innovations on financial performance (Andries et al., 2019; Chu, Wang, et al., 2018; Qiu et al., 2020; Liao, 2018; Li et al., 2020; Li, 2014; Xie et al., 2016; Yurdakul et al., 2020) many studies report negative (Borsatto et al., 2020; Duque-Grisales et al., 2020; Przychodzen et al., 2019; Padgett et al., 2012, Ryszko, 2016) or dual effect, i.e., having a positive impact on some financial indicators, environmental innovations weaken others (Aguilera-Caracuel et al., 2013; Bermudez-Edo et al., 2016; Hoang et al., 2020; Yan et al., 2016).

Some of the reasons for the ambivalent results have their roots in various methodological approaches used in the studies, different control variables, and heterogeneity of the researched financial indicators. Endogeneity issues, specifically reversed causality, also quite often take place: Environmental innovations might have a positive impact on financial performance, and, vice versa, the stable financial situation of a firm provides a solid basis for the implementation of environmental innovations.

Following Semenova et al. (2022), this study aims to provide a deeper understanding of how environmental innovations affect financial performance by performing a meta-analysis of the 74 selected studies dedicated to this topic. The main goal of the study was to find out how the implementation of environmental innovations affects firms' financial performance. Additionally, we analyzed the results of the study from the following perspectives: The number of firms in the samples, the source of data used in the studies, the firms' location and industry. The following research questions were set forth: 1) How does the implementation of environmental innovations affect firms' financial performance? 2) How do other factors (industry, firms' location, data source, etc.) affect the assessment of the environmental innovations' financial implications?

The probability-based meta-analysis approach was exclusively developed for the needs of this study which helped to overcome the limitations of other meta-analysis approaches. Since different studies have different sample sizes and use different variables in various research designs to assess the influence of environmental innovations on financial performance, the conventional meta-analysis approaches usually turn out to be quite unwieldy for the accuracy level that is eventually obtained. Moreover, they are often based on explicit and implicit assumptions and deal with approximate results that might lead to systematic biases in the calculated estimates and affect the overall conclusions. Using a probability-based meta-analysis approach, we demonstrated that the probability that the impact of environmental innovations on financial performance is significant for each paper's sample, so we could reliably aggregate the results of a total of 4,390,754 firm-year observations.

We found that the overall impact of environmental innovation on financial performance is positive with a probability between 0.85 and 0.97. The study's results provide exhaustive empirical evidence for the resource-based view (RBV) and the Porter hypothesis: The implementation of environmental innovation normally positively affects the firms' financial performance. The type of industry has a significant influence on the relationship between environmental innovations and financial performance: Manufacturing firms generally benefit more from environmental innovations than firms from other industries. Studies that use surveys as a data source tend to assess the relationship between environmental innovations and firms' financial performance in a more positive way than studies based on secondary data.

The paper proceeds as follows. First, the theoretical framework is described, and the hypotheses are set. Then, the comparative overview of the selected studies is presented, and the methodology of the study is discussed. Finally, the key findings of the study are presented, and the limitations and conclusions are drawn.

2. Theoretical framework and hypotheses

Different theories explore the impact of eco-innovations on financial performance offering nuanced explanations from various perspectives. The natural resource-based view (NRBV) theory (Hart, 1995) applies the framework of the traditional resource-based view (RBV) theory (Barney, 1991; Wernerfelt, 1984) which assumes that valuable, costly-to-copy firm resources and capabilities provide the key sources of sustainable competitive advantage, to the firm's relationship to the natural environment. The NRBV theory suggests that firms with superior resources and capabilities may achieve enhanced higher performance in meeting environmental challenges: 1) preventing pollution, 2) working with the whole supply chain to minimize its ecological impact, and 3) sustainable development (investments into less developed regions). The three strategies require different capabilities and bring different competitive advantages.

The Porter hypothesis (Porter et al., 1995) claims that well-designed environmental regulations can stimulate innovation and ultimately lead to improved financial performance for firms. According to this hypothesis, stringent environmental standards can push companies to overcome existing behavioral or informational limitations and invest in research and development of new technologies and processes that can reduce costs and enhance competitiveness. However, these benefits may be unevenly allocated between the firms depending on their capabilities to seize the opportunities as predicted by the NRBV theory.

The stakeholder theory (ST) (Freeman, 1984) states that firms have a responsibility not only to shareholders but also to various stakeholders, including employees, customers, communities, and the environment. In the context of environmental innovations, ST suggests that firms that prioritize sustainable practices and develop eco-friendly products or processes may benefit from positive relationships with stakeholders. This, in turn, can lead to improved financial performance through factors like enhanced reputation, increased customer loyalty, and greater market share (this corresponds to the second strategy in NRBV).

The institutional theory (DiMaggio et al., 1983) examines how organizations are shaped by societal norms, regulations, and institutional pressures. Regarding environmental innovations, this theory suggests that companies adopt eco-friendly practices in response to external pressures from stakeholders, industry peers, and regulatory bodies. These innovations can positively impact financial performance by enhancing the firm’s legitimacy, reputation, and compliance with prevailing norms and regulations. By aligning with societal expectations for sustainable business practices, organizations may achieve improved financial outcomes through factors like reduced costs, increased customer loyalty, and access to new markets.

These theories offer a comprehensive understanding of the various factors that influence the financial returns of environmental innovations. These frameworks complement each other by highlighting different aspects: NRBV focuses on the strategic resource capabilities necessary for addressing environmental challenges; the Porter hypothesis emphasizes the role of regulatory pressure in stimulating cost-effective innovations; stakeholder theory underscores the importance of fostering positive relationships with all stakeholders through sustainable practices; and institutional theory explains how external pressures and societal norms drive the adoption of eco-friendly practices. Collectively, these theories provide a nuanced and multi-faceted explanation of how environmental innovations can affect the financial performance of firms.

2.1. Environmental innovations and financial performance

Debates over how environmental innovations affect firms’ financial performance have been ongoing for a long time. Traditionally, economists assumed a trade-off between environmental activities and firms’ performance. Expenses on environmental innovations were expected to increase the costs, i.e., on capital and labor, and supersede more high-yielding investments (Stefan et al., 2008). However, in the past decades, the general view on this has been modified dramatically, and now the investment in environmental activities is expected to make it possible for a win-win situation for both the environment and the firm, as was shown in the introduction to Section 2 (Andries et al., 2019).

Research on the relationship between environmental-social performance and financial performance has shown mixed results since the 1970s. Early studies presented a range of findings: some identified a robust positive relationship (Belkaoui, 1976; Newgren et al., 1985; Waddock et al., 1997), while others reported controversial or inconclusive results (Anderson et al., 1980; Fry et al., 1976) or even negative relationships (Davidson et al., 1987; Jarrel et al., 1985).

Despite these varying outcomes, the evolving landscape of environmental innovation, influenced by increasing regulatory requirements and a growing commitment to corporate transparency, has driven companies to adopt robust environmental management systems and innovate to reduce their ecological footprint. In recent years, the necessity for firms to disclose environmental impacts and issues, as mandated by guidelines and frameworks, has significantly contributed to this shift. Investments in green technologies and sustainable practices have become more prevalent, spurred by both the legal obligation to report on pollution control, waste management, and greenhouse gas emissions, and the desire to demonstrate corporate responsibility. This regulatory push has incentivized firms to ensure accurate data management and continuous improvement in their environmental performance. Consequently, the relationship between environmental activities and financial performance is increasingly seen as beneficial, reflecting a broader understanding that sustainable business practices can lead to long-term financial gains.

This shift is supported by recent studies showing that green innovations not only improve operational, financial and environmental performance (Andries et al., 2019; Liao, 2018; Qiu et al., 2020; Xie et al., 2016) but also act as a mediator (Wu et al., 2023) that translates these benefits into enhanced financial performance over time (Ong et al., 2019). Additionally, while the immediate financial impact of green innovation may not be significant, its positive effects become more pronounced over time, often manifesting substantially after two years (de Azevedo Rezende et al., 2019). This underscores the long-term benefits and strategic importance of environmental innovations in enhancing firm performance eco-innovations generally mediate.

A series of studies, on the contrary, dwell on the negative effect of this relationship (Borsatto et al., 2020; Duque-Grisales et al., 2020; Przychodzen et al., 2019; Padgett et al., 2012). They state that the efforts of companies in green innovation do not reflect positively on their financial performance (Borsatto et al., 2020; Duque-Grisales et al., 2020). Green innovative activism only harms current financial performance when not carried out together with other types of innovative activism. Too much concentration on green innovation has a negative influence on both accounting and stock market performance (Przychodzen et al., 2019).

Furthermore, many studies demonstrate ambivalent results, i.e., having a positive impact on some of the financial indicators—i.e., revenue and ROA, environmental innovations might weaken others—profits, the efficiency of long-term capital employment (Aguilera-Caracuel et al., 2013; Bermudez-Edo et al., 2016; Hoang et al., 2020; Yan et al., 2016). Environmental innovations are characterized by higher returns on assets and equity and, at the same time, lower earnings retention (Przychodzen et al., 2015). The impact between environmental innovations and financial performance can be industry-related and positive at first but weakens during some time (Cortez et al., 2011). Green innovative firms do not experience improved financial performance; however, the intensity of green innovation is positively related to firm profitability (Aguilera-Caracuel et al., 2013). A summary of the studies with positive, negative, and ambivalent results is presented in Appendix A.

Although the studies demonstrate contradictory results, the majority of them found the relationship between environmental innovations and financial performance to be positive (Xie et al., 2016; Xue et al., 2019). The benefits of environmental innovations are supposed to counterbalance or even exceed their costs as by developing environmental innovations firms increase their competitiveness and product value due to the improved technical efficiency. Additionally, investing in environmental innovations positively impacts firms' reputation, diminishes waste disposal, and reduces public pressure (Andries et al., 2019; Khanna, 2001; Konar et al., 2001). According to NRBV, 'it is likely that strategy and competitive advantage in the coming years will be rooted in capabilities that facilitate environmentally sustainable economic activity' (Hart, 1995).

The Porter hypothesis (Porter et al., 1995) goes in line with this theory stating that environmentally benign innovations can lead to an increase in firms' performance. Still remaining controversial due to contrasting empirical evidence (Ozusaglam, 2012), the Porter hypothesis dwells on the innovation effect that follows the strict environmental regulation and subsequent introduction of cleaner technologies and makes production more efficient. According to the Porter hypothesis, efficient production inevitably results in cost savings that are sufficient to overcompensate the innovation costs.

Given the above arguments, our baseline hypothesis comes as follows:

- H1: Environmental innovations positively affect firms' financial performance.

2.2. Relationship between environmental innovations and financial performance: Industry effect

Industry type strongly influences the way environmental innovation affects firms' financial performance—in different industries, the effect might be different. Industry concentration, product, or service differentiation means of production are the factors that define this variability.

Quite many studies that explore the relationship between environmental innovations and financial performance focus on one certain industry: Minerals (Bogers et al., 2019), service (Tugores et al., 2015), automotive (Lin et al., 2019), banking (Zhu et al., 2021), etc. A large part of the studies has manufacturing firms in their samples (Burki et al., 2018; Xie et al., 2022; Zhu et al., 2017). For manufacturing firms, the effect is more explicit since in general environmental innovations usually come together with means of production enhancement and waste reduction (Zhou et al., 2022). Non-manufacturing firms, on the contrary, might not experience any changes, as they may find it difficult to develop green technologies (de Azevedo Rezende et al., 2019).

Therefore, the second hypothesis addressed by this study comes as follows:

- H2: Industry type strongly influences the relationship between environmental innovations and firms' financial performance.

2.3. Relationship between environmental innovations and financial performance: Data source effect

Papers that study the relationship between environmental innovations and financial performance mainly obtain the data from two data sources: surveys and datasets. Surveys are usually considered a subjective data source as they largely depend on the subjective view of the respondents and might be affected by personal emotions. Data obtained from datasets, i.e., financial data and other secondary data are usually considered impartial (Liao et al., 2021). When studying the effect of environmental innovations on financial performance, data should not be obtained only through subjective evaluations; it is recommended to use data from different data sources to maximize the data objectivity and avoid bias (Xue et al., 2019).

Therefore, our third hypothesis comes as follows:

- H3: The type of data source used in a study affects the assessment of the relationship between environmental innovations and financial performance.

3. Method

3.1. Literature search and selection

The study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) principles (Page et al., 2021)—the related checklist is shown in Appendix B. To select the studies for the meta-analysis, we focused on the papers that researched and analyzed how environmental innovations affect firms' financial performance. To ensure the inclusion of all the relevant papers that studied this relationship, we conducted searches in the EBSCO, Scopus, Web of Science, Emerald, Google Scholar, Wiley Online Library, and SpringerLink databases. According to the relevant literature, the terms 'environmental', 'green', 'eco', and 'sustainability innovation' can be used interchangeably (Hermundsdottir et al., 2020; Schiederig et al., 2012; Tariq et al., 2017). Financial performance is quite often replaced synonymously by economic performance or firm performance in the literature (Yi et al., 2021). Thereby, our search inquiry was formed as follows: ('environmental innovation*' OR 'green innovation*' OR 'sustainable innovation*' OR 'eco-innovation*') AND ('financial performance' OR 'economic performance' OR 'firm performance').

The result of our search inquiry formed our first rough sample consisting of 638 papers.

Next, following Anand et al. (2020), Centobelli et al. (2020) and Walsh et al. (2018), we filtered this rough sample by selecting the domain and field-specific documents to focus more accurately on economic and financial performance-related documents—we selected 'business, management and accounting', 'economics, econometrics and finance', and 'social sciences'. We chose 'article' as a document type and 'journal' as a source type. Additionally, we restricted our sample by the publication date—we selected only papers that have been published in the last 10 years following (Anand et al., 2020).

Thus, we obtained our next rough sample with a total of 182 papers. It was further manually filtered based on the relevance to the topic—we looked for the papers where authors focused on environmental innovations and financial performance relationship and quantitively studied it using regression, structural equation modeling (SEM), or other methods.

The study selection was first made in April 2021. Since then, we performed it twice—in January 2022 and in May 2022 to make sure that we have selected all the fresh relevant works. In April 2021 we got 62 papers and by May 2022 we obtained the final sample of a total of 74 papers for meta-analysis.

Then we scanned each paper to check for the sample size, regression and/or correlation coefficients, *t*-values, *p*-values, and variables.

3.2. Selected papers processing

For every selected study, we built a point estimate q^* of the probability q based on the statement that the impact of environmental innovations on financial performance is generally positive. The q^* value serves as an indicator that the mentioned impact is positive, negative, or dual – generally speaking, if $q^* < 0.5$ the impact is considered negative; if $q^* \approx 0.5$ the impact is considered dual; if $q^* > 0.5$ the impact is positive.

Additionally, we built the boundaries I_Q of the confidence interval for q, such that $\text{Prob}(q \in I_Q) = Q$, where Q is the confidence probability. Reasoning using I_Q allows for making more accurate conclusions: if all values in I_Q are larger than 0.5 then we can state with confidence larger than Q that the impact of environmental innovations on financial performance is positive; if they are smaller than 0.5, we can state the negative impact; if $0.5 \in I_Q$ the impact can be considered ambivalent or dual.

Most of the selected studies apply SEM to process the data from surveys or least-squares-based techniques to process panel data. A linear multivariable model is normally used to evaluate the dependency between the explanatory and response variables. Regardless of the model type (fixed or random effects model, etc.), the studied impact is described by a slope α (i.e., the coefficient of response variable sensitivity to the explanatory variable). The estimates α^* of this slope's value α were constructed using regression or other techniques that quantitatively link the environmental innovations indicators (or the results of the corresponding surveys) with the financial performance indicators. Thereby, it was assumed that $q = \text{Prob}(\alpha > 0)$, where $\text{Prob}(\alpha > 0)$ is the probability that the statement ($\alpha > 0$) is true. So, H1 can be reformulated as

$$\text{Prob}(\alpha > 0) > 0.5 \tag{1}$$

We had to use different methods to obtain q^* estimate since the studies' results were presented differently in different papers, even though research designs could be the same. Estimation scenarios used in our meta-analysis are listed below.

a) For 23 papers that used the estimated coefficient α^* of the regression model and its standard deviation or standard error estimate σ^*, the probability was estimated as follows.

For a point estimate of the probability $q = \text{Prob}(\alpha > 0)$, it is necessary to find such a value of q^* that will satisfy the following fiducial condition:

$$\text{A}^* + \sigma^* \cdot t_{1-q*}(n-1) = 0 \quad (2)$$

where $t_p(f)$ is the $p \cdot 100\%$ quantile of the Student's t distribution with the number of degrees of freedom equal to f; and n is the sample size.

This equality directly comes from the one-sided confidence interval for the mathematical expectation, the right boundary of which is fixed at $+\infty$:

$$\text{Prob}\left(\alpha^* + \sigma^* \cdot t_{1-q*}(n-1) < \alpha < +\infty\right) = q^* \quad (3)$$

Having found such a value of q^* when the left boundary of the interval would be equal to zero, we found the desired estimate of the probability $\text{Prob}(\alpha > 0)$.

This expression is equivalent to:

$$q^* = 1 - T(-\alpha^*/\sigma^*, n-1) \quad (4)$$

where $T(\gamma, f)$ is the Student distribution cdf with the number of degrees of freedom equal to f.

The confidence interval for the inverse value of the coefficient of variation (CV) should be constructed to estimate the limits of the confidence interval for q. The coefficient of variation is the argument of the student's distribution function in the equality above. Traditionally, this value is commonly referred to as the signal-to-noise ratio (SNR):

$$\text{SNR}^* = 1/\text{CV}^* = \alpha^*/\sigma^* \quad (5)$$

Since we have no access to the initial sample of values used in the papers to estimate the SNR, it would be natural to assume that its distribution is normal or close to it. In this case, the confidence interval for the SNR is built as the inversion of boundaries of the Miller confidence interval for CV (Albatineh et al., 2014; Miller, 1991).

$$\text{Prob}\left(\underline{\text{SNR}}(Q) < \text{SNR} < \overline{\text{SNR}}(Q)\right) = Q \quad (6)$$

where Q is confidence probability; $z_{(1+Q)/2}$ is the $100\% \cdot (1+Q)/2$ quantile of the standard normal distribution, which has zero mean and variance equal to one; $\underline{\text{SNR}}(Q)$ and $\overline{\text{SNR}}(Q)$ are the left and right boundaries of the confidence interval for SNR respectively that can be found as

$$\left(\text{CV}^* \pm z_{(1+Q)/2} \cdot \sqrt{\text{CV}^{*2} \cdot \left(0.5 + \text{CV}^{*2}\right)/(n-1)}\right)^{-1}$$

(sign '+' corresponds to $\underline{\text{SNR}}(Q)$, the sign '–' corresponds to $\overline{\text{SNR}}(Q)$).

Since when performing strictly monotonic transformations to the boundaries of the intervals, their probabilistic measure does not change,

$$\text{Prob}\left(-\overline{\text{SNR}}(Q) < -\text{SNR} < -\underline{\text{SNR}}(Q)\right) = Q \quad (7)$$

$$\text{Prob}\left(T\left(-\overline{\text{SNR}}(Q), n-1\right) < T(-\text{SNR}, n-1) < T\left(-\underline{\text{SNR}(Q)}, n-1\right)\right) = Q \quad (8)$$

$$\text{Prob}\left(1 - T\left(-\underline{\text{SNR}}(Q), n-1\right) < q < 1 - T\left(-\overline{\text{SNR}(Q)}, n-1\right)\right) = Q \quad (9)$$

The boundaries of this double equality form the confidence interval corresponding to the specified confidence probability q.

All the transformations and equations are valid both for the case when the absolute values of the regression models' coefficients are presented in a paper, and for the case when a paper contains normalized values of the coefficients (betas) or path coefficients when using PLM-SEM.

b) For 15 papers that used the estimated coefficient α^* of the regression model and the value of the student's coefficient *t*, the probability was estimated as follows.

Since *t* is the statistic value when checking the significance of the statement that $\alpha \neq 0$, then

$$t = |\alpha^*|/\sigma^* \tag{10}$$

Hence, the equation (4) was transformed:

$$q^* = 1 - T(-t \cdot \mathrm{sign}(\alpha^*), n-1) \tag{11}$$

where sign(x) is the sign of the number x.

To estimate the confidence interval for q, equation (9) was applied, provided that

$$\mathrm{SNR}^* = t \cdot \mathrm{sign}(\alpha^*) \tag{12}$$

c) For 31 papers that used the estimated coefficient α^* and the *p*-value characterizing its significance, the probability q was estimated as follows.

For this case, the *p*-value estimates the probability of the following: When checking the significance of the coefficient α by the value of its estimate α^*, a wrong decision is being made that $\alpha \neq 0$ (i.e., its value is significant), while in reality $\alpha = 0$ (i.e., its value is insignificant).

Since in most mathematical statistics programs, *p*-value is calculated in the asymptotic approximation of $n \to +\infty$,

$$p/2 = 1 - Z(|\alpha^*|/\sigma^*) \tag{13}$$

where $Z(x)$ is the distribution function (cdf) of the standard normal distribution.

For the finite *n*, the best estimate of the p-value is obtained from the following expression when checking the significance of the regression coefficient

$$p/2 = 1 - T(|\alpha^*|/\sigma^*,\ n-1) \tag{14}$$

When $n \to +\infty$, the Student's distribution coincides with the standard normal distribution, and the selected papers contain a sufficient amount of statistical data, therefore it was decided to neglect the differences in the above relations.

In these calculations, it is assumed that if the value $\alpha^* > 0$ and $n >> 1$, then

$$p/2 = 1 - T(\alpha^*/\sigma^*, n-1) = T(-\alpha^*/\sigma^*, n-1) \tag{15}$$

$$q^* = 1 - T(-\alpha^*/\sigma^*, n-1) = 1 - p/2 \tag{16}$$

In case if $\alpha^* < 0$ and $n >> 1$, then

$$p/2 = 1 - T(-\alpha^*/\sigma^*, n-1) = q^* \tag{17}$$

Therefore

$$q^* = \begin{cases} 1 - p/2, & \alpha^* > 0, \\ p/2, & \alpha^* < 0. \end{cases} \tag{18}$$

To build a confidence interval for q using equation (9), we exploit the expression

$$\mathrm{SNR}^* = \mathrm{sign}(\alpha^*) \cdot t_{1-p/2}(n-1) \tag{19}$$

In some papers, *p*-value *p* was given with zeros in all significant digits, whose number was usually equal to $m = 2 \div 3$, i.e., $p = 0.00$ or $p = 0.000$. In this case (based on the principle of lower bound estimation of the probability q), the *p*-value was taken as $(5 \cdot 10^{-m-1} - \varepsilon)$, namely the maximum possible number by rounding which the result presented in the paper could be obtained. The value ε represents an infinitesimal positive number.

Some papers do not contain a specific *p*-value, instead, however, they only note that the *p*-value did not exceed the assigned level (usually from the range of 0.1, 0.05, 0.01, 0.001), i.e., $p < p_{\max}$. In this case (based on the principle of estimating the probability q from below), it was assumed that $p = p_{\max}$.

d) Papers by Forsman (2013); Fernando et al. (2010); Przychodzen et al. (2015); Tugores et al. (2015) directly compare the financial performance of the firms that introduced environmental innovations and the firms that did not.

In these papers, regression models with variables describing the impact of environmental innovation on financial performance were not presented. Instead, the papers assessed the financial performance of these two firms' groups separately. Conclusions were drawn by comparing the means or medians in the corresponding samples. The main statistical analysis tools were the *t*-test and Wilcoxon signed ranks test.

If we mark the normalized estimates of the 'green' and 'not green' firms' financial performance as β_G and β_{NG} respectively, then the impact of the environmental innovations' introduction can be estimated as $\alpha = \beta_G - \beta_{NG}$. Consequently, the estimates of the probability q = Prob ($\alpha > 0$) presented in clauses a-c can be reasonably applied for the cases when the results of the papers are presented in different ways.

In the paper (Aguilera-Caracuel, 2013), the matched pairs of 'green' and 'not green' firms were also compared, but in a different way: The differences in their indicators were directly studied and regression models were built notably for differences. This paper's results were processed in the way described in section a.

e) In the paper, a diagram in Figure 7 (Wysocki, 2021) demonstrated the results of an expert survey on the financial performance increase as a result of the environmental innovations' introduction. The grades used in the survey were as follows:

- Revenue increased no more than 1% of annual revenue (17.2%),
- Revenue increased from 1% to 5% of annual revenue (39.8%),
- Revenue increased from 6% to 10% of annual revenue (18.8%),
- Revenue increased above 10% of annual revenue (1.6%),
- No, the revenue did not increase (20.3%),
- I don't know, it's hard to say (2.3%).

The q^* value was calculated according to the data presented in this pie chart in the following way: $q^* = 1 - 0.023 - 0.203 = 0.774$. This value estimates the probability that a randomly selected expert would indicate the impact of environmental innovations on financial performance as positive: As it was mentioned before, if $q^* < 0.5$ the impact is considered negative; if $q^* \approx 0.5$ the impact is considered dual; if $q^* > 0.5$ the impact is positive. For that reason, we applied the Clopper-Pearson equations used for the Bernoulli scheme to build the confidence interval for the q value at a given confidence probability Q:

$$\sum_{m=\lceil q^*\cdot n\rceil}^{n} \binom{n}{m} \cdot \underline{q}^m \cdot \left(1-\underline{q}\right)^{n-m} = \sum_{m=0}^{\lfloor q^*\cdot n\rfloor} \binom{n}{m} \cdot \overline{q}^m \cdot (1-\overline{q})^{n-m} = \frac{1-Q}{2} \qquad (20)$$

where $\binom{n}{m} = \frac{n!}{m!(n-m)!}$ is the binomial coefficient or number of combinations; $\lfloor x\rfloor$ is the result of rounding x toward negative infinity, and $\lceil x\rceil$ is the result of rounding x toward positive infinity.

The number of binomial trials in the Bernoulli scheme equaled the number of interviewed experts ($n = 128$).

Two papers by Chu, Xu, et al. (2018) and Chu, Wang, et al. (2018) from our sample were written by the same principal author, dwelling on the same industry, same country, and same time period. The chances that these papers' results were based on the same data source were quite high, therefore, it was decided to average the results of these two works and use them in the future as a result of one study. The inclusion of both papers in the meta-analysis would have led to a bias in the results due to these papers' results' statistical dependence.

3.3. Meta-analysis approach

The summary tables presented in Appendix A might form a superficial conclusion that, overall, the selected papers state the positive impact of environmental innovations on financial performance. This conclusion, however, might be misleading as the sample sizes of each paper also need to be considered. In addition, apparently, not every firm in each sample showed only positive or negative effects. Most papers do not provide data on how many firms in their samples reported positive or negative effects, therefore we could assess this indirectly only by the quantitative analysis results presented in the papers. Additionally, every paper had its own way of presenting the results and even though the papers studied the same problem, their methods and variables could differ tremendously. Therefore, in our research, we study the relationship between environmental innovations and financial performance from a probabilistic point of view, and the use of meta-analysis methodology exclusively allows getting a reasonable answer about the probability of positive, negative, and dual effects.

Meta-analysis has firmly been anchored in economic research as a tool for drawing generalized conclusions based on the studies' results that research the same phenomenon, process, or laws (Stanley, 2001). Studies on similar topics, performed in slightly different conditions (various regions and study periods, different data samples, diverse research designs, and different mathematical models) often demonstrate divergent results. Meta-analysis enables us to consider and analyze the whole amount of data provided by the studies together. Nevertheless, the use of meta-analysis as a research method in economics still has not formed unified standards for its application, like those developed in evidence-based medicine with Cochrane reviews (Higgins et al., 2019).

The meta-analysis approach used in this study is compliant with the recommendations of the Cochrane for Evidence-Based Medicine (Higgins et al., 2019), specifically the section 'Analyzing data and undertaking meta-analyses' (Deeks et al., 2021). This helps to overcome the following difficulties. Studies on similar topics performed in quite different conditions (different regions, time periods, samples, research designs, and mathematical models), often show conflicting results. Meta-analysis allows considering the whole amount of data collected from papers together.

Simple aggregation of the samples from different papers might give an illusion that it is possible just to combine them into one sample due to the similar conditions in which the studies were conducted. Aggregating the studies with moderate statistical significance makes it possible, however, to get a statistically significant result in the integrated sample. At the same time, different sample sizes, dissimilar research environments, and various research designs lead to systematic biases in the calculated estimates, that, in their turn, might lead to incorrect overall conclusions. Samples' differences usually can be well-controlled, and their impact on the final results can be taken into account and assessed. However, the impact of other above-mentioned factors can be easily confused with, for example, the well-known Yule-Simpson paradox (or unification paradox) (Wagner, 1982). It takes place when the conclusions, obtained as a result of two homogeneous samples' separate processing, reverse when the integrated sample is processed. So, we should follow closely the properties of the samples that are included in the meta-analysis.

Let us suppose that we obtained the estimations q_1^*, q_2^*, … q_N^* from N different studies that dealt with samples of sufficiently large sizes n_1, n_2, … n_N correspondingly. Then we can estimate the averaged value of Prob($\alpha > 0$) for all processed studies in the following manner:

$$\text{Prob}^*_{\text{total}}(\alpha > 0) = \left(\sum_{i=1}^{N} \frac{q_i^*}{\text{Var}[q_i^*]}\right) \cdot \left(\sum_{j=1}^{N} \frac{1}{\text{Var}[q_j^*]}\right)^{-1} \quad (21)$$

where $\text{Var}[q_i^*]$ is the variance of the estimate q_i^*.

If the estimation q_i^* belongs to the Bernoulli process with the probability that the probability that impact of environmental innovations on the financial performance is positively equal precisely to q_i^* and the number of trials equals to n_i, we can state that

$$\text{Var}[q_i^*] = q_i^* \cdot (1 - q_i^*)/n_i \quad (22)$$

So,

$$\text{Prob}^*_{\text{total}}(\alpha > 0) = \left(\sum_{i=1}^{N} \frac{n_i}{1 - q_i^*}\right) \cdot \left(\sum_{j=1}^{N} \frac{n_j}{q_j^* \cdot (1 - q_j^*)}\right)^{-1} \quad (23)$$

The statistical error margin of this value can be estimated as

$$\pm Z^{-1}\left(\frac{1+Q}{2}\right) / \sqrt{\sum_{j=1}^{N} \frac{n_j}{q_j^* \cdot (1 - q_j^*)}}$$

where Q is the confidence probability.

This estimation suggests that all the estimations q_1^*, q_2^*, … q_N^* belong to the same general probability Prob($\alpha > 0$). This is an acceptable assumption: the final analysis result is the *averaged* value of the probability that environmental innovations positively affect financial performance. The weighted mean value is an effective way to construct such estimation following the De Moivre-Laplace theorem that states the asymptotical normality of binomial distribution.

Such an approach might face an obstacle if $q_i^* \approx 1.0$. Indeed, in this case, $\text{Var}[q_i^*] \approx 0.0$ and the Equation (23) will provide an estimate that turns out to be close to q_i^* disregarding other terms included in the weighted average.

A better way to obtain the total average estimate of Prob($\alpha > 0$) is to study the distribution of estimates q_1^*, q_2^*, … q_N^* directly. Then we can derive the necessary bounds by analyzing the possible values of this distribution cdf. This variant of meta-analysis is preferable because it is the closest to the most nonparametric and corresponds to fewer assumptions.

Different studies use various methodologies to assess the influence of environmental innovations on financial performance. This can become an unsurmountable obstacle when there is a need to obtain a positive effect total estimation of the averaged indicators expressed in the absolute form. The relative-form indicators (like the probability that environmental innovations positively affect financial performance) are preferable in this case. This meta-analysis approach is more advantageous than the analysis of the absolute value of slope α taken from different studies—the latter depends on scale factors, geography, time period, and other variables.

4. Results

The obtained results of assessing the q^* value and confidence intervals (CI, hereinafter—for the confidence probability $Q = 0.95$) for all selected studies are presented in **Table 1**. The mean q^* and the aggregated confidence limits for q (from the lowest to the highest among all confidence intervals corresponding to the presented models) are provided for the studies that demonstrated the results of several mathematical models, that fit the initial data well.

Incidentally, several selected studies state the ambivalent effect of environmental innovations implementation on financial performance, yet the quantitative results presented in these papers argue rather for the positive effect (Bermudez-Edo et al., 2016; Hoang et al., 2020).

To obtain a weighted-average estimate that considers the samples sizes, we applied the Equation (23) to results from **Table 1**, and assumed that one could interpret the probability $q = \text{Prob}(\alpha > 0)$ as the mean probability of the positive impact of environmental innovations on financial performance for every single firm:

$$q^*_{\text{aggr}} = 1.000 \pm 0.000$$

Table 1. Assessed probability $q = \text{Prob}(\alpha > 0)$ that environmental innovations positively affect the financial performance.

Paper	q^*	CI for q
Qiu et al. (2020)	0.983	[0.961, 0.997]
Gangi et al. (2020)	0.988	[0.964, 0.998]
Duque-Grisales et al. (2020)	0.277	[0.148, 0.366]
Li et al. (2020)	0.999	[0.999, 1.000]
Hoang et al. (2020)	0.655	[0.624, 0.708]
Andries et al. (2019)	0.999	[0.996, 1.000]
Xue et al. (2019)	0.999	[0.999, 1.000]
Ong et al. (2019)	0.999	[0.999, 1.000]
Liao (2018)	0.999	[0.998, 1.000]
Chu, Xu et al. (2018), Chu, Wang et al. (2018)	0.995	[0.989, 0.998]
Xie et al. (2016)	0.989	[0.951, 1.000]

Table 1. (*Continued*).

Paper	***q****	**CI for *q***
Przychodzen et al. (2015)	0.999	[0.999, 1.000]
Lee et al. (2015)	0.979	[0.936, 1.000]
Li (2014)	0.995	[0.989, 0.998]
Cortez et al. (2011)	0.642	[0.000, 0.999]
Bermudez-Edo et al. (2016)	0.738	[0.652, 0.863]
Yan et al. (2016)	0.907	[0.814, 0.982]
Chaudhry et al. (2020)	0.995	[0.991, 0.997]
Xie et al. (2019)	0.971	[0.938, 0.993]
Przychodzen et al. (2019)	0.527	[0.083, 0.963]
de Azevedo Rezende et al. (2019)	0.672	[0.292, 0.999]
Lin et al. (2019)	0.990	[0.974, 0.998]
Tariq et al. (2019)	0.999	[0.995, 1.000]
Aguilera-Caracuel et al. 2013	0.973	[0.916, 0.979]
Marin-Vinuesa et al. (2018)	0.976	[0.951, 0.993]
Lopes Santos et al. (2019)	0.997	[0.990, 1.000]
Borsatto et al. (2020)	0.303	[0.000, 0.743]
Cainelli et al. (2011), Antonioli et al. (2016)	0.743	[0.741, 0,746]
Tugores et al. (2015)	0.987	[0.960, 1.000]
Ghisetti et al. 2014	0.570	[0.325, 0.809]
Scarpellini et al. (2019)	0.999	[0.999, 1.000]
Forsman (2013)	0.515	[0.503, 0.527]
Sánchez-Medina et al. (2013)	0.997	[0.993, 0.999]
García-Sánchez et al. (2015)	0.333	[0.000, 1.000]
Bogers et al. (2019)	0.662	[0.611, 0.792]
Rexhäuser et al. (2013)	0.967	[0.963, 0.970]
Huang et al. (2010)	0.999	[0.999, 1.000]
Chan et al. (2016)	0.999	[0.998, 1.000]
Zailani et al. (2015)	0.999	[0.999, 1.000]
Severo et al. (2017)	0.999	[0.999, 1.000]
Hojnik et al. (2016)	0.975	[0.961, 0.986]
Long et al. (2017)	0.999	[0.999, 1.000]
Amores-Salvadó et al. (2014)	0.524	[0.502, 0.556]
Ar (2012)	0.995	[0.989, 0.998]
Burki et al. (2018)	0.536	[0.514, 0.558]
Ebrahimi et al. (2017)	0.999	[0.997, 1.000]
Guo et al. (2019)	0.999	[0.999, 1.000]
Leyva-de la Hiz et al. (2018)	0.997	[0.996, 0.998]
Ryszko (2016)	0.745	[0.714, 0.796]
Wu (2017)	0.995	[0.989, 0.998]
Yu et al. (2017)	0.950	[0.921, 0.975]
Wysocki (2021)	0.774	[0.726, 0.817]

Table 1. (*Continued*).

Paper	*q**	CI for *q*
Zandi et al. (2019)	0.999	[0.999, 1.000]
Fernando et al. (2010)	0.925	[0.903, 0.944]
Cai et al. (2018)	0.998	[0.997, 0.999]
Zhu et al. (2017)	0.975	[0.964, 0.985]
Suat et al. (2019)	0.997	[0.989, 1.000]
Yurdakul et al. (2020)	0.999	[0.999, 1.000]
Ma et al. (2021)	0.975	[0.967, 0.982]
Padgett (2012)	0.001	[0.000, 0.001]
Aastvedt et al. (2021)	0.718	[0.095, 0.999]
Colombelli et al. (2019)	0.990	[0.980, 0.999]
Tang et al. (2017)	0.756	[0.504, 0.998]
Zhang et al. (2019)	0.625	[0.592, 0.671]
Johl et al. (2021)	0.999	[0.999, 1.000]
Xu et al. (2021)	0.986	[0.965, 0.997]
Weng et al. (2015)	0.999	[0.999, 1.000]
Zhu et al. (2021)	0.999	[0.994, 0.999]
Xie et al. (2022)	0.000	[0.000, 0.001]
Qing et al. (2022)	0.328	[0.001, 0.989]
Rodrigez-Espindola et al. (2022)	0.999	[0.998, 0.999]
Vasileiou et al. (2022)	0.999	[0.999, 1.000]

One of the reasons for such a result is that the analyzed sample includes the paper (Colombelli et al., 2019) that studied almost half of a million firms, whereas other papers studied several hundreds or thousands of firms. If we look at Equation (23), we can see that the term corresponding to the mentioned paper will have a weight close to one and will be prevailing and others—close to zero and will be neglectable compared to it. The method proposed in this paper easily overcomes this obstacle: we suggest studying the distribution of interval estimations of probability q^* as it doesn't require taking into account the sample sizes in original studies—the confidence of interval estimations of q^* depends on the significance of the quantitative estimation of the impact of environmental innovations on financial performance and generally does not depend on the quantity of the studied firms (only on the quality of the registered dependence between green activities and economical result of their implementation).

As mentioned in the section above, this estimate seems overestimated. Such a result was obtained due to the prevailing contribution of estimates q^* close to one. This value does not change in the given significant digits if in Equation (23) we specify the value of the variance of binomially distributed quantities after considering the natural averaging that takes place since different papers consider different time periods.

4.1. Time period covered in the meta-analysis

The selected papers studied different time periods and different samples of firms (see Appendix A). We performed the following calculations to determine the best-fit time period and to truncate corresponding distribution tails which the obtained results refer to. We excluded two outliers—the papers that studied very large firms' samples—Colombelli et al. (2019) with 456,240 firms and Vasileiou et al. (2022) with 14,430 firms.

We calculated the number of firms in every sample for each year between 1996 and 2022. The obtained set of firm-year values was used to construct a frequency histogram that reflected the distribution of firms' quantities throughout the years (**Figure 1**). The vertical axis shows the percentage of firm-years in a specific year in the total number of firm-year observations.

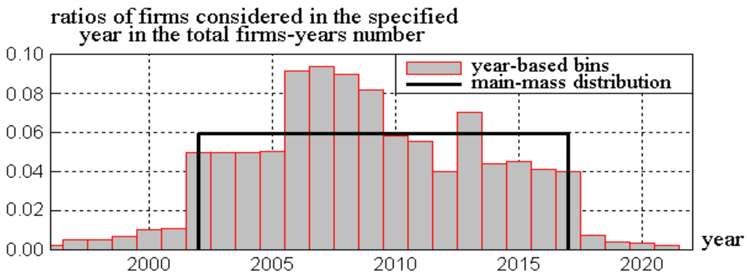

Figure 1. Firm-years ratios distribution.

Figure 1 shows that most of the analyzed firms belong to the time period from 2002 to 2017. The contribution of the rest of the years to the total number of firm-year observations is insignificant. Meanwhile, the firms in the interval 2002–2017 are distributed almost uniformly:

$$\chi 2 = 18.21 < \chi^2_{1-0.05}(13) = 22.36,$$

if we consider the distribution of papers-years values (here $\chi^2_\beta(f)$ is the β × 100%th quantile of chi-squared distribution with degrees of freedom equal to *f*, the null hypothesis that states the goodness-of-fit is accepted at a significance level of 0.05). This circumstance indicates that the influence of the firms' distribution non-uniformity is to a certain extent insignificant within the considered time period.

Figure 2 shows a graph of the empirical cumulative distribution function (empirical cdf) of firm-years by years, as well as estimates of 5% and 95% quantiles, which set the boundaries of the 90% interquartile range (contains. 90% of all values of the variable firms-years).

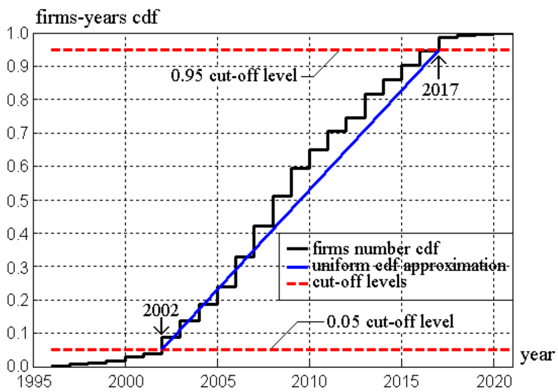

Figure 2. Firm-years cdf and estimate of 90% interquartile range.

When considering papers-years distribution, the Kolmogorov-Smirnov test also provides grounds for accepting the hypothesis of a uniform distribution: KS = 0.0857 < $KS_{crit}(0.05)$ = 0.0872 at a significance level of 0.05.

4.2. Distribution characteristics of the *q** estimates

We studied the statistical characteristics of the obtained set of *q** estimates. The results are summarized in **Table 2**.

Table 2. Statistical characteristics of the sample of the *q** estimates representing the probability of environmental innovations' positive impact on financial performance.

Estimate	Mean	Median	Standard deviation	Skewness	Kurtosis
Point	0.850	0.987	0.246	−1.799	5.602
95% CI	[0.793, 0.908]	[0.971, 0.995]	[0.212, 0.294]	[−2.626, −1.242]	[3.566, 10.030]

This distribution is characterized by significant skewness and large kurtosis. The absolute difference between the mean and the median reaches 0.2 ÷ 1.0 of the standard deviation. As will be shown below, these characteristics of the obtained distribution argue for the absence of unaccounted biases when designing the sample of papers.

Apparently, this distribution cannot be fitted by the normal one with any combination of parameters. Shapiro-Wilk and Shapiro-Francia normality tests (the latter is better for leptokurtic samples, Ku > 3) provided the following results, respectively: SW = 0.6740, $p = 2.314 \times 10^{-11}$; SF = 0.6739, $p = 7.608 \times 10^{-10}$. As a consequence, the use of Grubbs-type tests for checking the sample's homogeneity (absence of outliers) is inappropriate, since they are based on the hypothesis that the population distribution from which the sample is extracted is close to normal (although even its purely formal application shows the absence of outliers: G = 3.427 < G_{crit} = 3.431 for a significance level of 0.025).

4.3. Compliance with natural regularities

We used the obtained confidence intervals for the value $q = \text{Prob}(\alpha > 0)$ to build a range of possible values of the cdf of *q** estimates based on the selected papers (i.e., the probability box) (**Figure 3**). Since the width of the confidence intervals depends on the statistical error associated with the number of firms that were included in a particular study and/or on the statistical significance of the findings, such a probability box sufficiently reflects the degree of the residual uncertainty of our knowledge of the distribution of *q** values, related to the time period 2002–2017.

The probability box, presented in **Figure 3**, shows that the probability of a positive impact of environmental innovation on financial performance is greater than 50%—following the meta-analysis results, it is between 85% to 97%. Mathematically this result is expressed as

$$\text{Prob}(\text{Prob}(\alpha > 0) > 0.5) = 0.91 \pm 0.06.$$

We analyzed these results for compliance with the regularities that describe real-life samples. Since the estimates of *q** are obtained by processing quantitative data that corresponds to the natural setting of firms' performance characteristics, these estimates should be likely in line with these natural regularities, too.

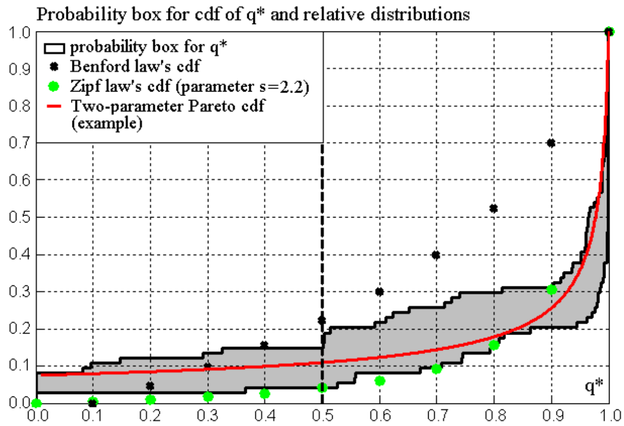

Figure 3. Probability box for q^* cdf and relative distributions.

It is well-known that the frequencies of a certain first significant digit occurrence in distributions of quantities taken from real life follow Benford's law, also known as the first-digit law. This is true for many of these distributions, but not for all. The Benford distribution law does not contain parameters and indicates the frequencies of occurrence of the first significant digits in the q^* values presented in **Table 3**.

Table 3. Probabilities of different first significant digits occurrence in q^* estimates according to Benford's law.

Digit	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
Prob	0.046	0.051	0.058	0.067	0.079	0.097	0.125	0.176	0.301

The form of the obtained probability box for the cdf of estimates of q^* is quite similar to the cdf of the Benford distribution. At the same time, the distribution of the first digits in the obtained set does not fully correspond to this pattern. This might be caused both by the insufficient papers' sample size and by the possible inapplicability of this pattern to this case. However, the fact that the mean (0.850) is very different from the median (0.987) in the sample and that the distribution has a significant skewness (–1.799) argue for the fact that the resulting sample of q^* estimates should follow Benford's law (Durtschi et al., 2004). On the other hand, a relatively small sample size ($N = 74$), limited values in the sample, as well as the fact that Benford's law holds for distributions that are wide compared to the unit distance on a logarithmic scale (while the analyzed set does not correspond to this), indicate possible reasons for non-compliance with this law (Durtschi et al., 2004).

We presume that the evidence both in favor of compliance with Benford's law and against it is consistent with the presented in **Figure 3** rate of divergence between the probability box's bounds and cdf of the Benford distribution.

In addition to the first-digit law compliance check, we carried out others to check if the obtained estimates q^* comply with natural regularities that have a selected parameter.

The set of q^* estimates is highly consistent with Zipf's law, which is similar in meaning to Benford's law: when analyzing the frequency of element occurrence in naturally generated quantitative sets, the rank-frequency distribution is in an inverse relationship. The first significant digits in the q^* values were also taken as such elements.

The graph in **Figure 3** demonstrates compliance with Zipf's law with its parameter equal to $s = 2.2$. This fact indicates that the set of q^* estimates correspond to the naturally following requirement that the rank-frequency distribution is in an inverse relationship. To a certain extent, it signals that the obtained results are free from the bias caused by the unaccounted factors and indicates the internal self-consistency of the selected sample of papers.

Finally, the obtained probability box was checked for compliance with the Pareto distribution, which, in a way, is a continuous analog of Zipf's law. Truncation was applied on a significantly large pdf's argument value to reduce the interval of values generated by a given distribution to the interval of possible probability values, i.e., to [0, 1]. The resulting uncertainty was insignificant in the context of the statistical error caused by the relatively small, from a statistical point of view, sample size of the selected papers ($N = 74$). **Figure 3** demonstrates that the probability box for the distribution of q^* values contains a whole family of two-parameter Pareto distributions, one example of which is shown in the graph.

Thus, the obtained results confirm the reliability of the findings and their compliance with the natural regulations that are true for the data obtained from real-life sources.

4.4. Internal regularities detection

The selected papers make naturally distinguished groups, and the differences in the estimates of q^* between these groups might be systematic.

The diagram in **Figure 4** shows the distribution of analysis methods used in the selected studies. Apparently, there are two distinguished groups: based methodologically on regression analysis and related methods and based on survey results processing. **Table 4** contains the main statistical characteristics estimates for the corresponding sub-samples.

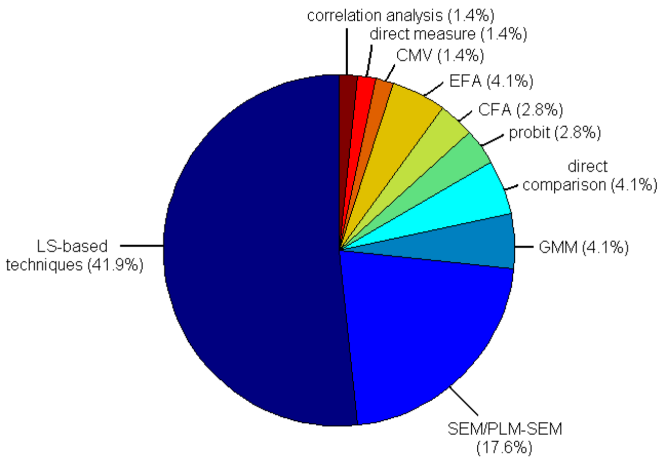

Figure 4. Methods used in the selected studies.

Table 4. Sources of data in the selected papers and differences in distributions between them.

Data sources	**Ratio**	***q** mean*	***t***	**median**	**Mann-Whitney *z***
In-group q^* distribution characteristics					
Databases	42%	0.772	2.271 ($p = 0.0263$) ⇒ reject means' equality	0.973	1.971 ($p = 0.049$) ⇒ reject medians' equality
Surveys	58%	0.903		0.995	
In-group q CIs distribution characteristics (confidence probability $Q = 0.95$)					
Databases	42%	[0.655, 0.889]	[1.472, 2.869] ($p \in [0.005, 0.146]$)	[0.655, 0.990]	[1.411, 2.223] ($p \in [0.026, 0.158]$)
Surveys	58%	[0.849, 0.956]		[0.975, 0.999]	

Figure 5 shows the probability boxes built by the confidence intervals of the estimates included in the studied groups. Apparently, there are significant reasons to consider the corresponding distributions to be different.

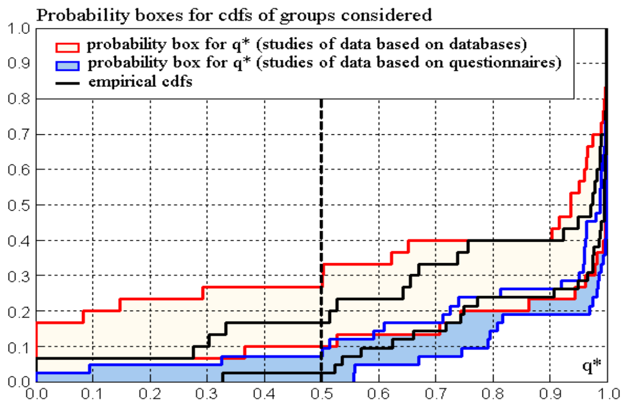

Figure 5. Probability boxes for cdfs for two groups of data sources: Databases and surveys.

Probability boxes, shown in **Figure 5**, demonstrate that the probability of a positive impact of environmental innovations on financial performance is greater than 50%. Namely, for the studies based on the data from databases, this probability has the following range—from 73% to 90%. For studies based on survey data—from 93% to 100%. Mathematically this result is expressed as:

$\text{Prob}(\text{Prob}(\alpha > 0) > 0.5 \mid \text{databases}) = 0.815 \pm 0.085$,

$\text{Prob}(\text{Prob}(\alpha > 0) > 0.5 \mid \text{surveys}) = 0.965 \pm 0.035$.

We checked the compliance of empirical cdfs to each other using the Lemann-Rosenblatt test and KS-test for two samples. The first (statistics value $\omega^2 = 0.421$ is greater than the critical value 0.347 corresponded to significance level 0.10) test indicates the statistical significance of the differences between the distributions, and the second (statistics value KS = 0.271, *p*-value is equal to $p = 0.126$) shows that we cannot treat cdfs as equal. Since the statistical power of the Lemann-Rosenblatt test is greater, we can carefully interpret these results as weakly indicating the difference in distributions in the analyzed groups. The situation remains approximately the same if we take the 95% confidence intervals for these statistics derived from p-box: $\omega^2 \in [0.256, 0.800]$ and $\text{KS} \in [0.214, 0.405]$ (*p*-value $p \in [0.004, 0.356]$).

The same analysis was carried out for papers that studied only ROA as an indicator of financial performance (19 studies), and papers that considered an aggregated indicator of financial performance (39 studies). There is no reason to consider differences in the mean values of q^* estimates – as well as when comparing medians (**Table 5**). Comparing empirical cdfs shows the same picture: $\omega^2 = 0.334$ (critical value is 0.461 for significance level equal to 0.05) and KS = 0.301 (p-value $p = 0.162$). If we look at 95% confidence intervals for ω^2 and KS derived from p-box, then we see that overall the situation doesn't change: $\omega^2 \in [0.072, 0.454]$ and KS$\in[0.150, 0.377]$ (p-value $p \in [0.039, 0.915]$). This circumstance expresses the sufficiency of using ROA as a measure of financial performance when assessing the impact of environmental innovations on firms' financial performance.

Table 5. Sources of financial data in the selected papers and differences in distributions between them.

Financial indicator	**Ratio**	***q** mean**	***t***	**median**	**Mann-Whitney *z***
In-group q^* distribution characteristics					
ROA	26%	0.803	0.577 ($p = 0.566$) ⇒ do not reject means' equality	0.950	1.491 ($p = 0.136$) ⇒ do not reject medians' equality
Aggregated indicators	53%	0.846		0.995	
In-group q CIs distribution characteristics (confidence probability $Q = 0.95$)					
ROA	26%	[0.690, 0.916]	[0.000, 1.277] ($p \in [0.207, 1.000]$)	[0.662, 0.990]	[1.411, 2.223] ($p \in [0.066, 0.679]$)
Aggregated indicators	53%	[0.755, 0.937]		[0.975, 0.999]	

Figure 6 shows the probability boxes built by the confidence intervals of the estimates included in the studied groups. Apparently, there are no grounds to interpret the shown distributions as different.

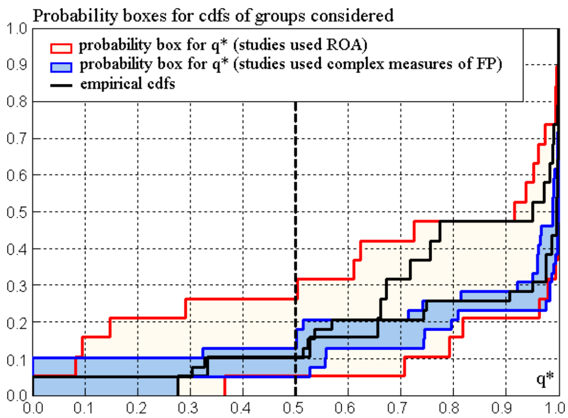

Figure 6. Probability boxes for cdfs for studies that used ROA and studies that used complex financial performance indicators.

Similarly, we compared papers that studied firms from Europe (17 papers), Asian countries (37 papers), and American countries (6 papers). This comparison did not reveal significant differences in the mean, median, and cdf of corresponding q^* estimates (see **Table 6**). This, however, might be partly a result of the small sample size or the feature of the q^* as a measure of the impact of environmental innovations on firms' financial performance (for all comparisons of the mean p-value $p \geq 0.42$, for medians—$p \geq 0.38$, for cdfs—$p \geq 0.23$). This circumstance also testifies to the fact that the influence of the geographic factor in the performed meta-analysis is averaged and does not cause bias.

Table 6. Testing the difference between geographic regions.

Test	Confidence interval for *p*-value (confidence probability $Q = 0.95$)		
	Europe-America	**Asia-Europe**	**America-Asia**
t	[0.420, 0.991]	[0.438, 0.822]	[0.429, 0.697]
Mann-Whitney	[0.381, 0.882]	[0.421, 1.000]	[0.587, 1.000]
Lemann-Rosenblatt	[0.234, 0.755]	[0.322, 0.799]	[0.419, 0.686]
Kolmogorov-Smirnov	[0.142, 0.990]	[0.342, 0.994]	[0.488, 0.952]

Distribution analysis of q^* estimates over the years did not reveal any significant regularities, which also testifies to the sufficient homogeneity of this meta-analysis sample.

Similarly, we analyzed the papers that studied firms from different industries. We selected only two categories because the size of the paper sample was not sufficient: manufacturing (29 papers) and miscellaneous industries where manufacturing firms were not prevailing (18 papers). Here we analyzed the papers that specified industries as manufacturing or investigated sets of firms from different industries where manufacturing firms did not prevail (such industries in the papers were denoted as miscellaneous). This allowed us to directly compare two groups of firms - manufacturing and non-manufacturing. Papers that were not included in this analysis studied specific industries (on average, one paper focused on one specific industry), so we could not directly compare them with papers that studied the manufacturing industry as one set of comparison would be of size 1. We could not merge the results of the papers that studied non-manufacturing industries because of the wide variation of results' values from paper to paper. So, the comparison of means or medians was associated with sizable statistical uncertainty that did not allow for the rejection of the null hypothesis stating the equality of the means.

We followed the papers' descriptions of the firms' samples to determine the category for a paper. The main result is that there is a significant difference in the mean values of q^* estimates for these groups (**Table 7**) and a possible difference in the median values. Comparing empirical cdfs gives the uncertain result (probably, caused by the small sizes of samples): For the confidence probability $Q = 0.95$, $\omega^2 \in [0.212, 0.639]$ (p-value $p \in [0.016, 0.241]$) and KS$\in[0.251, 0.460]$ (p-value $p \in [0.043, 0.875]$). The corresponding p-boxes are shown in **Figure 7**.

Table 7. Industries and differences in distributions between them.

Industry	Ratio	q^* mean	t	median	Mann-Whitney z
In-group q^* distribution characteristics					
Manufacture	39%	0.913	2.802 ($p = 0.007$) ⇒ reject means' equality	0.967	1.573 ($p = 0.116$) ⇒ do not reject medians' equality
Miscellaneous	24%	0.704		0.990	
In-group q CIs distribution characteristics (confidence probability $Q = 0.95$)					
Manufacture	39%	[0.857, 0.970]	[2.054, 3.423] ($p \in [0.001, 0.045]$)	[0.333, 0.997]	[1.160, 2.260] ($p \in [0.024, 0.246]$)
Miscellaneous	24%	[0.539, 0.870]		[0.971, 0.997]	

As per the results presented in **Table 7**, the type of industry has a significant influence on the relationship between environmental innovations and financial performance: Manufacturing firms generally benefit more from environmental innovations implementation than firms from other industries.

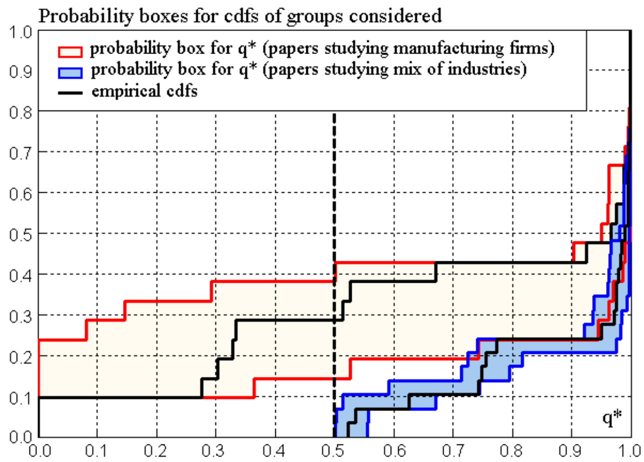

Figure 7. Probability boxes for cdfs for papers studying manufacturing firms and miscellaneous industries.

5. Discussion, implications, and conclusion

5.1. Discussion and conclusion

In this study, we performed a meta-analysis of the 74 most relevant papers to assess the effect of environmental innovations on firms' financial performance. As studies substantially differ in their research designs, have different sample sizes, and use different variables, for the needs of this study we developed a meta-analysis approach to ensure the consistency of the meta-analysis results. Based on Cochrane review recommendations, the probability-based approach helped to overcome the limitations of the conventional meta-analysis approach—unwieldiness for the accuracy level that is eventually obtained and reliance on explicit and implicit assumptions. This helped not only to get the overall assessment of how environmental innovations affect firms' financial performance but also to obtain a refined probabilistic estimate of this effect.

Our key findings indicate:

1) With a total of 4,390,754 firm-year observations in our sample, we found that environmental innovations positively affect firms' financial performance with a probability between 0.85 and 0.97.

2) Survey-based studies show a more positive impact than those using secondary data, with probabilities ranging from 93% to 100% versus 73% to 90%, respectively.

3) Manufacturing firms benefit more from environmental innovations than non-manufacturing firms, aligning with industry-specific pressures and adaptation.

4) Return on assets (ROA) is a sufficient financial performance indicator when assessing environmental innovations.

5) This study supports the resource-based view (RBV) and the Porter hypothesis, highlighting policy implications for tailored incentives and information-sharing mechanisms. It underscores the importance of diverse data sources in ensuring robust research results.

The use of the presented probability-based approach revealed the following advantages:

1) It is less influenced by external factors than other approaches that use absolute values (the studied sample of $N = 74$ papers did not show the dependence of q^* values on the geographic factor);

2) The q^* values are on the unified scale and can be easily compared in different studies in spite of other measures whose values depend on the study design and generally cannot be compared directly without normalization;

3) The q^* values naturally represent the averaged risk of environmental innovation implementation and can be used for decision-making and strategic planning;

4) q^* values comply with natural regulations like Benford, Zipf, or Pareto laws, whereas other approaches do not.

Using q^* meta-analysis makes the results almost independent of the size of the sample—this facilitates studies aggregation simplifying the evaluation of different studies' significance. All information on the study's significance is contained in the uncertainty estimation for q^* value.

In practice, the sample size is not always a decent measure of the results' statistical significance: A large sample does not necessarily lead to registering the significant dependence or effect because of noise and effects obtained in studies with small-size samples can also be biased due to incorrect data collection and filtering. So, having a measure and its estimate of the significance or statistical uncertainty is much more convenient for further use and aggregation during meta-analyses.

The main practical conclusion here is the following: in empirical studies, it is much better to present the *p*-values estimation values accurately, not their bounds (like stating that the *p*-value is less than the given bound—0.1, 0.05 or 0.01) or to place the accurate values of parameters of performed statistical tests (the statistic and the sample size). Our study might come as a practical illustration for this conclusion.

We analyzed the obtained set of quantitative estimates for compliance with Benford's and Zipf's laws in addition to standard statistical analysis, as the data on environmental innovations and financial performance belongs to naturally generated sets of quantitative data. This provided an additional check for the bias caused by hidden unintentional filtering of the processed sample and ensured onward data compliance and results' reliability. The data distribution compliance with Benford's law (or analysis of the reasons in case of non-compliance) is used in sociology and financial control to identify data irregularities (Busta et al., 1998; Bhattacharya et al., 2011), including fraud identification in elections and financial documents (Nigrini, 1999).

To ensure the reliability of the statistical results we constructed the confidence intervals. Since the pointwise estimates do not contain information on their significance and on how far they are from the real values of measured quantities, the use of the confidence intervals provides more reliable reasoning for decision-making: using them, we understand if the obtained effects happen systematically, or this is just the result of errors. The confidence intervals allow us to get more precise estimates more accurately to obtain more reliable final results than after processing such heterogeneous (in the sense of its uncertainty) data on equal terms.

Our obtained data set was also tested for homogeneity. The studied set of data can be considered homogeneous and approximately uniform in terms of data per year within the time period from 2002 to 2017. There are reasons to presume that the influence of the geographic factor in the sample is averaged and does not cause bias.

The results show that survey-based studies demonstrate, on average, a more positive impact of environmental innovations on financial performance than studies that use secondary data. Namely, for the studies based on the data from databases, the probability that environmental innovations positively affect firms' financial performance has the following range—from 73% to 90%. For the survey-based studies—from 93% to 100%. Unlike Liao et al. (2021), this result complies with the findings of the study by Sánchez-Medina et al. (2013). Having built an elaborate experiment, Sánchez-Medina et al. (2013) demonstrates that the impact of environmental innovations on ROA (impartial indicator) is lower than on firms' financial performance subjectively assessed by an expert survey.

Industry analysis showed that the type of industry has a significant influence on the relationship between environmental innovations and financial performance: manufacturing firms generally benefit more from the implementation of environmental innovations than firms from other industries. This result complies with de Azevedo Rezende et al. (2019): Manufacturing firms are naturally more adapted to environmental innovations implementation due to the industry specifics (stakeholders and society pressure on emission reduction, pollution prevention activities, etc.), whereas non-manufacturing firms are more prone to introduce environmental innovations for the reasons other than institutional and stakeholders' pressure. Therefore, it often happens that non-manufacturing firms are less prepared for environmental innovations introduction which results in their financial results.

Additionally, the study provides statistical grounds to assume that it is sufficient to use ROA as a financial indicator when assessing the impact of environmental innovations on financial performance. This fact indicates the sufficiency of using ROA as a measure of financial performance when assessing the impact of environmental innovations on financial performance. This result complies with Aguilera-Caracuel et al. (2013), de Azevedo Rezende et al. (2019) and Xie et al. (2019) that stated that ROA commonly serves as a proxy for a firm's financial performance.

5.2. Theoretical and practical implications

This study offers several theoretical contributions to the existing literature and practical implications for policy and future research. The most essential of them are presented below.

This study makes the following key theoretical contributions.

1) We have developed probability-based meta-analysis approach—an approach tailored to the needs of this study. This approach overcomes the limitations of conventional meta-analysis by reliably aggregating and analyzing data from diverse studies with varying research designs, sample sizes, and variables. This method can be beneficially applied in other economic research and studies on similar topics.

2) We demonstrated the importance of checking natural sets of quantitative data for compliance with Benford's and Zipf's laws. Integrating this compliance check with

standard statistical analysis can help ensure ongoing data reliability and prevent biases from hidden unintentional filtering, as is common in sociology and financial control practices.

3) Our findings revealed that data sources significantly affect the assessment of the relationship between environmental innovations and financial performance. To achieve more stable and convincing results and avoid potential biases, it is crucial to incorporate diverse data types, including impartial secondary data, rather than relying solely on subjective evaluations.

4) By analyzing a total sample of 4,390,754 firm-year observations, our study provides empirical evidence supporting the RBV and Porter hypothesis. The results suggest that environmental innovations typically offer competitive advantages and lead to increased financial performance, particularly in manufacturing firms.

This paper also lends itself to several practical implications.

1) The study confirms a consistent positive relationship between environmental innovations and firms' financial performance. This suggests that environmental efforts are likely to enhance ROA, market share, and profits by reducing costs, improving production processes, and attracting more customers.

2) Detailed evidence on how environmental innovations affect financial performance can help mitigate investors' and shareholders' concerns. This can incentivize managers to undertake more environmentally related initiatives, as they can plan their financial expectations with greater confidence.

3) Regardless of the firm's size, industry, resources, or capabilities, demonstrating tangible environmental results to stakeholders, such as customers, can lead to better financial outcomes. This is a general recommendation for firms considering the implementation of environmental innovations.

4) Since manufacturing firms benefit more from environmental innovations, policymakers can introduce more incentives and public subsidies specifically for non-manufacturing firms. Additionally, policymakers can focus on information sharing and technology transfer mechanisms to help these firms access the necessary knowledge and resources for environmental technology development and implementation.

5.3. Research limitations and future research

While this study provides valuable insights, it is important to acknowledge its inherent limitations.

Firstly, the results from the selected papers were assumed to be unbiased. Despite efforts to ensure objectivity, some bias may still exist in the original research.

Secondly, it was assumed that the samples from the papers, particularly those using surveys, were independently acquired and free from censorship or filtration, potentially introducing variability.

Lastly, the study assumes the sample sizes in the selected papers were sufficient to consider the distribution of coefficient values from regression analysis or structural equation modeling (SEM) as nearly normal, relying on the asymptotic normality of least-squares-based estimation results.

These limitations highlight opportunities for future research. Future studies could use more rigorous methodologies to assess and mitigate potential biases, employing advanced statistical techniques.

Additionally, exploring the impact of different sampling strategies on the relationship between environmental innovations and financial performance would provide a deeper understanding of the robustness and generalizability of the findings.

Sensitivity analyses could also be conducted to examine the influence of sample size variations on the estimated effects, using simulations or bootstrap resampling techniques to assess the stability and reliability of the findings under different sample size scenarios.

By addressing these research limitations in future studies, we can further refine our understanding of the relationship between environmental innovations and financial performance, ultimately contributing to more informed and effective sustainability strategies for businesses and industries.

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References

Aastvedt, T. M., Behmiri, N. B., Lu, L. (2021). Does green innovation damage financial performance of oil and gas companies? Resources Policy, 73, 102235. https://doi.org/10.1016/j.resourpol.2021.102235

Aguilera-Caracuel, J., & Ortiz-de-Mandojana, N. (2013). Green Innovation and Financial Performance. Organization & Environment, 26(4), 365–385. https://doi.org/10.1177/1086026613507931

Albatineh, A. N., Florence G., Golam Kibria, B. M., Wilcox, M. L. (2014). Confidence interval estimation of the signal-to-noise ratio using ranked set sampling: A simulation study. Thailand Statistician, 12(1), 55–69.

Amores-Salvadó, J., Castro, G. M., & Navas-López, J. E. (2014). Green corporate image: moderating the connection between environmental product innovation and firm performance. Journal of Cleaner Production, 83, 356–365. https://doi.org/10.1016/j.jclepro.2014.07.059

Anand, A., Brøns Kringelum, L., Øland Madsen, C., et al. (2020). Interorganizational learning: a bibliometric review and research agenda. The Learning Organization, 28(2), 111–136. https://doi.org/10.1108/tlo-02-2020-0023

Anderson, J., Frankle, A. (1980). Voluntary social reporting: An isobeta portfolio analysis. The Accounting Review, 55(3), 467–479.

Andries, P., & Stephan, U. (2019). Environmental Innovation and Firm Performance: How Firm Size and Motives Matter. Sustainability, 11(13), 3585. https://doi.org/10.3390/su11133585

Angelo, D., Jabbour, J., Vasconcellos, S. (2012). Environmental innovation: in search of a meaning. World Journal of Entrepreneurship, Management and Sustainable Development, 8(2/3), 113–121. https://doi.org/10.1108/20425961211247734

Antonioli, D., Borghesi, S., & Mazzanti, M. (2016). Are regional systems greening the economy? Local spillovers, green innovations and firms' economic performances. Economics of Innovation and New Technology, 25(7), 692–713. https://doi.org/10.1080/10438599.2015.1127557

Ar, I. M. (2012). The Impact of Green Product Innovation on Firm Performance and Competitive Capability: The Moderating Role of Managerial Environmental Concern. Procedia—Social and Behavioral Sciences, 62, 854–864. https://doi.org/10.1016/j.sbspro.2012.09.144

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99–120.

https://doi.org/10.1177/014920639101700108

Belkaoui, A. (1976). The Impact of the Disclosure of the Environmental Effects of Organizational Behavior on the Market. Financial Management, 5(4), 26. https://doi.org/10.2307/3665454

Ben Arfi, W., Hikkerova, L., & Sahut, J.-M. (2018). External knowledge sources, green innovation and performance. Technological Forecasting and Social Change, 129, 210–220. https://doi.org/10.1016/j.techfore.2017.09.017

Bermúdez-Edo, M., Hurtado-Torres, N. E., & Ortiz-de-Mandojana, N. (2016). The Influence of International Scope on the Relationship Between Patented Environmental Innovations and Firm Performance. Business & Society, 56(2), 357–387. https://doi.org/10.1177/0007650315576133

Bhattacharya, S., Xu, D., & Kumar, K. (2011). An ANN-based auditor decision support system using Benford's law. Decision Support Systems, 50(3), 576–584. https://doi.org/10.1016/j.dss.2010.08.011

Ghassim, B., & Bogers, M. (2019). Linking stakeholder engagement to profitability through sustainability-oriented innovation: A quantitative study of the minerals industry. Journal of Cleaner Production, 224, 905–919. https://doi.org/10.1016/j.jclepro.2019.03.226

Boons, F., Montalvo, C., Quist, J., et al. (2013). Sustainable innovation, business models and economic performance: an overview. Journal of Cleaner Production, 45, 1–8. https://doi.org/10.1016/j.jclepro.2012.08.013

Borsatto, J., Bazani, C., & Amui, L. (2020). Environmental Regulations, Green Innovation and Performance: An Analysis of Industrial Sector Companies from Developed Countries and Emerging Countries. Brazilian Business Review, 17(5), 559–578. https://doi.org/10.15728/bbr.2020.17.5.5

Burki, U., Ersoy, P., & Dahlstrom, R. (2018). Achieving triple bottom line performance in manufacturer-customer supply chains: Evidence from an emerging economy. Journal of Cleaner Production, 197, 1307–1316. https://doi.org/10.1016/j.jclepro.2018.06.236

Busta, B., & Weinberg, R. (1998). Using Benford's law and neural networks as a review procedure. Managerial Auditing Journal, 13(6), 356–366. https://doi.org/10.1108/02686909810222375

Cai, W., & Li, G. (2018). The drivers of eco-innovation and its impact on performance: Evidence from China. Journal of Cleaner Production, 176, 110–118. https://doi.org/10.1016/j.jclepro.2017.12.109

Cainelli, G., Mazzanti, M., & Zoboli, R. (2011). Environmental innovations, complementarity and local/global cooperation: evidence from North-East Italian industry. International Journal of Technology, Policy and Management, 11(3/4), 328. https://doi.org/10.1504/ijtpm.2011.042090

Chan, H. K., Yee, R. W. Y., Dai, J., et al. (2016). The moderating effect of environmental dynamism on green product innovation and performance. International Journal of Production Economics, 181, 384–391. https://doi.org/10.1016/j.ijpe.2015.12.006

Chaudhry, N., Asad, H., Amir Ch, M., Hussian, R. I. (2020). Environmental innovation and financial performance: Mediating role of environmental management accounting and firm's environmental strategy. Pakistan Journal of Commerce and Social Science, 14(3), 715–737.

Chu, Z., Xu, J., Lai, F., et al. (2018). Institutional Theory and Environmental Pressures: The Moderating Effect of Market Uncertainty on Innovation and Firm Performance. IEEE Transactions on Engineering Management, 65(3), 392–403. https://doi.org/10.1109/tem.2018.2794453

Chu, Z., Wang, L., & Lai, F. (2018). Customer pressure and green innovations at third party logistics providers in China. The International Journal of Logistics Management, 30(1), 57–75. https://doi.org/10.1108/ijlm-11-2017-0294

Centobelli, P., Cerchione, R., Chiaroni, D., et al. (2020). Designing business models in circular economy: A systematic literature review and research agenda. Business Strategy and the Environment, 29(4), 1734–1749. https://doi.org/10.1002/bse.2466

Colombelli, A., Krafft, J., & Quatraro, F. (2019). Firms' growth, green gazelles and eco-innovation: evidence from a sample of European firms. Small Business Economics, 56(4), 1721–1738. https://doi.org/10.1007/s11187-019-00236-8

Cortez, M., Cudia, C. (2011). The virtuous cycles between environmental innovations and financial performance: Case study of Japanese automotive and electronics companies. Academy of Accounting and Financial Studies Journal, 15(s2), 31–44.

Davidson, W. N., Chandy, P. R., & Cross, M. (1987). Large Losses, Risk Management and Stock Returns in the Airline Industry. The Journal of Risk and Insurance, 54(1), 162. https://doi.org/10.2307/252888

de Azevedo Rezende, L., Bansi, A. C., Alves, M. F. R., Galina, S. V. R. (2019). Take your time: Examining when green innovation affects financial performance in multinationals. Journal of Cleaner Production, 233, 993–1003. https://doi.org/10.1016/j.jclepro.2019.06.135

Deeks, J., Higgins, J., Altman, D. (2021). Chapter 10: Analysing data and undertaking meta-analyses. In: Higgins, J. P. T.,

Thomas, J., Chandler, J., et al. (editors). Cochrane Handbook for Systematic Reviews of Interventions. Wiley.
Díaz-García, C., González-Moreno, Á., & Sáez-Martínez, F. J. (2015). Eco-innovation: insights from a literature review. Innovation, 17(1), 6–23. https://doi.org/10.1080/14479338.2015.1011060
DiMaggio, P. J., & Powell, W. W. (1983). The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. American Sociological Review, 48(2), 147. https://doi.org/10.2307/2095101
Durtschi, C., Hillison, W., Pacini, C. (2004). The effective use of Benford's law to assist in detecting fraud in accounting data. Journal of Forensic Accounting, 5, 17–34.
Duque-Grisales, E., Aguilera-Caracuel, J., Guerrero-Villegas, J., et al. (2020). Does green innovation affect the financial performance of Multilatinas? The moderating role of ISO 14001 and R&D investment. Business Strategy and the Environment, 29(8), 3286–3302. https://doi.org/10.1002/bse.2572
Ebrahimi, P., & Mirbargkar, S. M. (2017). Green entrepreneurship and green innovation for SME development in market turbulence. Eurasian Business Review, 7(2), 203–228. https://doi.org/10.1007/s40821-017-0073-9
Fernando, C. S., Sharfman, M., & Uysal, V. B. (2010). Does Greenness Matter? Environmental Performance, Ownership Structure and Analyst Coverage. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1571596
Forsman, H. (2013). Environmental Innovations as a Source of Competitive Advantage or Vice Versa? Business Strategy and the Environment, 22(5), 306–320. https://doi.org/10.1002/bse.1742
Freeman, R. E. (1984). Strategic Management: A Stakeholder Approach. Pitman Publishing Inc.
Fry, F., Hock, R. (1976). Who claims corporate responsibility? The biggest and the worst. Business and Society Review, 18, 62–65.
Gangi, F., Daniele, L. M., & Varrone, N. (2020). How do corporate environmental policy and corporate reputation affect risk-adjusted financial performance? Business Strategy and the Environment, 29(5), 1975–1991. https://doi.org/10.1002/bse.2482
García-Sánchez, I., Gallego-Álvarez, I., & Zafra-Gómez, J. (2019). Do the ecoinnovation and ecodesign strategies generate value added in munificent environments? Business Strategy and the Environment, 29(3), 1021–1033. https://doi.org/10.1002/bse.2414
Ghisetti, C., & Rennings, K. (2014). Environmental innovations and profitability: how does it pay to be green? An empirical analysis on the German innovation survey. Journal of Cleaner Production, 75, 106–117. https://doi.org/10.1016/j.jclepro.2014.03.097
Guo, Y., Wang, L., Wang, M., et al. (2019). The Mediating Role of Environmental Innovation on Knowledge Acquisition and Corporate Performance Relationship—A Study of SMEs in China. Sustainability, 11(8), 2315. https://doi.org/10.3390/su11082315
Hart, S. L. (1995). A Natural-Resource-Based View of the Firm. The Academy of Management Review, 20(4), 986. https://doi.org/10.2307/258963
Hermundsdottir, F., & Aspelund, A. (2020). Sustainability innovations and firm competitiveness: A review. Journal of Cleaner Production, 280, 124715. https://doi.org/10.1016/j.jclepro.2020.124715
Higgins, J., Thomas, J., Chandler, J., et al. (2019). Cochrane Handbook for Systematic Reviews of Interventions. John Wiley & Sons.
Hoang, T., Przychodzen, W., Przychodzen, J., et al. (2020). Does it pay to be green? A disaggregated analysis of U.S. firms with green patents. Business Strategy and the Environment, 29(3), 1331–1361. https://doi.org/10.1002/bse.2437
Hojnik, J., & Ruzzier, M. (2016). What drives eco-innovation? A review of an emerging literature. Environmental Innovation and Societal Transitions, 19, 31–41. https://doi.org/10.1016/j.eist.2015.09.006
Huang, Y., & Jim Wu, Y. (2010). The effects of organizational factors on green new product success. Management Decision, 48(10), 1539–1567. https://doi.org/10.1108/00251741011090324
Jarrell, G., & Peltzman, S. (1985). The Impact of Product Recalls on the Wealth of Sellers. Journal of Political Economy, 93(3), 512–536. https://doi.org/10.1086/261313
Johl, S. K., & Toha, M. A. (2021). The Nexus between Proactive Eco-Innovation and Firm Financial Performance: A Circular Economy Perspective. Sustainability, 13(11), 6253. https://doi.org/10.3390/su13116253
Karakaya, E., Hidalgo, A., & Nuur, C. (2014). Diffusion of eco-innovations: A review. Renewable and Sustainable Energy Reviews, 33, 392–399. https://doi.org/10.1016/j.rser.2014.01.083
Kemp, R., Pearson, P. (2008). Final Report MEI Project about Measuring Eco-innovation: Deliverable 15 of MEI Project (D15). Available online: http://www.oecd.org/greengrowth/consumption-innovation/43960830.pdf (accessed on 20 June 2024).

Khanna, M. (2001). Non-Mandatory Approaches to Environmental Protection. Journal of Economic Surveys, 15(3), 291–324. https://doi.org/10.1111/1467-6419.00141

Konar, S., & Cohen, M. A. (2001). Does the Market Value Environmental Performance? Review of Economics and Statistics, 83(2), 281–289. https://doi.org/10.1162/00346530151143815

Lee, K. H., & Min, B. (2015). Green R&D for eco-innovation and its impact on carbon emissions and firm performance. Journal of Cleaner Production, 108, 534–542. https://doi.org/10.1016/j.jclepro.2015.05.114

Leyva-de la Hiz, D. I., Ferron-Vilchez, V., & Aragon-Correa, J. A. (2018). Do Firms' Slack Resources Influence the Relationship Between Focused Environmental Innovations and Financial Performance? More is Not Always Better. Journal of Business Ethics, 159(4), 1215–1227. https://doi.org/10.1007/s10551-017-3772-3

Li, L., Msaad, H., Sun, H., et al. (2020). Green Innovation and Business Sustainability: New Evidence from Energy Intensive Industry in China. International Journal of Environmental Research and Public Health, 17(21), 7826. https://doi.org/10.3390/ijerph17217826

Liao, Z. (2018). Corporate culture, environmental innovation and financial performance. Business Strategy and the Environment, 27(8), 1368–1375. https://doi.org/10.1002/bse.2186

Liao, Z., Liu, P., & Liu, S. (2021). A meta-analysis of environmental innovation and firm performance. Journal of Environmental Planning and Management, 64(11), 2047–2065. https://doi.org/10.1080/09640568.2020.1855129

Lin, W. L., Cheah, J. H., Azali, M., et al. (2019). Does firm size matter? Evidence on the impact of the green innovation strategy on corporate financial performance in the automotive sector. Journal of Cleaner Production, 229, 974–988. https://doi.org/10.1016/j.jclepro.2019.04.214

Li, Y. (2014). Environmental innovation practices and performance: moderating effect of resource commitment. Journal of Cleaner Production, 66, 450–458. https://doi.org/10.1016/j.jclepro.2013.11.044

Long, X., Chen, Y., Du, J., et al. (2017). The effect of environmental innovation behavior on economic and environmental performance of 182 Chinese firms. Journal of Cleaner Production, 166, 1274–1282. https://doi.org/10.1016/j.jclepro.2017.08.070

Lopes Santos, D. F., Valente Rezende, M. D., & Cruz Basso, L. F. (2019). Eco-innovation and business performance in emerging and developed economies. Journal of Cleaner Production, 237, 117674. https://doi.org/10.1016/j.jclepro.2019.117674

Ma, Y., Zhang, Q., & Yin, Q. (2021). Top management team faultlines, green technology innovation and firm financial performance. Journal of Environmental Management, 285, 112095. https://doi.org/10.1016/j.jenvman.2021.112095

Marín-Vinuesa, L. M., Scarpellini, S., Portillo-Tarragona, P., et al. (2018). The Impact of Eco-Innovation on Performance Through the Measurement of Financial Resources and Green Patents. Organization & Environment, 33(2), 285–310. https://doi.org/10.1177/1086026618819103

Miller, G. E. (1991). Asymptotic test statistics for coefficients of variation. Communications in Statistics - Theory and Methods, 20(10), 3351–3363. https://doi.org/10.1080/03610929108830707

Newgren, K., Rasher, A., Laroe, M., Szabo, M. (1985). Environmental assessment and corporate performance: A longitudinal analysis using market-determined performance measure. Research in Corporate Social Performance and Policy, 7, 153–164.

Nigrini, M. J. (1999). I've got your number. Journal of Accountancy, 187(5), 79–83.

Ong, T. S., Lee, A. S., Teh, B. H., et al. (2019). Environmental Innovation, Environmental Performance and Financial Performance: Evidence from Malaysian Environmental Proactive Firms. Sustainability, 11(12), 3494. https://doi.org/10.3390/su11123494

Ozusaglam, S. (2012). Environmental innovation: A concise review of the literature. Vie & Sciences de l'entreprise, N° 191-192(2), 15–38. https://doi.org/10.3917/vse.191.0015

Padgett, R. C., & Moura-Leite, R. C. (2012). Innovation with High Social Benefits and Corporate Financial Performance. Journal of Technology Management & Innovation, 7(4), 59–69. https://doi.org/10.4067/s0718-27242012000400005

Page, M. J., McKenzie, J. E., Bossuyt, P. M., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ.

Porter, M. E., & Linde, C. van der. (1995). Toward a New Conception of the Environment-Competitiveness Relationship. Journal of Economic Perspectives, 9(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Przychodzen, W., Leyva-de la Hiz, D. I., & Przychodzen, J. (2019). First-mover advantages in green innovation—Opportunities and threats for financial performance: A longitudinal analysis. Corporate Social Responsibility and Environmental Management, 27(1), 339–357. https://doi.org/10.1002/csr.1809

Przychodzen, J., & Przychodzen, W. (2015). Relationships between eco-innovation and financial performance – evidence from publicly traded companies in Poland and Hungary. Journal of Cleaner Production, 90, 253–263. https://doi.org/10.1016/j.jclepro.2014.11.034

Qing, L., Chun, D., Dagestani, A. A., et al. (2022). Does Proactive Green Technology Innovation Improve Financial Performance? Evidence from Listed Companies with Semiconductor Concepts Stock in China. Sustainability, 14(8), 4600. https://doi.org/10.3390/su14084600

Qiu, L., Hu, D., & Wang, Y. (2020). How do firms achieve sustainability through green innovation under external pressures of environmental regulation and market turbulence? Business Strategy and the Environment, 29(6), 2695–2714. https://doi.org/10.1002/bse.2530

Rexhäuser, S., & Rammer, C. (2013). Environmental Innovations and Firm Profitability: Unmasking the Porter Hypothesis. Environmental and Resource Economics, 57(1), 145–167. https://doi.org/10.1007/s10640-013-9671-x

Rodríguez-Espíndola, O., Cuevas-Romo, A., Chowdhury, S., et al. (2022). The role of circular economy principles and sustainable-oriented innovation to enhance social, economic and environmental performance: Evidence from Mexican SMEs. International Journal of Production Economics, 248, 108495. https://doi.org/10.1016/j.ijpe.2022.108495

Ryszko, A. (2016). Proactive Environmental Strategy, Technological Eco-Innovation and Firm Performance—Case of Poland. Sustainability, 8(2), 156. https://doi.org/10.3390/su8020156

Sánchez-Medina, P. S., Díaz-Pichardo, R., Bautista-Cruz, A., et al. (2013). Environmental Compliance and Economic and Environmental Performance: Evidence from Handicrafts Small Businesses in Mexico. Journal of Business Ethics, 126(3), 381–393. https://doi.org/10.1007/s10551-013-1945-2

Scarpellini, S., Portillo-Tarragona, P., & Marin-Vinuesa, L. M. (2019). Green patents: a way to guide the eco-innovation success process? Academia Revista Latinoamericana de Administración, 32(2), 225–243. https://doi.org/10.1108/arla-07-2017-0233

Schiederig, T., Tietze, F., & Herstatt, C. (2012). Green innovation in technology and innovation management – an exploratory literature review. R&D Management, 42(2), 180–192. https://doi.org/10.1111/j.1467-9310.2011.00672.x

Semenova, A., Semenov, K. (2022). The Impact of Environmental Innovations on Corporate Financial Performance: Examining the Influential Factors. In: Proceedings of the 3rd Euro-Mediterranean Conference for Environmental Integration (EMCEI 2021).

Severo, E. A., Guimarães, J. C. F. de, & Dorion, E. C. H. (2017). Cleaner production and environmental management as sustainable product innovation antecedents: A survey in Brazilian industries. Journal of Cleaner Production, 142, 87–97. https://doi.org/10.1016/j.jclepro.2016.06.090

Stanley, T. D. (2001). Wheat From Chaff: Meta-Analysis As Quantitative Literature Review. Journal of Economic Perspectives, 15(3), 131–150. https://doi.org/10.1257/jep.15.3.131

Stefan, A., & Paul, L. (2008). Does It Pay to Be Green? A Systematic Overview. Academy of Management Perspectives, 22(4), 45–62. https://doi.org/10.5465/amp.2008.35590353

Suat, L., San, O. (2019). Corporate environmental management: Eco-efficiency and economics benefits among manufacturers certified with EMS14001 in Malaysia. International Journal of Recent Technology and Eng, 7(6), 873–886.

Tang, M., Walsh, G., Lerner, D., et al. (2017). Green Innovation, Managerial Concern and Firm Performance: An Empirical Study. Business Strategy and the Environment, 27(1), 39–51. https://doi.org/10.1002/bse.1981

Tariq, A., Badir, Y., & Chonglerttham, S. (2019). Green innovation and performance: moderation analyses from Thailand. European Journal of Innovation Management, 22(3), 446–467. https://doi.org/10.1108/ejim-07-2018-0148

Tariq, A., Badir, Y. F., Tariq, W., et al. (2017). Drivers and consequences of green product and process innovation: A systematic review, conceptual framework, and future outlook. Technology in Society, 51, 8–23. https://doi.org/10.1016/j.techsoc.2017.06.002

Tugores, M., & García, D. (2015). The Impact of Innovation on Firms' Performance: An Analysis of the Hotel Sector in Majorca. Tourism Economics, 21(1), 121–140. https://doi.org/10.5367/te.2014.0440

Vasileiou, E., Georgantzis, N., Attanasi, G., et al. (2022). Green innovation and financial performance: A study on Italian firms. Research Policy, 51(6), 104530. https://doi.org/10.1016/j.respol.2022.104530

Waddock, S., Graves, S. (1997). The corporate social performance—financial performance link. Strategic Management, 18(4), 303–319.

Wagner, C. H. (1982). Simpson's Paradox in Real Life. The American Statistician, 36(1), 46–48. https://doi.org/10.1080/00031305.1982.10482778

Walsh, I., & Kalika, M. (2018). Network Dynamics in the French-Speaking and English-Speaking IS Research Communities. Systèmes d'information & Management, Volume 23(4), 67–145. https://doi.org/10.3917/sim.184.0067

Weng, H.-H., Chen, J.-S., & Chen, P.-C. (2015). Effects of Green Innovation on Environmental and Corporate Performance: A Stakeholder Perspective. Sustainability, 7(5), 4997–5026. https://doi.org/10.3390/su7054997

Wernerfelt, B. (1984). A resource-based view of the firm. Strategic Management Journal, 5(2), 171–180. https://doi.org/10.1002/smj.4250050207

Wu, G.-C. (2017). Environmental innovation approaches and business performance: effects of environmental regulations and resource commitment. Innovation, 19(4), 407–427. https://doi.org/10.1080/14479338.2017.1358102

Wu, S., Zhou, X., & Zhu, Q. (2023). Green credit and enterprise environmental and economic performance: The mediating role of eco-innovation. Journal of Cleaner Production, 382, 135248. https://doi.org/10.1016/j.jclepro.2022.135248

Wysocki, J. (2021). Innovative Green Initiatives in the Manufacturing SME Sector in Poland. Sustainability, 13(4), 2386. https://doi.org/10.3390/su13042386

Xie, X., Hoang, T. T., & Zhu, Q. (2022). Green process innovation and financial performance: The role of green social capital and customers' tacit green needs. Journal of Innovation & Knowledge, 7(1), 100165. https://doi.org/10.1016/j.jik.2022.100165

Xie, X., Huo, J., Qi, G., et al. (2016). Green Process Innovation and Financial Performance in Emerging Economies: Moderating Effects of Absorptive Capacity and Green Subsidies. IEEE Transactions on Engineering Management, 63(1), 101–112. https://doi.org/10.1109/tem.2015.2507585

Xie, X., Huo, J., & Zou, H. (2019). Green process innovation, green product innovation, and corporate financial performance: A content analysis method. Journal of Business Research, 101, 697–706. https://doi.org/10.1016/j.jbusres.2019.01.010

Xu, Q., Xu, L., Xie, Z., Jin, M. (2021). Does Business Group Matter for the Relationship between Green Innovation and Financial Performance? Evidence from Chinese Listed Companies. Sustainability, 13, 13204. https://doi.org/10.3390/su132313204

Xue, M., Boadu, F., & Xie, Y. (2019). The Penetration of Green Innovation on Firm Performance: Effects of Absorptive Capacity and Managerial Environmental Concern. Sustainability, 11(9), 2455. https://doi.org/10.3390/su11092455

Yan, W., Cui, Z., & Gil, M. J. Á. (2016). Assessing the impact of environmental innovation in the airline industry: An empirical study of emerging market economies. Environmental Innovation and Societal Transitions, 21, 80–94. https://doi.org/10.1016/j.eist.2016.04.001

Yi, Y., Zeng, S., Chen, H., et al. (2021). When Does It Pay to Be Good? A Meta-Analysis of the Relationship Between Green Innovation and Financial Performance. IEEE Transactions on Engineering Management, 70(9), 3260–3270. https://doi.org/10.1109/tem.2021.3079098

Yu, W., Ramanathan, R., & Nath, P. (2017). Environmental pressures and performance: An analysis of the roles of environmental innovation strategy and marketing capability. Technological Forecasting and Social Change, 117, 160–169. https://doi.org/10.1016/j.techfore.2016.12.005

Yurdakul, M., & Kazan, H. (2020). Effects of Eco-Innovation on Economic and Environmental Performance: Evidence from Turkey's Manufacturing Companies. Sustainability, 12(8), 3167. https://doi.org/10.3390/su12083167

Zailani, S., Govindan, K., Iranmanesh, M., et al. (2015). Green innovation adoption in automotive supply chain: the Malaysian case. Journal of Cleaner Production, 108, 1115–1122. https://doi.org/10.1016/j.jclepro.2015.06.039

Zandi, G. R., Ghani, E. K., Lestari, R. M. E., et al. (2019). The impact of management accounting systems, eco-innovations and energy efficacy on firm's environmental and economic performance. International Journal of Energy Economics and Policy, 9(6), 394–400. https://doi.org/10.32479/ijeep.8364

Zhang, D., Rong, Z., Ji, Q. (2019). Green innovation and firm performance: Evidence from listed companies in China. Resources, Conservation and Recycling, 144, 48–55. https://doi.org/10.1016/j.resconrec.2019.01.023

Zhou, X., Zhou, D., Zhao, Z., et al. (2022). A framework to analyze carbon impacts of digital economy: The case of China. Sustainable Production and Consumption, 31, 357–369. https://doi.org/10.1016/j.spc.2022.03.002

Zhu, Q., Feng, Y., & Choi, S. B. (2017). The role of customer relational governance in environmental and economic performance improvement through green supply chain management. Journal of Cleaner Production, 155, 46–53. https://doi.org/10.1016/j.jclepro.2016.02.124

Zhu, X., & Yang, Y. (2021). Big Data Analytics for Improving Financial Performance and Sustainability. Journal of Systems Science and Information, 9(2), 175–191. https://doi.org/10.21078/jssi-2021-175-17

Appendix A. Analyzed studies characteristics

Table A1. Aggregation of the studies concluding the positive impact of environmental innovations on corporate financial performance.

Source	Data source	Location	Number of firms	Time period	Findings
Qiu et al. (2020)	Databases	China	472 firms	2006–2017	Environmental regulation has a positive impact on green process innovation and green product innovation and then improves financial performance.
Gangi et al. (2020)	Databases	Various countries	101 firms	2013–2017	Corporate environmental responsibility and green practices represent cospecialized assets that enhance an intangible asset, namely, corporate reputation. The latter influence constitutes a missing link between sustainable development and the firm's financial performance.
Yurdakul et al. (2020)	Questionnaires	Turkey	219 firms	2011–2016	Eco-innovation has a direct effect on pollution prevention, resource-saving and recycling; furthermore, it has an indirect positive effect on cost reduction and thus on economic performance.
Ma et al. (2021)	Databases	China	613 firms	2016–2017	Both green technology innovation and environmental information disclosure have positive effects on financial performance.
Andries et al. (2019)	Databases	Belgium	1761 firms	2006–2008	Environmental innovations generally lead to improved financial performance, as they allow firms to reduce waste disposal and raw material cost, increase product value and firm competitiveness, reduce public and community pressure, and even help shape future regulations which raise competitors' relative costs.
Xue et al. (2019)	Questionnaires	China	253 firms	2018	Green innovation has a robustly positive effect on firm performance dimensions (operational, financial and environmental).
Ong et al. (2019)	Questionnaires	Malaysia	124 firms	2019	Environmental innovation is found to be the mediator that transforms the benefits of environmental performance into financial performance.
Liao (2018)	Databases	China	366 firms	2017	The three dimensions of environmental innovation all promote a firm's financial performance.
Chu et al. (2018)	Questionnaires	China	165 firms	2015	Green innovation positively affects financial performance for 3PL providers in China.
Xie et al. (2016)	Databases	China	10 years panel data from 28 industries in China.	2002–2011	The results show that clean technologies and end-of-pipe technologies are positively related to financial performance at the industry level, thus it pays to be 'green.' Data are obtained from China Statistical Yearbook (2002–2011).
Lee et al. (2015)	Databases	Japan	3467 firm-year observations	2001–2010	Green research and development are positively related to financial performance at the firm level.
Li et al. (2020)	Questionnaires	China	229 firms	2020	Green product innovation has more impact on financial performance than green publicity. It was also found that environmental performance has a positive effect on financial and social performance results.

Table A1. (*Continued*).

Source	Data source	Location	Number of firms	Time period	Findings
Li (2014)	Questionnaires	China	148 firms	2014	Environmental innovation practices have a significant positive impact on firms' environmental performance, while the effect on financial performance should be through the mediating role of environmental performance. The further analysis reveals that the relationship between environmental innovation practices and financial performance is moderated by the level of resource commitment. As resource commitment increases, the financial performance yielded from environmental innovation practices will be better.
Chaudhry et al. (2020)	Questionnaires	Pakistan	363 firms	2020	Environmental innovations have positive and significant impacts on financial performance.
Xie et al. (2019)	Questionnaires	China	209 firms	2019	Green process innovation has a positive impact on green product innovation, and that both green process innovation and green product innovation can improve a firm's financial performance.
de Azevedo Rezende et al. (2019)	Databases	Various countries	356 multinational firms	2006–2015	There is no significant association of green innovation's intensity with firm financial performance in the immediate year, however, the association is positive, lasts during the subsequent years and becomes expressively higher after 2 years.
Lin et al. (2019)	Databases	Various countries	163 international firms	2011–2017	The empirical results indicated that the green innovations strategy positively affected corporate financial performance.
Tariq et al. (2019)	Databases	Thailand	202 firms	2016	The findings reveal that green product innovation performance exerts a significant influence on a firm's financial performance, i.e., the higher green product innovation performance, the higher the firm's profitability and lower the firm's financial risk.
Marin-Vinuesa et al. (2018)	Questionnaires	Spain	87 firms	2015	The results suggest that there is a positive relationship between the level of eco-innovation performed by companies and their financial performance.
Cainelli et al. (2011)	Questionnaires	Italy	555 firms	2006–2008	The economic performance (profits, turnover, employment) of eco-inno-vating firms in 2006–2008 during the global crisis was better than that of non-innovating firms. Investment in EI seems not to have weakened firms but rather made them more economically resilient to shocks.
Antonioli et al. (2016)	Databases	Italy	555 firms	2006–2008	Environmental innovations turn out to be positively and significantly correlated to revenue.
Tugores et al. (2015)	Questionnaires	Majorca	200 firms	2008	Some particular environmental innovations are found to have a positive impact on hotel performance, revenue in particular.
Scarpellini et al. (2019)	Databases	Various countries	2218 firms	2013	The findings confirm the positive influence of implementing eco-innovation on companies' financial performance.
Sánchez-Medina et al. (2013)	Databases	Mexico	186 firms	2013	The findings provide empirical evidence on the importance of successful environmental regulation in small businesses as a means of promoting environmental innovation and improving economic performance.

Table A1. (*Continued*).

Source	Data source	Location	Number of firms	Time period	Findings
Bogers et al. (2019)	Databases	Norway	101 firms	2013–2017	Sustainability-oriented innovations fully mediate the association between stakeholder and financial performance (measured by profitability). Engaging external stakeholders in sustainability-oriented processes generates economic, environmental and social improvements, which consequently enhance a firm's financial performance.
Huang et al. (2010)	Questionnaires	Taiwan	181 firms	2010	Green product innovation performance has a positive effect on financial performance.
Cai et al. (2018)	Databases	China	442 firms	2018	Eco-innovation behavior can significantly enhance a firm's environmental performance, and, through environmental performance, has an indirect positive impact on its economic performance.
Chan et al. (2016)	Questionnaires	China	250 responses	2015	Green product innovation could bring firms not only cost efficiency but also profitability, thus for firms with either orientation, green product innovation development is a key capability for competitiveness.
Chu (2018)	Questionnaires	China	165 firms	2015	Green innovation practices have a positive effect on the financial performance of 3PL providers.
Zailani et al. (2015)	Questionnaires	Malaysia	153 firms	2015	Green innovation initiatives have a positive effect on the three categories of sustainable performance (i.e., environmental, social, and economic).
Zhu et al. (2017)	Questionnaires	China	333 firms	2015	Both green innovation and green purchasing can facilitate economic performance, but only under the right customer relational governance.
Severo et al. (2017)	Questionnaires	Brazil	762 firms	2013–2014	Sustainable Product Innovation is positively related to financial performance.
Hojnik et al. (2016)	Questionnaires	Slovenia	223 firms	2014–2015	Process eco-innovation is worthwhile in terms of company profitability, growth, and competitive benefits.
Suat et al. (2019)	Questionnaires	Malaysia	85 firms	2019	Environmental innovation was found to be positively associated with both competitive advantage and financial performance.
Amores-Salvado et al. 2014	Questionnaires	Spain	157 firms	2011	Environmental product innovations have a positive but not statistically significant effect on firm performance.
Ar (2012)	Questionnaires	Turkey	140 firms	2011	Green product innovation generally positively affects firm performance, in particular financial performance (i.e., return on investment).
Burki et al. (2018)	Questionnaires	Turkey	181 firms	2018	Green innovations enhance economic performance.
Ebrahimi et al. (2017)	Questionnaires	Iran	112 firms	2017	There is a significant relationship between green innovation and financial performance growth with regards to the mediating role of green entrepreneurship.
Guo et al. (2019)	Questionnaires	China	416 firms	2018	Environmental innovation has a significant positive impact on economic performance.
Leyva de la Hiz et al. (2018)	Databases	Various countries	5845 firms	2006–2009	There exists positive relationship between focused environmental innovations and a firm's financial performance.
Yu et al. (2017)	Mixed	UK	121 firms	2009–2010	Environmental innovation strategy is positively related to financial performance.
Wysocki (2021)	Databases	Poland	342 firms	2017	Innovative green initiatives bring measurable benefits to the implementers (e.g., revenue growth).

Table A1. (*Continued*).

Source	Data source	Location	Number of firms	Time period	Findings
Zandi et al. (2019)	Questionnaires	Indonesia	319 responses	2019	Ecological innovations have positive and significant impact on economic performance.
Wu (2017)	Databases	Taiwan	166 sets of sample data	2017	Exploratory environmental innovation has no significant effect on ROA. In contrast, exploitative environmental innovation does have a significant, positive effect on ROA.
Colombelli et al. (2019)	Databases	France, Italy, Germany, Spain, the UK, Sweden	456,240	2002–2010	The involvement in the generation of green technologies is positively associated with firms' growth rates.
Tang et al. (2017)	Questionnaires	China	188	2017	We find that green process innovation and green product innovation both significantly (positively) predict firm performance, when not considering managerial concern for the environment.
Zhang et al. (2019)	Databases	China	764	2000–2010	We find a positive and significant relationship between green patenting and firm performance.
Johl et al. (2021)	Databases	Malaysia	31	2015–2019	Proactive eco-innovation (product eco-innovation, process eco-innovation, and technology ecoinnovation) has a direct effect on firm financial performance.
Xu et al. (2021)	Databases	China	202	2013–2017	BG-affiliated firms' supply chain (suppliers and customers) concentration and trust positively moderate the relationship between green innovation and financial performance.
Weng et al. (2015)	Questionnaires	Taiwan	202	2012	The results also indicate that green innovation has positive effects on firm performance, both financial and non-financial. Through these practices, firms cannot only generate better financial performance (e.g., increase their market share, increase sales revenues); they can also improve their corporate image to attract additional customers.
Zhu et al. (2021)	Questionnaires	Various countries	37	2021	It was found that internal and external green supply chain management practices have a positive effect on the environmental and financial performance of banks.
Rodrigez-Espindola et al. (2022)	Questionnaires	Mexico	165	2018–2019	The overarching finding is that circular economy promoting sustainability-oriented innovation has a positive impact on financial, environmental, and social performance.
Vasileiou et al. (2022)	Questionnaires	Italia	144,30	2006–2008	We find that environmental benefits achieved due to organizational change have a significant effect on the Italian firms' turnover.

Table A2. Aggregation of the studies concluding the negative impact of environmental innovations on corporate financial performance.

Source	Data source	Location	Number of firms	Time period	Findings
Duque-Grisales et al. (2020)	Databases	Latin America	86 firms	2013–2017	Implementing effective green innovations is not associated with greater financial performance.
Przychodzen et al. (2019)	Databases	Various countries	Standard and Poor's 500 companies	1999–2016	High green innovative activism, measured by patent data, only harms current financial performance when not carried out in conjunction with other types of innovative activism. Too much concentration on green innovation relative to other types of innovative activism has a negative influence on both accounting and stock market performance.

Table A2. (*Continued*).

Source	Data source	Location	Number of firms	Time period	Findings
Borsatto et al. (2020)	Databases	Various countries	159 industrial companies.	2015	The efforts of companies in green innovations do not reflect positively on their financial performance. Companies were studied that listed in the Financial Times' 500 largest companies by market value in 2015.
Padgett et al. (2012)	Databases	Various countries	418 firms	1996–2007	There is a negative and significant effect between innovation with high social benefit and financial performance.
Ryszko (2016)	Databases	Poland	292 firms	2013	The direct effect of technological eco-innovation on financial performance is not statistically significant.
Fernando et al. (2019)	Databases	USA	718 firm-years	1997–2007	Green environmental strategies do not increase market valuation, but there is also not a statistically significant difference in performance between green and environmentally neutral firms. Only inappropriate environmental management is valued lower by the market.

Table A3. Aggregation of the studies concluding the dual impact of environmental innovations on corporate financial performance.

Source	Data source	Location	Number of firms	Time period	Findings
Hoang et al. (2020)	Databases	USA	361 firms	2007–2016	Environmental transparency positively influences current accounting and stock market performance, but negatively influences the return on capital employed. Lower pollution emissions tend to improve the current return on assets while being harmful to the efficiency of long-term capital employment at the same time. The Global Financial Crisis (2007–2010) increased the environmental transparency of firms with green patents but negatively impacted their price-to-earnings ratio.
Przychodzen et al. (2015)	Databases	Poland, Hungary	439 firms	2006–2013	The results indicated that eco-innovators were generally characterized by higher returns on assets and equity and lower earnings retention.
Cortez et al. (2011)	Databases	Japan	20 firms	2001–2009	The automotive companies exemplify the resource-based view perspective as positive impacts of environmental innovations that are observed on revenues, profits, assets, long-term debt and equity, and vice-versa. However, these impacts seem to weaken over time. The electronics companies show only revenues and long-term debt as significantly controlled by environmental innovations and vice-versa.
Bermudez-Edo et al. (2016)	Databases	Various countries	79 firms	2005–2009	The geographical scope of the exploitation of environmental patents increases the positive relationship between patented environmental innovation and financial performance whereas the geographical scope of knowledge sourcing of environmental patents does reduce this performance.
Yan et al. (2016)	Databases	Various countries	40 firms	2016	Both technology- and process-based environmental innovations positi-vely influence airlines' revenue, but only process-based environmental innovations have positive impacts on airlines' profit. There is a negative interaction relationship between technology- and process-based environmental innovations on airlines' financial performance. In relation to operational efficiency, only process-based environmental innovations exert a positive impact on the occupancy rate of airlines.
Garcia-Sanchez et al. (2019)	Databases	Various countries	6454 firms	2002–2017	Although environmental innovation strategies do not entail higher returns, they are well valued by the capital market.

Table A3. (*Continued*).

Source	Data source	Location	Number of firms	Time period	Findings
Rexhäuser et al. (2013)	Mixed	Germany	3618 observations	2013	Environmental innovations which do not improve firms' resource efficiency do not provide positive returns to profitability. However, innovations that increase a firm's resource efficiency in terms of material or energy consumption per unit of output have a positive impact on profitability.
Lopes Santos et al. (2019)	Databases	Various countries	231 firms	2012–2014	The environmental and social variables were significant only for return on sales (ROS) and differed between companies located in emerging and developed countries.
Ghisetti et al. (2014)	Questionnaires	Germany	1063 observations	2009–2011	If we look at innovations leading to a reduction in the use of energy and resources, we can conclude that it definitely pays to be green. If we then turn to innovations aimed at reducing externalities, such as harmful materials and air, water, noise and soil pollution, we should conclude that it does not pay to be green. Although it may be profitable in the long run due to improved environmental regulation, it does not pay off in the short run when environmental regulation has to be faced as an external restriction.
Forsman (2013)	Databases	Finland	128 firms	2002–2010	The findings suggest that green innovators have gained strong market-related competitive advantage in terms of high sales growth. Instead, the findings suggest that the development and exploitation of environmental innovations have not created such competitive advantage that has led to improved performance in terms of the return on total assets and the rate of operating earnings.
Aguilera-Caracuel et al. (2013)	Databases	Various countries	88 firms	2007–2008	Green innovative firms do not experience an improved financial performance, however, at the same time, the intensity of green innovation is positively related to firm profitability.
Long et al. (2017)	Questionnaires	China	76 pairs of innovative and non-innovative firms	2015–2016	Generally environmental innovations have positive effect on financial performance. Environmental innovations related to product design and production processes positively affect economic performance, while raw materials have no significant impact on economic performance.
Aastvedt et al. (2021)	Databases	The USA and Europe	44	2010–2018	In the US, at low level of environmental pillar score, there is a positive effect and at higher levels the effect turns to negative. In Europe, at low level of environmental pillar score, there is a negative effect, which turns positive at higher levels.
Qing et al. (2022)	Questionnaires	China	126	2010–2020	It was found that proactive green process innovation has a significant positive effect on both short-term and long-term corporate financial performance. Moreover, proactive green product innovation has a significant positive effect on long-term corporate financial performance. However, it does not improve short-term corporate financial performance.
Xie et al. (2022)	Questionnaires	China	221	2021	Green process innovation has a U-shaped impact on firms' financial performance, such that the impact is initially negative but then becomes more positive as the level of green process innovation increases

Appendix B.

Table B1. Prisma checklist.

Section and topic	Item #	Checklist item	Location where item is reported
Title			
Title	1	Identify the report as a systematic review.	Title
Abstract			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract
Introduction			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction
Methods			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Method (Literature search and selection)
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Method (Literature search and selection)
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Method (Literature search and selection)
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Method (Literature search and selection)
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Method (Literature search and selection)
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g., for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Method (Literature search and selection)
	10b	List and define all other variables for which data were sought (e.g., participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Method (Literature search and selection)
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Method (Selected Papers Processing)
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Method (Selected Papers Processing)

Table B1. (*Continued*).

Section and topic	Item #	Checklist item	Location where item is reported
Methods			
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Method (Selected Papers Processing)
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Method (Selected Papers Processing)
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Method (Selected Papers Processing)
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Method (Meta-analysis Approach)
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Method (Meta-analysis Approach)
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Method (Meta-analysis Approach)
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Method (Selected Papers Processing)
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Method (Meta-analysis Approach)
Results			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Results
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Results
Study characteristics	17	Cite each included study and present its characteristics.	Results
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Results
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Results
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Results
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Results
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Results
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Results

Table B1. (*Continued*).

Section and topic	Item #	Checklist item	Location where item is reported
Results			
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Results
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Results
Discussion			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion, implications, and conclusion (Discussion and Conclusion)
	23b	Discuss any limitations of the evidence included in the review.	Discussion, implications, and conclusion (Research Limitations and Future Research)
	23c	Discuss any limitations of the review processes used.	Discussion, implications, and conclusion (Research Limitations and Future Research)
	23d	Discuss implications of the results for practice, policy, and future research.	Discussion, implications, and conclusion (Research Limitations and Future Research; Theoretical and practical implications)
Other information			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Not registered
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Not prepared
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Acknowledgements
Competing interests	26	Declare any competing interests of review authors.	Not applicable
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Appendix A