

Stockholm School of Economics

MSc Thesis in Business and Management

Digital Transformation and Its Differential Impact on ESG disclosure Practices -

A Comparative Study of Traditional and Clean Energy Companies

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Abstract

This study examines how digital transformation influences Environmental, Social, and Governance (ESG) disclosure quality in the energy sector, focusing on differences between traditional fossil fuel-based firms and clean energy companies across China, Europe, and the United States. This study analyzes data from 2018–2022 on 204 publicly listed energy companies to examine four hypotheses linking digital maturity—proxied by R&D expenditures—to ESG reporting outcomes. The findings indicate that greater digital maturity generally corresponds to higher-quality ESG disclosures. Clean energy firms not only display higher digital maturity but also translate these capabilities more effectively into improved ESG reporting, reflecting their strategic emphasis on innovation and sustainability. While traditional energy companies benefit less from digital investments in enhancing ESG transparency. Regional factors further moderate these effects, supportive regulatory environments and strong sustainability norms in China and Europe strengthen the link between digital maturity and ESG disclosure, while the relationship is less pronounced in the U.S., where fewer regulatory pressures and greater emphasis on financial metrics prevail. The results underscore the importance of aligning digital initiatives with sustainability goals, adapting strategies to regional conditions, and recognizing that digital transformation can serve as a powerful enabler of improved ESG practices in energy companies.

Keywords: Digital Transformation, ESG Disclosure, Digital Maturity, Energy Sector, Clean Energy, Traditional Energy, Sustainability Reporting

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1. Introduction

1.1 Background

In recent years, the rapid growth of digital technologies has changed how companies operate, communicate, and disclose information. Many firms now use digital tools to improve efficiency, openness, and decision-making. These tools create a technical base that lets companies refine their internal information systems, which helps increase the accuracy and speed of corporate disclosures. As companies move toward digital transformation, it is important to see how these advances affect how firms report their activities and commitments, especially in areas related to sustainability.

Society's expectations of corporate responsibility have also shifted, because of rising concerns about environmental risks and sustainability. Climate change, resource depletion, and pollution have increased public awareness, which leads to more scrutiny of corporate behavior. This new focus brings environmental, social, and governance (ESG) issues to the forefront of business strategy. ESG reporting is now an important way to measure corporate responsibility and sustainability, giving stakeholders a view of a company's environmental impact, social responsibility, and governance practices. Investors and other stakeholders see ESG performance as a sign of a company's long-term strength, believing that firms with strong ESG practices are better equipped to handle risks and find opportunities in a changing world.

The energy industry, which strongly affects the environment, faces specific challenges in the global push for sustainable development. On one side, energy companies power economies and societies. On the other side, the sector is a major source of greenhouse gas emissions and environmental harm, so it gets a lot of attention regarding ESG issues. Clean energy firms continue to grow and innovate, while traditional energy firms deal with increasing pressure to adapt. It is crucial to see how digital transformation affects ESG disclosure in the energy sector. Clean energy companies often lead in using

advanced technologies and aiming for sustainable goals, while traditional energy companies face more complex hurdles. They must either lead a shift toward clean energy or improve their existing operations to meet stakeholder demands for clearer disclosure.

1.2 Research Questions

While existing research has extensively examined ESG reporting and digital transformation as independent factors, there has been limited exploration into how these two areas intersect and influence each other.

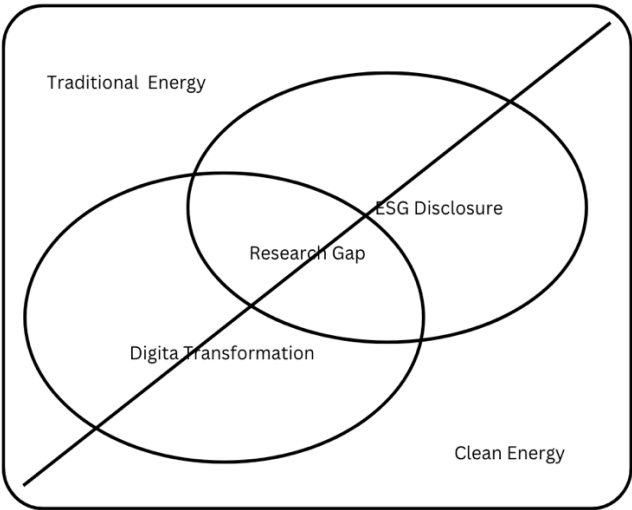


Table 1

This gap (table 1) is particularly significant in industries like the energy sector, which is currently under immense pressure from both environmental and societal demands. The traditional energy industry, dominated by fossil fuels, faces increasing environmental scrutiny due to its significant contribution to pollution and climate change. Stakeholders—including governments, investors, and the public—are paying closer attention to corporate responsibility and sustainability, particularly in relation to environmental risks and social impacts. The expectation for greater transparency in ESG disclosures has risen sharply because of both growing societal concern and stricter regulatory requirements. At the same time, the energy industry is undergoing a

significant shift towards digital transformation, which is seen as a necessary step for improving operational efficiency, enhancing transparency, and meeting sustainability goals. And for the clean energy sector, driven by ESG trends and government policies promoting sustainability, is experiencing rapid growth. Clean energy companies are often viewed as leaders in sustainability practices, and digital transformation is increasingly being leveraged to optimize their operations and enhance the quality of their ESG reporting. However, the extent to which digital maturity level influences ESG disclosure practices across both traditional and clean energy companies remains underexplored.

Given the critical role of the energy sector in global sustainability efforts and the dual pressures of environmental risk and the need for digital transformation, there is a pressing need to investigate the relationship between digital maturity and ESG disclosure. This study aims to address the following central research question: **How does digital maturity—consider as a level of digital transformation process—influence the quality and transparency of ESG disclosures in traditional energy companies versus clean energy companies?** It explores whether clean energy firms, often seen as more progressive in adopting digital technologies, experience a greater benefit in ESG reporting compared to their traditional counterparts. These questions are vital for understanding how energy companies can leverage digital transformation to enhance their sustainability efforts and meet the rising expectations for corporate responsibility.

1.3 Research Objectives

This study will look at how digital transformation affects ESG disclosure among energy companies, with a special focus on the differences between traditional energy firms and clean energy firms. It will use a sample of energy companies in China, Europe, and the United States during a five-year period from 2018 to 2022. The objectives are: (1) to

see how digital maturity (shown by R&D spending) influences the quality and clarity of ESG reporting, and reveal how a company's digital maturity helps or hinders ESG disclosure; (2) to examine how digital transformation affects ESG disclosure differently in traditional energy companies and clean energy firms. Because these two types of firms differ in how far they have developed digitally and in their environmental impacts, this research aims to understand the unique problems each group faces and how various levels of digital transformation shape their disclosure behavior: (3) to focus on three regions—China, Europe, and the United States—to see how regional differences matter. These three regions have distinct ESG and energy conditions: China, a big energy producer, faces rising regulatory demands to improve ESG standards, and its ESG rules are advancing quickly, which may influence energy companies' ESG disclosure. Europe leads in clean energy development, and companies and society stress ESG, setting high sustainability standards. The United States has a very active commercial market, and it is a key place to study how regulation and market-driven sustainability interact. By looking at energy companies in these three regions, the study can offer accuracy and reference value; (4) to identify other possible factors, like company size, profitability, governance structure, and local policy frameworks, that may affect how digital transformation and ESG disclosure connect, giving a full picture of what drives ESG openness in different settings.

1.4 Significance of the Study

This study adds to current research by seeing how digital transformation affects ESG reporting in the energy sector. By focusing on both traditional and clean energy firms for comparison, it can address gaps in the existing work on digital transformation and ESG disclosure in the energy industry. So, the study's significance is twofold: it covers a big gap in academic studies, and it offers practical guidance for industry and policymaking.

First, the study meets an important gap in the current literature. Prior studies have examined ESG disclosure and digital transformation on their own, but few have looked at the link between them, especially in the energy sector. Since this sector is heavily influenced by digital development and ESG factors, this work provides new insights into how digital transformation can shape ESG disclosure by contrasting traditional and clean energy companies. This approach deepens understanding of digital transformation as a driver of corporate sustainability reporting and offers evidence for future studies in various energy segments.

Second, this study has practical value for energy companies that face rising pressure for clear information and sustainable operations. As the energy sector undergoes big changes and sees intense competition between traditional and clean energy due to new technology and stricter rules, this study points out digital maturity (based on R&D spending) as a main factor in ESG disclosure quality. This can guide companies to understand how digital transformation upgrades their ESG reporting and to plan strategies that meet the needs of investors, regulators, and consumers.

Third, the study can help policymakers by taking a cross-regional view of how digital transformation relates to ESG disclosure in different regulatory settings. By comparing data from China, Europe, and the United States, it shows how policy setups, market conditions, and development levels affect ESG practices. Insights from this cross-regional analysis can help policymakers shape better ESG regulations and strategies that improve transparency and sustainability in the energy sector.

Fourth, the paper shows how digital innovation can move the energy industry toward more sustainable practices, giving ideas for wider discussions about global sustainable development.

2. Literature Review

2.1 Introduction to the Literature Review

This literature review aims to provide a thorough examination of existing research on digital transformation and Environmental, Social, and Governance disclosure practices within the energy industry. By exploring definitions, core technologies, impacts, and evaluation frameworks of digital transformation alongside the evolution, standards, and sector-specific challenges of ESG reporting, this chapter will build a solid theoretical basis for present studies. Central to this review is the intersection of digital transformation and ESG disclosure, highlighting how digital maturity influences reporting practices, particularly within traditional and clean energy sectors. Furthermore, it identifies gaps in current literature, emphasizing the need for a comparative analysis that incorporates regional perspectives and considers additional influencing factors.

2.2 Digital Transformation in the Energy Industry

2.2.1 Definition of Digital Transformation

In today's changing environment, it is important to tell the difference between digitization, digitalization, and digital transformation. Each stands for a different stage and depth of using digital technologies in organizations. Digitization means turning analog information into digital form (Hess et al., 2016; Parviainen et al., 2017). This step lets data be stored, processed, and shared electronically, which lays the groundwork for later digital improvements. Digitalization builds on digitization by using digital tools to make existing business processes more efficient and effective (Schwarzmueller et al., 2018; Gökalp & Martinez, 2022). It focuses on raising productivity and service quality in current organizational structures and business models. But digital transformation is a deep change that goes beyond improving processes. It brings digital technologies into every part of an organization, changing how businesses run and how they provide value to customers (Vial, 2019; Teichert, 2019). It is a strategic move that

reshapes business models, organizational structures, and market limits, making it key for staying competitive in the digital era. As Vial (2019) says, digital transformation is “a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies.” This means digital transformation involves more than technology alone. It also needs changes in culture, ways of thinking, and abilities within the organization (Kraus et al., 2021).

Digital transformation is not just about using new technologies. It also involves rethinking how a company works and creates value. This shift affects many layers of the organization, from inside processes and structures to outside relationships with various stakeholders. One part of this shift is changing organizational structures and cultures. Old hierarchical setups often give way to more flexible, team-based, and faster decision-making approaches (Sjödín et al., 2018; Bumann & Peter, 2019). This makes it easier for companies to react quickly to changes in the market and advances in technology. Building a digital culture is also very important because it shapes how employees accept and use new tools (Teichert, 2019; Vial, 2021). A digital mindset that values agility, innovation, and ongoing learning is vital for digital transformation efforts. Another part of digital transformation involves rethinking business models. Companies use digital technologies to offer new value, enter new markets, and design creative products and services (Beverungen et al., 2017; Plekhanov et al., 2023). For example, big data analytics, the Internet of Things (IoT), and artificial intelligence (AI) let companies provide personalized and data-driven solutions that improve the customer experience and competitive position (Frank et al., 2019; Solis, 2015). Also, bringing in advanced technologies can lead to better operational efficiency and innovation. Automation, AI, and data analytics help organizations optimize processes, lower costs, and make more accurate decisions (Gökalp & Martinez, 2021; Parida et al., 2015). Kane et al. (2015) note that digital transformation boosts organizational agility, so firms can keep up with market changes and stay competitive. The last point is how digital

transformation strengthens interactions with stakeholders by improving openness, teamwork, and quick response (Liu, Liu, & He, 2023). Through real-time data analytics and digital communication platforms, organizations can serve customers more effectively, leading to higher satisfaction and loyalty (Sjödín et al., 2016; Richter et al., 2017).

2.2.2 Digital Transformation in Energy

Digital transformation in the energy sector is driven by key digital technologies. These include AI, IoT, big data analytics, and blockchain. They are important for better operational efficiency, improved energy production and consumption, and more transparent, sustainable practices (Ahmad et al., 2022; Nambisan et al., 2019). For example, AI can handle large datasets for predictive analytics, equipment failure predictions, and weather analysis. This helps energy companies lower downtime, reduce maintenance costs, and improve renewable energy operations (Ahmad et al., 2021). Also, IoT devices share data in real time to monitor energy use, balance supply and demand with smart grids, and support dynamic grid management (Working, 2022). Big data analytics helps analyze consumption trends, forecast demand, and smoothly bring renewable energy into existing grids (Zhou et al., 2016). Blockchain improves transparency and security in energy trading and resource tracking. This builds trust in renewable energy certificates (Atzori, 2015).

These technologies also require careful tradeoffs. Companies often need large initial spending on infrastructure, training, and system integration. This can be hard for firms with limited funds or little digital knowledge (Nambisan et al., 2019). Also, cybersecurity threats are a big concern, because IoT networks can open the door to attacks that disrupt vital operations or steal sensitive data (Working, 2022). Companies with low digital maturity often deal with old systems, weak technology skills, and resistance to change. This leads to higher costs and less ability to benefit from digital

ideas (Ahmad et al., 2022). So energy firms need a clear plan for digital transformation.

2.2.3 Impact of Digital Transformation on Energy Companies

Digital transformation affects energy companies by changing their operations, business models, and relationships with stakeholders. With advanced digital tools, these companies improve efficiency, encourage innovation, and create new ways to meet market needs. AI and IoT enable predictive maintenance that reduces downtime and extends equipment life, which lowers costs and human mistakes (Wang et al., 2020). For example, traditional energy firms use AI to improve drilling and manage supply chains, while clean energy firms improve renewable generation and storage (Gürdür Broo et al., 2020; Kuo & Huang, 2018). Big data analytics lets energy companies predict demand, spot trends, and customize services. This helps them innovate and make decisions based on data (Zhou et al., 2016). Blockchain supports decentralized energy markets and peer-to-peer trading, which opens new opportunities (Andoni et al., 2019).

Digital transformation also changes how energy companies see themselves in the market. Traditional firms are adding renewables to their portfolios and using digital platforms for integrated energy solutions (Westerman et al., 2014). Clean energy firms use digital tools to highlight sustainability, providing not only energy but also information about usage and cost-saving tips (Parida et al., 2019). The rise of prosumers—customers who produce their own energy—has shifted the market further. Companies now support decentralized production and offer services for energy sharing and management (Jamil et al., 2021). These digital advances help energy companies stay competitive and meet sustainability goals and stakeholder needs.

Another key point for this study is how digital transformation increases transparency

and stakeholder involvement. IoT and blockchain give real-time data about production, use, and environmental effects. This information builds trust and accountability when shared with stakeholders (Lee & Lee, 2015). Better data analytics also leads to more accurate and quick ESG reporting, which meets investor, regulator, and public expectations (Macey, 2022). Clean energy firms use digital platforms to show how they contribute to sustainability and to connect with local communities and customers (Parida et al., 2019). Traditional energy firms use digital tools to track emissions, manage risks, and follow regulations. This helps them deal with growing concerns about environmental impact (Votto et al., 2021).

2.3 Digital Maturity and Its Evaluation

After looking at the major digital technologies changing the energy sector and how they impact companies, it is important to see how firms measure their digital transformation progress. Digital transformation means broadly using digital technologies in all parts of a firm (Kane et al., 2015). Digital maturity focuses on how well a firm uses these technologies to reach strategic goals (Westerman et al., 2012). This difference matters because simply adopting digital tools is not enough. Firms also need leadership support, data sharing, and skilled workers to get the most value (Kane et al., 2017). Digital maturity is a way to check both the presence of digital tools and the firm's ability to use them effectively for better efficiency, transparency, and innovation.

In this research, digital maturity is used as a proxy to measure the progress and effectiveness of digital transformation. While digital transformation is inherently broad and multifaceted, encompassing a wide range of technologies and strategies, digital maturity captures the outcomes and capabilities that directly influence ESG disclosure practices (Ioannou & Serafeim, 2017). This alignment is particularly relevant in the energy sector, where the ability to integrate digital tools into sustainability reporting is a key indicator of transformation success. By evaluating digital maturity, this study

aims to connect the theoretical concept of digital transformation with measurable outcomes in ESG disclosure, providing a robust basis for empirical analysis.

2.3.1 Concept of Digital Maturity

Digital maturity is a firm's ability to use digital methods to create value by fully bringing digital technologies, processes, and skills into every part of its work (Kane et al., 2015). It includes not just adopting technology but also making cultural, strategic, and organizational shifts to use digital opportunities (Westerman et al., 2012). Deloitte (2017) says digital maturity is how far digital technologies have changed a firm's processes, employee engagement, and business models. We measure this by seeing how well a firm fits digital tech into its main strategies and day-to-day operations, which leads to better performance and value. Digital maturity matters because it gives companies a path for digital change, helping them see their strengths and weaknesses (Gill & VanBoskirk, 2016). Firms with high digital maturity can innovate more, react faster to market changes, improve customer experiences, and raise efficiency (Kane et al., 2017). In the energy sector, where new technologies and sustainability concerns grow fast, checking digital maturity is key to staying competitive and meeting what stakeholders want.

2.3.2 Frameworks and Models for Assessing Digital Maturity

Digital transformation is a wide change that brings digital technologies into every part of a firm's work, strategy, and culture. We use digital maturity to measure how deep and effective this transformation is (Kane et al., 2015; Westerman et al., 2012). Digital maturity shows a firm's ability to use digital tools for both operational gains and strategic goals. It looks at the mix of technology skills, internal processes, and strategic direction (Berghaus & Back, 2016).

A common way to measure digital maturity is the Digital Capability Framework (DCF). It looks at IT infrastructure, process digitization, strategic alignment, and transformation management (Berghaus & Back, 2016). IT infrastructure checks if a firm has the right tech base (Deloitte, 2017). Process digitization means using digital tools to make workflows faster and more efficient. Strategic alignment sees how digital efforts match the firm's broader strategy (Westerman et al., 2012). Transformation management involves oversight, tracking performance, and leadership backing (Gill & VanBoskirk, 2016).

But the DCF can be hard to use directly in studies because data is often limited. So, many researchers use R&D spending to show digital maturity. This spending shows how committed a firm is to innovation and new technologies (Westerman et al., 2012; García-Sánchez et al., 2020). It reflects efforts to improve IT infrastructure and link innovation to the firm's long-term plans (Kane et al., 2017). By using R&D spending as a main measure of digital maturity, we can study how digital transformation ties to ESG reporting, especially in the energy field. Though this measure does not cover all parts of the DCF framework, it is a practical way to see how digital transformation affects corporate sustainability. Future research can add more DCF elements to explore bigger effects of digital maturity.

2.3.3 Importance of Digital Maturity in the Energy Sector

Digital maturity is very important in the energy sector because it affects both competitiveness and sustainability. The industry is changing quickly due to new technologies and environmental demands, and high digital maturity helps firms handle these changes better. High digital maturity boosts competitiveness by improving efficiency, encouraging innovation, speeding up decisions, and giving customers a better experience. Tools like IoT, AI, and big data help energy firms optimize operations, lower costs with predictive maintenance, and make smarter strategies that respond to

market shifts (Parida et al., 2019; Wang et al., 2017). Also, digital skills enable new products and services, such as customized energy management, which increases customer satisfaction (Sjödin et al., 2018; Lund et al., 2017).

Digital maturity also supports sustainability. It helps track the environment, include renewable energy, and share ESG information openly. For example, IoT sensors and analytics let companies monitor emissions and resource use in real time, reducing environmental harm and meeting rules (Attard et al., 2016). Also, digital tech helps bring in renewable energy, and tools like blockchain make ESG data more accurate and reliable (Sheehan et al., 2023; Di Silvestre et al., 2020).

2.4 ESG Disclosure Practices

2.4.1 Overview of ESG Reporting

ESG reporting has grown from a small corporate task to a central part of openness and responsibility. It began from corporate social responsibility efforts. ESG reports give details about a company's non-financial performance in areas like the environment, social issues, and governance (KPMG, 2020). It has become more important because people are more aware of sustainability, and they want companies to be open about their practices. They also see that these issues can affect a company's long-term success and risk (Eccles et al., 2014).

ESG reporting started in the late 20th century when firms began voluntarily sharing info on their environmental and social projects. Over time, it expanded with globalization, climate worries, and social topics like labor and diversity (Kolk, 2008). Technology and digital platforms have also made ESG reporting more complete and easier to access (Pavlopoulos et al., 2017). Studies show that solid ESG reporting can help a company's reputation, investor trust, and capital access (Friede et al., 2015).

Companies that clearly communicate their ESG work can set themselves apart, attract investors who care about social issues, and reduce risks related to environment and society (Clark et al., 2015).

Investors, customers, workers, and regulators want firms to be open about ESG practices. Investors factor ESG into their decisions, knowing these points can affect profits and stability (Amel-Zadeh & Serafeim, 2018). This is seen in the growth of responsible investment funds and the use of ESG checks in standard investment strategies (Global Sustainable Investment Alliance, 2018). Regulators worldwide are reacting by issuing rules on ESG reporting. For example, the EU's Non-Financial Reporting Directive requires large companies to disclose environmental, social, human rights, and anti-corruption data (European Commission, 2014). In the US, the SEC is looking at rules to improve ESG reporting for public companies (SEC, 2021). Stock exchanges in many places have also introduced ESG guidelines or listing rules (SSE Initiative, 2020). These actions reflect a global push for more accountability and uniform ESG reporting.

2.4.2 ESG Disclosure Standards and Frameworks

Because ESG reporting is growing fast, several standards and frameworks help make reports consistent and reliable. A well-known one is the Global Reporting Initiative (GRI), which covers economic, environmental, and social impacts (GRI, 2016a; GRI, 2016b). The Sustainability Accounting Standards Board (SASB) sets rules for specific industries, focusing on ESG factors that matter to investors (SASB, 2018). Another key group is the Task Force on Climate-related Financial Disclosures (TCFD), which centers on governance, strategy, risk, and measurements for climate issues (TCFD, 2017).

New rules like the Corporate Sustainability Reporting Directive (CSRD) in the EU make more companies share ESG data using the European Sustainability Reporting Standards (ESRS) (EU, 2022). The Carbon Disclosure Project (CDP) looks at climate, water security, and deforestation (CDP, 2020). The International Integrated Reporting Council (IIRC) supports integrated reporting that combines financial and non-financial details (IIRC, 2013). The United Nations Sustainable Development Goals (SDGs) focus on global problems like climate change and inequality (UN, 2015). Though these frameworks vary, many firms use more than one to meet different stakeholder needs and follow changing rules. There are also efforts to merge these reporting rules (Achenbach, 2021).

2.4.3 ESG Reporting in the Energy Industry

The energy industry, which includes both fossil fuel-based companies and clean energy firms, is key to solving global sustainability problems, so ESG reporting is very important. Because of the industry's big environmental impact, close regulatory watch, and strong stakeholder interest, ESG reporting has become a main way to be transparent and accountable.

Energy companies face special challenges in ESG reporting. Traditional energy production, especially oil, can cause greenhouse gases, pollution, and ecological harm that are hard to measure and disclose fully. Many firms have global operations, making it harder to collect correct environmental data (IEA, 2020; Kolk et al., 2008). Also, energy regulations differ by location, so aligning ESG disclosures can be complex (Eccles & Krzus, 2018). Gathering reliable ESG data is tough when sites are remote or tech is limited, and companies may need costly systems or outside checks (Huang, Hu, & Zhu, 2018). They also must balance being open with protecting proprietary info, since the public and investors watch them closely (Dixon-Fowler et al., 2013). The global shift to renewables creates risks for traditional energy firms, and reporting on

asset stranding or changing market demand adds complexity (TCFD, 2017). But ESG reporting also offers big benefits. It lets energy firms show commitment to sustainability, manage risks better, and boost reputation. Clear ESG reporting highlights work on cutting emissions, energy savings, and renewables, which appeals to investors who care about social issues (Ioannou & Serafeim, 2017). Strong ESG performance can also help firms find capital more easily (Amel-Zadeh & Serafeim, 2018). ESG reporting can lead to better operations by pushing firms to study their environmental and social risks. This can lower costs (Khan et al., 2016). Firms with solid ESG practices might gain an edge by creating green solutions and meeting new rules (KPMG, 2020).

Key trends in energy-sector ESG reporting include using major frameworks like GRI, SASB, and TCFD to improve disclosure quality (Sullivan & Gouldson, 2017). Climate reporting, especially with TCFD guidelines, is becoming more detailed (CDP, 2021). Some firms now put ESG info in financial reports or adopt integrated reporting to show how financial and non-financial results link (IIRC, 2021). Digital tools also change ESG reporting. Many companies use data analytics, online platforms, and blockchain to improve accuracy and openness, and they often include real-time dashboards (Broome et al., 2020). Engaging stakeholders is a big focus, as companies want to find important ESG issues and build trust (Manetti et al., 2017). ESG reporting differs between traditional and clean energy firms. Traditional ones often share their plans for switching to renewables or using carbon capture, and many aim for net-zero goals (AG, 2021). Clean energy firms emphasize emissions cuts, innovation, and market growth, along with social programs that help communities and employees (Ørsted, 2020).

2.5. Intersection of Digital Transformation and ESG Disclosure

2.5.1 The Benefits and Tradeoffs of Digital Transformation in ESG Reporting

Digital transformation significantly enhances ESG reporting by improving the collection and analysis of data, enabling real-time monitoring, and fostering

transparency and stakeholder engagement. The integration of advanced digital technologies has made it possible for companies to provide ESG disclosures that are more accurate, timely, and comprehensive, helping to meet the rising expectations of stakeholders and regulatory requirements. One key area where digital transformation impacts ESG reporting is in data collection and analytics. Those technologies play a pivotal role in gathering and processing ESG-related data. IoT can monitor environmental parameters such as energy consumption, emissions, and waste generation in real-time, which is essential for accurate environmental reporting (Porter & Heppelmann, 2014); Big data analytics allows companies to process large volumes of structured and unstructured data, uncovering trends and insights into ESG performance, and AI can analyze public sentiment on social media regarding a company's environmental and social initiatives, providing critical feedback on public perception (EY, 2022; Wamba et al., 2017). Digital transformation also enables real-time monitoring and reporting of ESG metrics, allowing companies to promptly address emerging issues and offer up-to-date information to stakeholders. Blockchain technology, for instance, can securely record and verify ESG data in real-time, significantly enhancing the reliability of disclosures (Saber et al., 2019). Real-time reporting tools move companies beyond traditional periodic reporting, enabling continuous communication with stakeholders. This immediacy in reporting not only builds trust but also bolsters a company's reputation for transparency and accountability (PwC, 2016).

Digital platforms and social media have revolutionized stakeholder engagement by allowing companies to interactively share ESG information. Online portals, mobile applications, and interactive dashboards provide accessible, transparent dissemination of data, enabling stakeholders to independently verify and trust the information provided (Manetti & Bellucci, 2016). Blockchain, in particular, creates immutable records of ESG data that further enhance transparency, fostering stronger engagement with investors, customers, and the public (Casino et al., 2019). Furthermore, digital

tools allow companies to engage stakeholders actively, soliciting feedback and ideas through crowdsourcing platforms, which can lead to improvements in ESG practices and foster community involvement in sustainability initiatives (Howlett et al., 2017).

2.5.2 Challenges in Adopting Digital Transformation for ESG Reporting

Despite its clear advantages, digital transformation is not used everywhere for ESG reporting. There are several big challenges that slow its progress. First, money constraints are a major problem. Smaller firms or those in areas with fewer resources often find the cost of getting and keeping new digital technology too high. Research shows that smaller firms have less access to capital and skilled labor, which stops them from fully using digital tools for ESG reporting (Michelon et al., 2015; Hahn & Kühnen, 2013). This challenge is worse in industries with low profit margins or unstable markets, where short-term costs matter more than long-term sustainability goals. Second, problems with system integration also cause major issues. Companies with old or separated systems often have trouble using new digital solutions. Older systems might not work well with new digital tools, which leads to data silos, slower operations, and incomplete ESG reporting (de Villiers et al., 2017). Also, if companies do not have a clear plan to connect digital efforts to ESG aims, even big investments may not lead to better reporting quality (Westerman et al., 2012).

Another barrier is resistance inside organizations and lack of skills. Workers used to older methods may resist new digital approaches, especially when these disrupt normal workflows or require a lot of training (Kane et al., 2015). In industries where employees do not have strong digital skills, bringing in digital transformation can require big training programs, which increases financial and operational costs (Rinaldi et al., 2018). Outside factors like unclear rules and changing markets also affect DT use for ESG reporting. Companies in places with weak ESG rules or poor enforcement might see little reason to spend money on DT. Likewise, industries with fewer demands from

investors or stakeholders might put ESG reporting improvements lower on their list, which slows the rate of adoption (Ioannou & Serafeim, 2017).

2.5.3 Empirical Studies Linking Digital Maturity and ESG Disclosure

Some studies show growing interest in how digital maturity affects ESG reporting. For example, García-Sánchez et al. (2020) find that higher digital investment leads to more complete and open sustainability disclosures. Raimo et al. (2021) note that using digital tools improves how companies share ESG information with stakeholders. These ideas match what is happening in the energy sector, where integrated reporting and advanced data analysis are more common in companies that use digital transformation.

In the energy sector, de Villiers et al. (2017) report that firms with strong digital skills often adopt integrated reporting, which combines financial and ESG data into a full picture of performance. These studies suggest that digital maturity has a good impact on ESG reporting because it allows faster data handling, quick reporting, and more openness (García-Sánchez et al., 2020; Liu et al., 2024). Digital maturity also helps add ESG issues to main decisions, which ties sustainability goals to business aims (De Villiers et al., 2014).

But there are differences in the research. Some works suggest that the link between digital maturity and ESG reporting differs by sector. Technology and finance industries often have stronger connections because they use digital tools more, while others may lag (Rinaldi et al., 2018). Also, smaller firms that have fewer resources might struggle to buy and use digital tools, which hurts their ESG reporting (Michelon et al., 2015). There is also a debate over cause and effect. Some researchers ask if digital maturity leads to better ESG reporting or if companies that already care about sustainability are more likely to try digital transformation (Hahn & Kühnen, 2013).

2.6 Other Influencing Factors

Digital transformation and ESG reporting are closely linked. But some other factors also shape a firm's digital maturity and ESG reporting. Company size and profitability matter a lot. Larger firms generally have more money, more skilled people, and better tech systems. They can spend more on digital transformation and detailed ESG reporting (Bonsón & Bednárová, 2015; Michelon & Parbonetti, 2012). They also face more pressure from investors and regulators, which pushes them to use advanced digital methods and open ESG practices (Luo et al., 2012). Being profitable further helps a company spend on new ideas and sustainability programs, which boosts ESG disclosures and digital systems for better data control (Cormier & Magnan, 2003; Branco & Rodrigues, 2006).

Governance structure also affects digital and ESG moves. Boards with independent members, varied skills, and tech-focused leaders are more likely to support digital innovation and strong ESG reporting (Bear et al., 2010; Ben-Amar & McIlkenny, 2015). Good governance and leadership that cares about innovation lead to a more active approach to digital change and sustainability, which lines up with stakeholder needs and promotes openness (Liao et al., 2015). Lastly, local policy settings make a big difference. Supportive rules, such as funds for tech spending or laws that require ESG reporting, drive firms to invest in digital tools and ESG efforts (Evangelista et al., 2014; Ioannou & Serafeim, 2017). Differences between regions also shape these results. In Europe, for example, forward-looking policies and a culture of sustainability often lead to higher digital maturity and better ESG disclosures, compared to regions with fewer rules (Friede et al., 2015). These factors—company size, profitability, governance, and local policies—offer a wider view of what drives digital and ESG maturity in companies.

2.7 Research Gaps and Theoretical Framework

There is much research on digital transformation and ESG disclosure. But the specific link between digital maturity and ESG practices in the energy sector is not well studied. Most work looks at how digital transformation affects performance in general or how ESG reporting helps engage stakeholders and build a good image (Kane et al., 2015; Eccles et al., 2014). Few studies focus on how digital maturity directly shapes ESG reporting in energy companies. This is important because energy firms face special operational issues and high environmental impacts (García-Sánchez et al., 2020; Raimo et al., 2021).

Another gap is the comparison of traditional and clean energy sectors. Some research notes the unique hurdles and chances for ESG reporting in these areas, but there are not many in-depth comparisons (Parida et al., 2019; Gangi et al., 2020). Such comparisons are key for seeing sector-specific ESG problems, stakeholder needs, and strategy ideas in light of digital maturity (Kolk et al., 2008; Lund et al., 2017). Traditional energy firms, many founded decades ago, often depend on older structures and older IT systems. This makes it hard to update their systems for modern digital technologies, which slows down digital transformation for operations and ESG reporting. For instance, older systems can cause data silos, uneven reporting, and higher costs for upgrades (de Villiers et al., 2017). Traditional firms also tend to have rigid hierarchies, which may slow them in adopting digital tools and culture changes (Westerman et al., 2012). But clean energy firms, usually created more recently in response to global sustainability trends, often act like “digital natives.” They usually start with newer IT systems and easily use digital tools in their main business. This approach leads to more speed, efficiency, and openness in ESG reporting. Clean energy firms also face higher stakeholder and social demands to lead in sustainability, which pushes them to use advanced tech for stronger ESG disclosure (Ioannou & Serafeim, 2017).

There is also a shortage of regional comparisons that look at how local rules, culture, and markets in places like China, Europe, and the United States affect digital maturity and ESG practices in energy firms. Filling this gap would add more detail about how policy and culture in each region shape corporate approaches to ESG reporting and digital transformation (Matten & Moon, 2008; Hofstede, 2001).

3. Theoretical Framework and Hypotheses

3.1 Theoretical Foundations

This study examines the relationship between digital maturity and ESG disclosure in energy companies through the lens of three prominent theoretical frameworks: the Resource-Based View (RBV), Institutional Theory, and Stakeholder Theory. These frameworks collectively offer a comprehensive perspective for understanding how internal resources, external institutional pressures, and stakeholder expectations shape corporate strategies around digital transformation and ESG practices.

3.1.1 Resource-Based View (RBV)

The Resource-Based View says a firm's lasting advantage comes from using valuable, rare, hard-to-copy, and non-replaceable resources (Barney, 1991). Digital abilities count as strategic resources because they help firms improve efficiency, spark innovation, and adjust to market shifts (Kane et al., 2015). For energy firms, AI, IoT, big data analytics, and blockchain are key tools. They let companies run operations more smoothly through predictive maintenance and resource control, and they also improve ESG reporting with better data analysis and openness (Parida et al., 2019).

3.1.2 Institutional Theory

Institutional Theory explains how outside pressures, like rules, shape what

organizations do (DiMaggio & Powell, 1983). For ESG disclosure, policies such as the EU Non-Financial Reporting Directive push firms to be more open about ESG and use digital systems to meet these rules. Also, energy firms face different regional factors that affect their digital transformation and ESG methods, since some places demand more sustainable business (Matten & Moon, 2008). Institutional Theory, then, helps us see how these outside forces push energy companies to mix digital maturity with ESG targets.

3.1.3 Stakeholder Theory

Stakeholder Theory says organizations should meet the needs of many groups—like investors, customers, communities, and NGOs—in their key decisions (Freeman, 1984). More and more, these groups want clear and open ESG performance. Investors also look at ESG factors when judging firms (Amel-Zadeh & Serafeim, 2018). Digital transformation supports these needs by making communication better and offering up-to-date ESG data. For energy companies, meeting stakeholder demands through digital-based ESG practices can boost their reputation and tie their operations to sustainable goals.

3.2 Hypotheses

Based on the theoretical foundations of the Resource-Based View, Institutional Theory, and Stakeholder Theory, this study proposes the following hypotheses to investigate the relationship between digital maturity and ESG disclosure quality in both traditional and clean energy companies.

3.2.1 Digital Maturity and ESG Disclosure Quality

RBV says that firms with valuable, rare, hard-to-copy, and not easily replaced resources can gain a lasting advantage (Barney, 1991). Digital maturity is one such resource. It

helps firms collect, analyze, and report ESG data in a better way. Firms with higher digital maturity can create more complete and higher-quality ESG disclosures.

Stakeholder Theory says that organizations should meet the needs and expectations of different groups, like investors, customers, and regulators, who want clear and accountable ESG performance (Freeman, 1984). Firms with strong digital skills can meet these demands by using modern technologies to improve ESG reporting. Institutional Theory says that outside pressures, like rules and industry standards, shape how companies act (DiMaggio & Powell, 1983). Firms might use digital tools to follow ESG reporting rules and be seen as legitimate by stakeholders. Based on these ideas, we propose:

H1: There is a positive relationship between a firm's digital maturity and the quality of its ESG disclosure.

3.2.2 Digital Maturity in Clean Energy vs. Traditional Energy Companies

Clean energy companies often center on sustainability and innovation (Parida et al., 2019). From the RBV viewpoint, these firms might see digital innovation as a key resource for keeping and growing their advantage. Institutional Theory suggests that clean energy companies face strong pressures to adopt innovation and sustainability, such as environmental laws and social calls for green solutions (Matten & Moon, 2008). These pressures can push clean energy firms to reach higher digital maturity. According to Stakeholder Theory, people expect clean energy companies to lead in digital transformation because their goals match sustainable practices (Ioannou & Serafeim, 2017). Meeting these expectations can make stakeholder ties stronger and improve a firm's reputation. Thus, we propose:

H2: Clean energy companies exhibit higher levels of digital maturity compared to traditional energy companies.

3.2.3 Moderating Effect of Company Type on the Relationship Between Digital Maturity and ESG Disclosure Quality

The strategic orientation of clean energy companies towards sustainability may enable them to leverage digital capabilities more effectively for ESG reporting. The RBV suggests that the value of digital resources may be amplified when aligned with a firm's strategic focus (Barney, 1991). Stakeholder Theory indicates that clean energy firms face heightened stakeholder expectations regarding ESG performance, which may intensify the impact of digital maturity on ESG disclosure quality (Freeman, 1984). These firms may use digital technologies not only to improve operational efficiency but also to enhance transparency and accountability. Institutional Theory supports the notion that clean energy companies operate within contexts that reinforce both digital and ESG objectives, leading to a stronger relationship between digital maturity and ESG disclosure quality (DiMaggio & Powell, 1983). The following hypothesis is proposed:

H3: The positive relationship between digital maturity and ESG disclosure quality is stronger in clean energy companies than in traditional energy companies.

3.2.4 Moderating Role of External Factors

Institutional Theory emphasizes that external factors such as regulatory policies, market demand, and technological infrastructure shape organizational practices (DiMaggio & Powell, 1983). These external factors may influence the extent to which digital transformation impacts ESG disclosure practices.

From the RBV and Stakeholder Theory perspectives, regional differences impact resource availability and stakeholder expectations, potentially affecting how firms integrate digital maturity into ESG reporting (Barney, 1991). For instance, companies

operating in regions with supportive policies and advanced technological environments may experience a greater positive impact of digital maturity on ESG disclosure quality. Thus, the final hypothesis is articulated as:

H4: Regional factors moderate the relationship between digital maturity and ESG disclosure quality.

4. Research Methodology

This chapter presents the research methodology designed to examine the impact of digital transformation on ESG disclosure practices among traditional and clean energy companies across China, Europe, and the United States.

4.1 Research Design

This study employs a quantitative comparative design to investigate the relationship between digital maturity and ESG disclosure quality in energy companies. This design is suited for examining and statistically analyzing the hypotheses developed from the theoretical framework, enabling pattern identification, relationships assessment, and group comparison (Creswell & Creswell, 2018).

The research involves a comparative analysis between traditional energy companies and clean energy companies, And the companies from three regions: China, Europe, and the United States. This design facilitates understanding of whether and how digital transformation impacts ESG disclosure differently based on company type and regional context.

All data is collected over a five-year period (2018–2022), enabling a longitudinal design

that strengthens the study by capturing trends and changes over time, minimizing the influence of short-term fluctuations, and allowing for an examination of lagged effects between digital transformation and ESG disclosure practices. This period was chosen due to its alignment with the accelerated adoption of key clean energy technologies and the global surge in ESG reporting driven by stakeholder demands and regulatory advancements. Notably, during this timeframe, ESG disclosures gained prominence as investors and policymakers increasingly emphasized sustainability metrics, while digital technologies such as IoT and AI became more integrated into corporate reporting frameworks.

4.2 Data Collection

4.2.1 Sample Selection

The population consists of publicly listed energy companies in China, Europe, and the United States. The sampling frame includes companies classified under the energy sector according to the Global Industry Classification Standard (GICS) and with available data on the Bloomberg Terminal for the variables of interest from 2018 to 2022.

Region	Traditional Energy Companies	Clean Energy Companies	Total Companies
China	9	40	49
Europe	40	40	80
United State	40	35	75
Total	89	115	204

Table 2

The final sample consists of 204 companies, with a total of 1020 firm-year observations over five years. The sample distribution is presented in Table 2, and this sample ensures adequate representation of both traditional and clean energy companies across the selected regions, facilitating robust comparative analysis.

4.2.2 Variables

Variable	Symbol	Measurement
Dependent Variable		
ESG Disclosure Score	ESGD	Bloomberg ESG_DISCLOSURE_SCORE
Independent Variables		
R&D Expenditure	RD_EXPEND	IS_RD_EXPEND
Control Variables		
Sales Revenue	SALES_REV	SALES_REV_TURN
Total Assets	TOT_ASSET	BS_TOT_ASSET
Profit Margin	PROF_MARGIN	PROF_MARGIN
Return on Equity	ROE	RETURN_COM_EQY
Debt-to-Asset Ratio	DAR	TOT_DEBT_TO_TOT_ASSET
Moderating Variables		
Company Type	TYPE	1 = Clean Energy, 0 = Traditional Energy
Region	REGION	China, Europe, United States

Table 3

The primary dependent variable is the ESG Disclosure Score (ESGD), sourced from Bloomberg's ESG_DISCLOSURE_SCORE, which measures the quality and comprehensiveness of a company's ESG disclosures. The main independent variable, R&D Expenditure (RD_EXPEND), serves as a proxy for digital maturity, reflecting a company's investment in innovation and technological capabilities. This approach aligns with prior studies (e.g., Westerman et al., 2012; Parida et al., 2019) that associate R&D spending with a firm's ability to adopt and integrate advanced digital tools and processes. R&D expenditure captures an organization's commitment to fostering

innovation, which is a critical driver of digital transformation.

However, it is acknowledged that R&D expenditure does not fully encapsulate the multidimensional nature of digital maturity. Digital maturity also involves investments in IT infrastructure, workforce training, and the implementation of digital tools, which may not be directly reflected in R&D spending. Despite this limitation, R&D expenditure remains a viable proxy given its broad correlation with technological innovation and the lack of more granular, digital-specific investment data in the dataset. To mitigate this limitation, robustness checks are conducted using alternative proxies, such as capital expenditure, to validate the findings and ensure consistency across different measures of digital investment.

Control variables include Sales Revenue (SALES_REV_TURN) and Total Assets (BS_TOT_ASSET) to account for company performance and size, alongside financial indicators such as Profit Margin (PROF_MARGIN), Return on Equity (RETURN_COM_EQY), and Debt-to-Asset Ratio (TOT_DEBT_TO_TOT_ASSET) to capture variations in financial health and leverage. Moderating variables comprise Company Type, coded as 1 for clean energy companies and 0 for traditional energy companies, and Region, categorized into China, Europe, and the United States, to examine sectoral and regional differences in digital maturity and ESG practices.

5. Empirical Results and Analysis

5.1 Descriptive Statistics

This section presents the descriptive statistics for the key variables used in the analysis, providing an overview of the data's central tendencies and dispersion. Table 4 summarizes the mean, median, minimum, maximum, and standard deviation for each

variable across the 723 firm-year observations from 2018 to 2022.

Descriptive Statistics of Main Variables

VarName	Obs	Mean	Median	Min	Max	SD
ESG_DISCLOSURE_SCORE	723	47.812	49.029	16.296	76.803	14.904
CAPITAL_EXPEND	723	4.991	5.072	0.156	9.757	2.284
IS_RD_EXPEND	723	2.198	1.703	0.000	7.102	2.225
SALES_REV_TURN	723	14650.965	1590.699	0.533	276692.000	43233.308
BS_TOT_ASSET	723	20695.915	3072.411	30.658	346196.000	57505.214
PROF_MARGIN	723	-44.227	3.841	-2701.522	52.843	294.662
RETURN_COM_EQY	723	0.757	6.966	-142.053	61.821	30.212
TOT_DEBT_TO_TOT_ASSET	723	27.377	26.661	0.000	68.520	17.133

Note: Monetary values are in millions of USD.

Table 4

5.2 Correlation Analysis

ESG DI~E	CAPITA~D	IS RD ~D	SALES ~N	BS TOT~T	PROF M~N	RETURN~Y	
ESG DISCLO~E	1						
CAPITAL EX~D	0.707***	1					
IS RD EXPEND	0.213***	0.335***	1				
SALES REV ~N	0.381***	0.518***	0.389***	1			
BS TOT ASSET	0.403***	0.551***	0.406***	0.949***	1		
PROF MARGIN	0.148***	0.216***	0.073**	0.0560	0.0570	1	
RETURN COM~Y	0.092**	0.252***	0.140***	0.117***	0.085**	0.317***	1
TOT DEBT T~T	0.161***	0.225***	-0.136***	-0.086**	-0.063*	0.077**	-0.201***
TOT DE~T							

Table 5

The results show a positive link between ESG disclosure scores and capital spending ($r = 0.707$, $p < 0.01$). This means companies that spend more on assets and infrastructure often report higher ESG quality. One reason might be that capital spending includes adopting digital technologies. This supports the idea that digital maturity helps improve ESG disclosures. ESG disclosure scores are also tied to R&D spending ($r = 0.213$, $p < 0.01$). This suggests that companies investing more in R&D tend to have better ESG quality. This highlights the role of digital transformation in improving ESG disclosures.

Company size, measured by sales revenue and total assets, also relates to ESG disclosure scores ($r = 0.381$ and $r = 0.403$, $p < 0.01$). Bigger companies seem to focus more on ESG reporting, likely because of greater regulatory scrutiny and higher public and investor interest. The debt-to-asset ratio also shows a positive link with ESG scores ($r = 0.161$, $p < 0.01$). This might mean that companies with more debt improve their ESG reporting to boost investor confidence and reduce risks. However, sales revenue and total assets are very closely linked ($r = 0.949$, $p < 0.01$), which could cause issues in regression models. This should be handled carefully by choosing just one variable to represent company size.

Although the correlation results suggest digital maturity is linked to better ESG quality, these findings must be interpreted carefully. Correlation does not mean causation, and later regression tests will provide a clearer picture.

5.3 Hypotheses Testing

5.3.1 Hypothesis 1

This section aims to test Hypothesis 1, which posits that digital maturity has a positive

impact on the quality of ESG information disclosure among energy companies. To empirically examine this hypothesis, we use Research and Development expenditure (IS_RD_EXPEND) as a proxy for digital maturity. This choice is based on the premise that higher R&D investment reflects a firm's commitment to innovation and the adoption of digital technologies, which can enhance ESG reporting capabilities. The explained variable is the ESG information disclosure score (ESG_DISCLOSURE_SCORE), representing the quality of a firm's ESG disclosures. The baseline regression model is specified as follows:

$$H1: ESG_{DISCLOSURE_SCORE_{it}} = \beta_0 + \beta_1 IS_{RD_EXPEND_{it}} + \beta_2 CONTROL_{VARIABLES_{it}} + \varepsilon_{it}$$

Here are the regression results for the impact of digital maturity on ESG disclosure quality.

	(1)	(2)
	ESG_DISCLOSURE_SCORE	ESG_DISCLOSURE_SCORE
IS_RD_EXPEND	1.427*** (5.853)	0.488** (1.988)
CAPITAL_EXPEND		
SALES_REV_TURN		0.000 (0.064)
BS_TOT_ASSET		0.000*** (3.458)
PROF_MARGIN		0.004** (2.421)
RETURN_COM_EQY		0.031* (1.733)
TOT_DEBT_TO_TOT_ASSET		0.175*** (5.846)

_cons	44.677*** (58.630)	40.099*** (35.305)
N	723	723
r2	0.045	0.218

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6

Model 1 shows the linear relationship between R&D expenditure and ESG disclosure score without including control variables. The regression results indicate that the coefficient of IS_RD_EXPEND is 1.427, which is positive and statistically significant at the 1% level ($t = 5.853$). This finding suggests a significant positive correlation between digital maturity and the quality of ESG information disclosure, providing initial support for H1. And then include control variables in Model 2 to account for other factors that may influence ESG disclosure quality. After adding these control variables, the coefficient of IS_RD_EXPEND remains positive at 0.488 and is significant at the 5% level ($t = 1.988$). This result further reinforces the validity of H1, indicating that the positive impact of digital maturity on ESG disclosure quality persists even after controlling for firm-specific characteristics.

Among the control variables, Total Assets (BS_TOT_ASSET) and Debt-to-Asset Ratio (TOT_DEBT_TO_TOT_ASSET) exhibit significant positive effects on ESG disclosure scores. Specifically, Total Assets have a positive and significant coefficient (0.000, $t = 3.458$, $p < 0.01$), indicating that larger firms tend to have higher ESG disclosure scores. This may be attributed to larger firms having more resources and greater public scrutiny, prompting them to provide more comprehensive ESG disclosures.

Profit Margin (PROF_MARGIN) is also positive and significant (0.004, $t = 2.421$, $p < 0.05$), suggesting that more profitable companies disclose ESG information more

extensively. A higher profit margin may enable firms to allocate more resources toward ESG initiatives and reporting. The Debt-to-Asset Ratio (TOT_DEBT_TO_TOT_ASSET) also shows a positive and highly significant coefficient (0.175, $t = 5.846$, $p < 0.01$), indicating that firms with higher leverage may enhance their ESG disclosures to build investor confidence and mitigate perceived financial risks. The adjusted R-squared (R^2) increases from 0.045 in Model 1 to 0.218 in Model 2, demonstrating that the inclusion of control variables substantially improves the explanatory power of the model. This enhancement indicates that firm size, profitability, and leverage are important factors influencing ESG disclosure quality and will be accounted for in the discuss part.

The regression analysis provides robust evidence supporting Hypothesis 1. The positive and significant relationship between digital maturity, as proxied by R&D expenditure, and ESG disclosure quality suggests that energy companies investing more in digital capabilities tend to have better ESG reporting practices. This underscores the importance of digital transformation in enhancing transparency and accountability in ESG disclosures within the energy sector. This finding aligns with the Resource-Based View which posits that firms achieve competitive advantage by leveraging the resources (Barney, 1991). Digital maturity, as reflected in R&D expenditure, constitutes a critical resource enabling firms to integrate advanced technologies into their ESG reporting processes. By investing in innovation and technological capabilities, firms enhance their ability to collect, analyze, and disclose ESG-related data, thereby improving transparency and meeting stakeholder demands. These findings are consistent with prior research that highlights the strategic importance of R&D investments in driving organizational transformation and sustainability reporting (Westerman et al., 2012).

5.3.2 Hypothesis 2

Understanding the differential impact of digital transformation across various sectors is

crucial for comprehending the broader implications of technological advancement in the energy industry. In recent years, clean energy companies have been at the forefront of adopting innovative technologies to enhance efficiency, reduce costs, and meet increasing regulatory and environmental demands. This trend suggests that clean energy companies may exhibit higher levels of digital maturity compared to their traditional counterparts. To investigate this possibility, we conduct a comparative analysis of digital maturity between clean energy companies and traditional energy companies.

Digital maturity in this study is proxied by R&D expenditure (IS_RD_EXPEND), reflecting a firm's investment in innovation and technological advancement. Higher R&D spending indicates a greater commitment to developing digital capabilities, which are essential for enhancing operational efficiency and competitiveness in the energy sector.

After data cleaning, there are now 723 energy enterprise data in the sample, including 391 clean energy enterprises and 332 traditional energy enterprises. An independent sample t-test is used to compare the mean R&D expenditures of the two groups of enterprises in Table 7.

Group	Obs	Mean	Std. err.	Std. dev.	[95% conf. interval]	
0	332	1.84241	.1307733	2.382803	1.585158	2.099661
1	391	2.499214	.1029909	2.036514	2.296727	2.7017
Combined	723	2.197611	.0827477	2.224975	2.035156	2.360066
diff		-.656804	.1643541		-.9794737	-.3341342
diff = mean(0) - mean(1)				t = -3.9963		
H0: diff = 0				Degrees of freedom = 721		
Ha: diff < 0		Ha: diff != 0		Ha: diff > 0		
Pr(T < t) = 0.0000		Pr(T > t) = 0.0001		Pr(T > t) = 1.0000		

Table 7

The results indicate that clean energy companies have a higher average R&D

expenditure (mean = 2.499) compared to traditional energy companies (mean = 1.842). The mean difference of 0.657 is statistically significant at the 1% level ($t = 3.996$, $p < 0.01$). The significant difference in R&D expenditure suggests that, on average, clean energy companies may exhibit a higher degree of digital maturity. While this finding is consistent with H2, it is important to consider that strategic priorities, regulatory incentives, and market conditions may also influence these investment patterns. Thus, the observed disparity in digital maturity likely reflects both the inherent innovation-driven nature of the clean energy segment and the broader environmental and policy contexts that encourage technological advancement in these firms.

5.3.3 Hypothesis 3

The dynamic landscape of the energy sector underscores the importance of understanding how different types of energy companies leverage digital maturity to enhance their Environmental, Social, and Governance information disclosure. Building upon the previous findings that digital maturity positively impacts ESG disclosure quality, it is pertinent to explore whether this effect varies between clean energy companies and traditional energy companies. This analysis aims to investigate whether the positive influence of digital maturity on ESG disclosure quality is stronger in clean energy companies compared to their traditional counterparts.

To examine this potential moderating effect, we introduce an interaction term between digital maturity and company type into our regression model. Digital maturity is again proxied by Research and Development expenditure (IS_RD_EXPEND), while company type is represented by a dummy variable ($TYPE_i$), where clean energy companies are coded as 1 and traditional energy companies as 0. The interaction term ($IS_{RD_EXPEND_{it}} \times TYPE_i$) allows us to assess how the relationship between digital maturity and ESG disclosure quality differs based on company type. The regression model is specified as follows:

$$ESG_{DISCLOSURE_{SCORE}_{it}}$$

$$= \beta_0 + \beta_1 IS_{RD_{EXPEND}_{it}} + \beta_2 TYPE_i + \beta_3 (IS_{RD_{EXPEND}_{it}} \times TYPE_i) \\ + \beta_4 CONTROL_{VARIABLES_{it}} + \varepsilon_{it}$$

(1)	
ESG_DISCLOSURE_SCORE	
IS_RD_EXPEND_Clean	25.446*** (6.903)
SALES_REV_TURN	-0.000 (-0.183)
BS_TOT_ASSET	0.000*** (3.168)
PROF_MARGIN	0.002 (1.262)
RETURN_COM_EQY	0.018 (1.208)
TOT_DEBT_TO_TOT_ASSET	0.093*** (3.705)
Clean_Energy	-35.337*** (-12.154)
IS_RD_EXPEND	-6.207** (-2.284)
_cons	56.314*** (26.442)
N	723
r2	0.473

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8

The regression analysis reveals that the coefficient of the interaction term (β_3) is 25.446, which is positive and statistically significant at the 1% level ($t = 6.903$). This indicates that the positive impact of digital maturity on ESG disclosure quality is indeed stronger in clean energy companies. The negative and significant coefficient for IS_RD_EXPEND ($\beta_1 = -6.207$, $p < 0.05$) indicates that, in the absence of the interaction (i.e., for traditional energy firms), higher R&D expenditure does not translate into improved ESG disclosure quality and may even be associated with weaker performance in this regard. However, the large and positive interaction term (IS_RD_EXPEND $\times$ TYPE_i) implies that once we move from traditional to clean energy companies (TYPE_i = 1), the slope of ESG disclosure quality with respect to digital maturity shifts dramatically. Clean energy firms not only start from a different baseline but also leverage their investments in R&D more effectively to enhance ESG reporting. This suggests that clean energy companies, likely under greater sustainability scrutiny and aligned with stakeholder expectations for environmental stewardship, are able to convert digital capabilities into reporting transparency and accountability, while traditional energy firms struggle to achieve similar improvements. These results can be interpreted through the lens of Stakeholder Theory, which emphasizes that firms respond to the expectations and demands of their stakeholders, including investors, regulators, and customers (Freeman, 1984). Clean energy companies which often seen as leaders in sustainability are subject to heightened scrutiny and expectations for transparency in their ESG disclosures. Digital maturity provides these firms with the technological tools and capabilities to efficiently meet such demands, enhancing their legitimacy and maintaining competitive advantage. By contrast, traditional energy companies face relatively lower stakeholder pressures in terms of ESG transparency, which may explain the weaker or negative relationship observed.

5.3.4 Hypothesis 4

In the context of globalization and varying regulatory landscapes, it is essential to understand how regional factors influence the relationship between digital maturity and

the quality of Environmental, Social, and Governance information disclosure among energy companies. Different regions may present distinct regulatory environments, market demands, and cultural attitudes toward sustainability, which can affect how firms leverage digital technologies to enhance their ESG reporting. This section explores whether regional policy frameworks moderate the impact of digital maturity on ESG disclosure quality.

To examine this moderating effect, we categorize the sample firms into three regional groups: China, the United States, and Europe. By conducting separate regression analyses for each region, we can assess whether the influence of digital maturity on ESG disclosure quality varies across different geographical contexts. The regression model employed for this analysis is specified as follows:

$$H4: \quad ESG_{DISCLOSURE_{SCORE}_{it}} = \beta_0 + \beta_1 IS_{RD_{EXPEND}_{it}} + \sum_{\{k=1\}^{(2)}_{\{2k\} REGION_{\{ik\}}}} \beta_k + \sum_{\{k=1\}^{(2)}_{\{3k\} (IS_{RD_{EXPEND}_{it}} \times REGION_{\{ik\}})}} \beta_k + \beta_4 CONTROL_{VARIABLES_{it}} + \varepsilon_{it}$$

The results are as follow:

	(1)	(2)	(3)
	ESG_DISCLOSUR E_SCORE	ESG_DISCLOSUR E_SCORE	ESG_DISCLOSUR E_SCORE
IS_RD_EXPEN D	3.087*** (5.464)	0.198 (0.497)	2.428*** (4.511)
SALES_REV_T URN	0.000 (0.256)	-0.000 (-0.160)	0.000 (0.430)
BS_TOT_ASSE T	0.001** (2.571)	0.000*** (3.040)	0.000 (0.554)
PROF_MARGI	-0.031	0.004**	0.007

N			
	(-0.309)	(2.228)	(1.523)
RETURN_CO	0.071	0.054**	0.045
M_EQY			
	(0.909)	(2.038)	(1.595)
TOT_DEBT_T	-0.009	0.328***	0.156***
O_TOT_ASSET			
	(-0.182)	(7.337)	(2.987)
_cons	26.520***	38.589***	39.967***
	(10.777)	(22.586)	(21.427)
N	188	254	281
r2	0.468	0.336	0.261

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 9

China: Model 1

In the regression analysis for the Chinese sample, the results indicate a significant positive impact of digital maturity on ESG disclosure quality. Specifically, the coefficient for R&D expenditure (IS_RD_EXPEND) is 3.087, with a *t*-value of 5.464, significant at the 1% level ($p < 0.01$). This suggests that, in China, each additional unit increase in digital maturity is associated with an approximate 3.087 point improvement in the ESG disclosure score. Furthermore, total assets (BS_TOT_ASSET) also exhibit a significant positive effect (coefficient = 0.001, $t = 2.571$, $p < 0.05$), indicating that larger companies tend to have higher ESG disclosure quality. Other control variables do not show significant effects in the Chinese sample.

United States: Model 2

The regression analysis for the United States sample reveals that digital maturity does

not significantly impact ESG disclosure quality. The coefficient for R&D expenditure is 0.198, with a t-value of 0.497, failing to reach statistical significance. This suggests that, in the U.S., investments in digital transformation are not directly associated with improvements in ESG disclosure. While several control variables in the U.S. sample show significant positive effects on ESG disclosure quality. Total assets have a coefficient of 0.000 with a t-value of 3.040 ($p < 0.01$), indicating that larger firms tend to provide more comprehensive ESG disclosures. Profit margin (PROF_MARGIN) is also significant, with a coefficient of 0.004 and a t-value of 2.228 ($p < 0.05$), suggesting that more profitable companies allocate greater resources to ESG reporting. Similarly, return on common equity (RETURN_COM_EQY) has a positive coefficient of 0.054 ($t = 2.038, p < 0.05$), implying that firms with higher financial returns are more inclined to enhance ESG transparency. Lastly, the debt-to-asset ratio has a significant positive coefficient of 0.328 ($t = 7.337, p < 0.01$), highlighting that highly leveraged firms may use ESG disclosures to build investor confidence and mitigate perceived risks.

These findings indicate that, in the U.S., factors such as firm size and financial performance play a more critical role in determining ESG disclosure quality than digital maturity. This may reflect the relatively weaker regulatory environment and lower stakeholder pressure for ESG transparency compared to other regions. In such a context, energy companies may prioritize digital initiatives that align more closely with financial outcomes rather than sustainability reporting. While these interpretations align with observed patterns, they should be viewed as indicative rather than conclusive, given the observational nature of this study and the potential influence of unmeasured regional or firm-level factors.

Europe: Model 3

For the European sample, the regression results similarly demonstrate a significant positive relationship between digital maturity and ESG disclosure quality. The

coefficient for R&D expenditure is 2.428, with a t-value of 4.511, significant at the 1% level ($p < 0.01$). This implies that in Europe, enhancing digital maturity significantly contributes to improving ESG disclosure quality. Additionally, the debt-to-asset ratio ($TOT_DEBT_TO_TOT_ASSET$) is significant at the 1% level (coefficient = 0.156, $t = 2.987$), suggesting that European firms with higher leverage are more inclined to enhance their ESG disclosures to boost investor confidence. Other control variables are not statistically significant in the European sample.

5.4 Robustness Checks

To ensure the reliability and robustness of our research findings, several additional analyses were conducted, including employing fixed effects models, substituting the dependent variable, and replacing the independent variable. These robustness checks aim to verify whether the positive impact of digital maturity on the ESG information disclosure quality of energy companies remains consistent under different model specifications and measurement approaches.

5.4.1 Fixed Effects Model Analysis

Recognizing that firm-specific characteristics and temporal factors might influence the model results, we re-estimated the baseline regression using a fixed effects model. By incorporating firm fixed effects (γ_i) and year fixed effects (δ_t), we controlled for unobserved individual heterogeneity and time trends that could potentially bias the estimates. The adjusted regression model is specified as follows:

$$ESG_{DISCLOSURE_{SCORE\{it\}}} = \alpha_0 + \alpha_1 IS_{RD_{EXPEND\{it\}}} + \alpha_2 CONTROL_{VARIABLES\{it\}} + \gamma_i + \delta_t + \varepsilon_{it}$$

ε_{it} represents the random error term.

(1)	(2)
-----	-----

	ESG_DISCLOSURE_S	ESG_DISCLOSUR
	CORE	E_SCORE
IS_RD_EXPEND	3.172***	3.101***
	(5.550)	(5.410)
CAPITAL_EXPEND		
SALES_REV_TURN		-0.000
		(-0.089)
BS_TOT_ASSET		-0.000
		(-0.144)
PROF_MARGIN		0.001
		(0.555)
RETURN_COM_EQY		-0.020**
		(-2.131)
TOT_DEBT_TO_TOT_ASSET		0.078**
		(2.576)
_cons	26.841***	25.512***
	(6.812)	(6.432)
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	723	723
r2	0.934	0.936

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 10

The estimation results indicate that, even after controlling for firm and year fixed effects, the positive impact of R&D expenditure on ESG information disclosure quality remains significant. Specifically, the coefficients of IS_RD_EXPEND are 3.172 and 3.101, both significant at the 1% level. This suggests that the beneficial effect of digital maturity on

ESG disclosure quality is not merely driven by firm-specific characteristics or macroeconomic factors but represents an independent influence. Additionally, the adjusted r^2 values of 0.934 and 0.936 demonstrate a high explanatory power of the model, reinforcing the robustness of the results. The very high R^2 values after introducing firm and year fixed effects reflect that much of the variation in ESG disclosure scores is explained by unobserved time-invariant firm-specific attributes and common temporal trends.

5.4.1.1 Substituting the Dependent Variable

To enhance the comparability of ESG disclosure scores across different countries, we standardized the dependent variable. Specifically, we calculated the average ESG disclosure score for each country and year, and then divided each firm's ESG disclosure score by the corresponding country-year average to obtain a standardized ESG disclosure score. The modified regression model is as follows:

$$\begin{aligned} &Standardized_{ESG_DISCLOSURE_SCORE_{it}} \\ &= \beta_0 + \beta_1 IS_{RD_EXPEND_{it}} + \beta_2 CONTROL_{VARIABLES_{it}} + \varepsilon_{it} \end{aligned}$$

	(1)	(2)
	ESG_DISCLOSURE_SCO	ESG_DISCLOSURE_SCO
	RE	RE
IS_RD_EXPEND	0.041***	0.026***
	(8.820)	(5.506)
SALES_REV_TURN		-0.000
		(-0.027)
BS_TOT_ASSET		0.000***
		(2.821)
PROF_MARGIN		0.000***
		(2.936)

RETURN_COM_EQY		0.001***
		(2.645)
TOT_DEBT_TO_TOT		0.004***
_ASSET		
		(6.012)
_cons	0.910***	0.819***
	(62.410)	(37.082)
N	723	723
r2	0.097	0.235

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 11

The regression results show that R&D expenditure continues to have a significant positive effect on the standardized ESG disclosure score, with coefficients of 0.041 and 0.026, both significant at the 1% level. This finding indicates that the positive impact of digital maturity on ESG disclosure quality is robust and not influenced by cross-country differences in ESG measurement scales, indicating that the observed relationship does not appear to be driven by cross-country differences in ESG measurement scales, thus reinforcing the robustness of the core findings.

5.4.1.2 Using Capital Expenditure as an Alternative Measure of Digital Investment

One limitation of this study is the use of R&D expenditure as a proxy for digital maturity. While R&D investments broadly capture a firm's commitment to innovation and technology development, they may not fully represent other aspects of digital transformation, such as investments in IT infrastructure or workforce training. To address this limitation and enhance the robustness of our findings, we replaced R&D expenditure with capital expenditure (CAPITAL_EXPEND) as an alternative measure of digital investment. Capital expenditure captures a broader spectrum of investments,

including those related to infrastructure and digital tools, which are crucial components of digital transformation.

To examine whether our results are sensitive to the measurement of digital maturity, we replaced R&D expenditure with capital expenditure (CAPITAL_EXPEND) as an alternative proxy for digital investment. The revised regression model is specified as:

$$ESG_{DISCLOSURE_{SCORE}_{it}} = \gamma_0 + \gamma_1 CAPITAL_{EXPEND}_{it} + \gamma_2 CONTROL_{VARIABLES}_{it} + v_{it}$$

	(1)	(2)
ESG_DISCLOSURE_ SCORE	ESG_DISCLOSURE_ SCORE	
IS_RD_EXPEND		
CAPITAL_EXPE ND	4.616*** (26.865)	4.776*** (20.795)
SALES_REV_T URN		0.000 (0.614)
BS_TOT_ASSET		-0.000 (-0.500)
PROF_MARGIN		0.001 (0.898)
RETURN_COM_ EQY		-0.053*** (-3.611)
TOT_DEBT_TO _TOT_ASSET		-0.022 (-0.877)

_cons	24.772***	24.650***
	(26.269)	(22.033)
N	723	723
r2	0.500	0.510

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 12

The estimation results reveal that capital expenditure has a significant positive impact on ESG information disclosure quality, with coefficients of 4.616 and 4.776, accompanied by high *t*-values. This finding suggests that regardless of whether R&D expenditure or capital expenditure is used as the measure of digital maturity, the positive effect of digital investment on ESG disclosure quality is consistently observed. Therefore, our research conclusions are robust to different operationalizations of digital maturity. The consistency of results using capital expenditure as an alternative proxy suggests that the observed relationship between digital maturity and ESG disclosure quality is not driven by the specific choice of proxy variable. While R&D expenditure focuses on innovation and technology development, capital expenditure captures investments in physical and IT infrastructure, complementing the narrower focus of R&D. Together, these proxies provide a more comprehensive perspective on digital maturity, reducing concerns about measurement limitations. By showing consistent results when capital expenditure is used as the proxy, we highlight that the impact of digital maturity on ESG disclosure holds both for investments in innovation (R&D) and in broader digital-related infrastructures and tools (CapEx), reinforcing the robustness of our findings.

5.4.2 Model Diagnostics and Further Tests

Beyond the robustness checks, there are further diagnostics to ensure the appropriateness of the model specification and the reliability of the results. These

diagnostics included the Ramsey RESET test for model specification and the Breusch-Pagan test for heteroskedasticity. Based on the test outcomes, there are necessary adjustments to address potential econometric issues.

5.4.2.1 Model Specification Test

To assess whether the model suffers from omitted variable bias or incorrect functional form, we performed the Ramsey RESET test. This test evaluates whether including higher-order terms of the predicted values significantly improves the model fit. The null hypothesis is that the model is correctly specified without omitted variables. The test results show an F-value of 25.38 (degrees of freedom: 18 and 698) with a p-value of 0.0000, which is well below the 0.05 significance level. Therefore, it reject the null hypothesis, indicating that the model may have omitted variables or nonlinear relationships. This suggests caution in interpreting the results and the potential need to consider additional explanatory variables or nonlinear terms in future research. Although the main conclusions remain robust, the Ramsey RESET test suggests that exploring additional explanatory variables or allowing for nonlinear effects could further refine the model. Future research could incorporate more nuanced measures of digital capabilities or consider interaction terms with other strategic firm-level factors to address these potential omissions.

5.4.2.2 Heteroskedasticity Test

Breusch-Pagan test to detect the presence of heteroskedasticity in the model. The null hypothesis is that the variance of the error term is constant. The test results yield a Chi-square value of 31.16 with 6 degrees of freedom and a p-value of 0.0000, leading us to reject the null hypothesis. This indicates that heteroskedasticity is present in the model, which could affect the efficiency and validity of the OLS estimators.

To visually inspect the heteroskedasticity, the residuals were plotted against the fitted values (Figure 13). The scatter plot reveals a pattern where the spread of residuals increases with the fitted values, confirming the presence of heteroskedasticity.

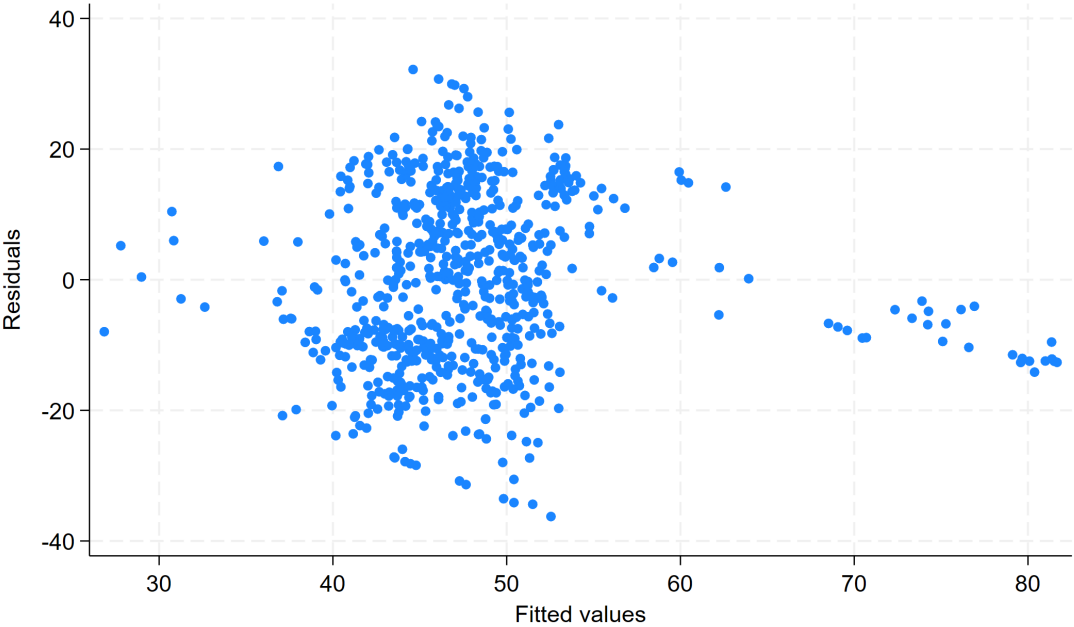


Figure 13

To address the heteroskedasticity issue, the regression model was re-estimated using robust standard errors (White’s heteroskedasticity-consistent standard errors). This adjustment allows us to obtain consistent parameter estimates and correct standard errors, ensuring the validity of statistical inference despite the presence of heteroskedasticity.

	(1)	(2)
	ESG_DISCLOSURE_	ESG_DISCLOSURE_
	SCORE	SCORE
IS_RD_EXPE	1.427***	0.488**
ND		
	(6.236)	(2.088)
SALES_REV_		0.000
TURN		

		(0.078)
BS_TOT_ASS		0.000***
ET		
		(4.266)
PROF_MARG		0.004***
IN		
		(4.081)
RETURN_CO		0.031
M_EQY		
		(1.536)
TOT_DEBT_T		0.175***
O_TOT_ASSE		
T		
		(5.643)
_cons	44.677***	40.099***
	(54.314)	(35.788)
N	723	723
r2	0.045	0.218

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 14

After applying robust standard errors to address the heteroskedasticity detected by the Breusch-Pagan test, the regression results indicate that the positive impact of R&D expenditure on ESG disclosure quality remains significant. Specifically, in Models 1 and 2, the coefficients of IS_RD_EXPEND are 1.427 and 0.488, with t-values of 6.236 and 2.088, respectively. In Model 1, the coefficient is significant at the 1% level ($p < 0.01$), and in Model 2, it is significant at the 5% level ($p < 0.05$). These values are consistent with the previous results, suggesting that heteroskedasticity does not substantially affect our core conclusions.

Moreover, control variables such as total assets and debt-to-asset ratio continue to exhibit significant effects on ESG disclosure quality after using robust standard errors. In Model 2, the coefficient of BS_TOT_ASSET (total assets) is 0.000 with a t-value of 4.266, significant at the 1% level. The coefficient of TOT_DEBT_TO_TOT_ASSET (debt-to-asset ratio) is 0.175 with a t-value of 5.643, also significant at the 1% level. This reaffirms the important roles of company size and leverage in influencing ESG disclosure quality.

The adjusted R^2 values for Models 1 and 2 are 0.045 and 0.218, respectively, which are consistent with the previous models. This indicates that the model's explanatory power remains stable after adjusting for heteroskedasticity, further strengthening the reliability of the results.

These findings underscore the robustness of the relationship between digital maturity and ESG disclosure quality. Despite the presence of heteroskedasticity, the significance and magnitude of the key variables remain largely unaffected after using robust standard errors. This provides strong empirical support for the argument that investments in digital capabilities, as proxied by R&D expenditure, enhance ESG reporting practices. The consistency of the results affirms that heteroskedasticity does not materially impact our core conclusions.

5.4.4 Summary of robustness checks

The consistency of results using capital expenditure as an alternative proxy suggests that the observed relationship between digital maturity and ESG disclosure quality is not driven by the specific choice of proxy variable. While R&D expenditure focuses on innovation and technology development, capital expenditure captures investments in

physical and IT infrastructure, complementing the narrower focus of R&D. Together, these proxies provide a more comprehensive perspective on digital maturity, reducing concerns about measurement limitations. The robustness checks affirm that the positive impact of digital maturity on ESG disclosure quality is consistent across different model specifications and measurement approaches. The fixed effects model analysis demonstrates that controlling for firm-specific characteristics and temporal factors does not alter the significance of R&D expenditure's effect on ESG disclosure quality. Substituting the dependent variable with a standardized ESG disclosure score and using capital expenditure as an alternative proxy for digital maturity yield consistent results, reinforcing the robustness of the conclusions.

The diagnostic tests show some problems in the study. The Ramsey RESET test suggests the model might not be properly specified. This means some factors that affect ESG disclosure quality could be missing from the model, or the relationship between digital maturity and ESG disclosure quality might not be linear. Due to limited data and the study's focus, we could not include more variables or test nonlinear relationships. We recognize this issue and suggest that future studies add more relevant variables and try nonlinear methods to improve the model.

The Breusch-Pagan test shows that the data has heteroskedasticity, which could make the results less reliable. We solved this by redoing the regression with robust standard errors. This made the results more reliable. After this adjustment, the main variables still had significant and expected results. This shows that heteroskedasticity does not change the core conclusions. Although the study has these limitations, the main findings stay strong. The positive link between digital maturity and ESG disclosure quality remains clear, highlighting the role of digital transformation in improving sustainability reporting in the energy sector.

6. Discussion

6.1 Interpretation of Findings

Through the above empirical analyses, Hypotheses 1, 2, and 3 have all been confirmed, while Hypothesis 4 yields varied results across different regions. Specifically, the findings for China and Europe support Hypothesis 4, whereas the results for the United States do not align with the hypothesis.

For the results in Hypothesis 1, the empirical analysis shows strong evidence that digital maturity positively affects ESG disclosure quality among energy companies. The clear positive link between digital maturity, measured by R&D spending as a sign of a company's digital transformation, and ESG disclosure quality suggests that firms investing more in digital capabilities often follow better ESG reporting practices. This is in line with the idea that digital transformation improves a company's ability to gather, handle, and share ESG information more effectively, which helps increase transparency and accountability. This is likely because digital transformation often brings advanced technologies—like data analytics, blockchain, and artificial intelligence—into ESG reporting. These technologies improve the accuracy, timeliness, openness, and ease of access of ESG disclosures, meeting growing stakeholder demands for dependable and complete sustainability information. As a result, energy firms that focus on digital transformation are better prepared to handle environmental and social problems, meet regulatory rules, and enhance their reputation among investors and the public.

For the control variables, the analysis finds that firm size, profitability, and leverage strongly affect ESG disclosure quality. Bigger firms tend to have higher ESG scores, possibly due to more public scrutiny and more resources for detailed reporting. These firms are often pressured by regulators, investors, and others to show their commitment to sustainable practices, which encourages them to improve their ESG disclosures. Profitability is also important. More profitable companies usually offer more thorough

ESG reporting because higher profit margins let them put money into sustainability efforts and reporting methods. This approach meets stakeholder expectations and can help with long-term value creation and risk management. Also, firms with higher leverage may boost their ESG disclosures to strengthen investor trust and lower worries about financial risks tied to debt. Clear and strong ESG reporting can show creditors and investors that the company manages its environmental and social risks well, which can lead to better financing terms and a lower cost of capital.

These findings show that ESG disclosure quality in the energy sector depends on many factors. Digital maturity is important, but firm features like size, profitability, and leverage also have strong effects. This shows why improving ESG disclosures requires a broad strategy that combines digital transformation with ways to use the firm's resources, financial strength, and stakeholder engagement.

The empirical analyses of Hypotheses 2 and 3 give a full view of how digital maturity, company type, and ESG disclosure quality connect in the energy sector. Hypothesis 2 finds that clean energy firms have higher digital maturity than traditional energy firms. Then Hypothesis 3 shows that digital maturity has a stronger positive effect on ESG disclosure quality in clean energy companies than in traditional ones. These linked results offer key insights into how digital transformation and sustainability practices work together in different energy firms.

The higher digital maturity in clean energy companies sets the stage for a bigger positive influence of digital maturity on ESG disclosure quality in these firms. This means clean energy firms are not only more advanced digitally, but they also use their digital skills more effectively to improve ESG reporting. This points to a mutually reinforcing bond between digital maturity and ESG goals, especially in clean energy

firms.

Several factors explain these outcomes. First, clean energy firms focus on environmental sustainability as a main part of their business models. They work to cut carbon emissions and promote renewable energy, which fits well with ESG principles. This focus pushes them to invest in digital tools that support sustainability, like advanced data analytics to track environmental impact or blockchain for supply chain clarity. Higher digital maturity in these firms allows better ESG data collection and reporting, which improves disclosure quality. Second, strict rules and market forces matter. Clean energy firms often must follow tough rules that require detailed ESG reporting. Government and regulatory bodies ask for extensive data on environmental performance, energy efficiency, and social effects. Investors and consumers also prefer companies with strong ESG profiles. To meet these demands, clean energy firms use their digital maturity to streamline compliance and give clear, high-quality ESG information. Further, the innovation-focused mindset seen in the clean energy sector creates a setting where technology is part of business success. This mindset extends to ESG reporting. Digital maturity helps test new technologies that can improve ESG disclosures, like Internet of Things devices for real-time tracking or AI for predictive sustainability analytics. The drive to adopt and blend these technologies explains the stronger positive impact in clean energy firms.

Traditional energy firms, on the other hand, have lower digital maturity and do not translate their digital investments into better ESG disclosure quality. Many issues may cause this. Traditional energy firms might use digital tools mainly for operational efficiency, cost cuts, or extraction improvements, without directly linking these efforts to ESG goals. Without a clear plan, digital maturity does not naturally lead to better ESG reporting. Also, sustainability may not be a main concern for traditional energy firms, which leads to limited ESG reporting efforts even if they have digital tools. The

weak or minimal effect of digital maturity on ESG disclosure quality suggests that digital tools are not fully used to promote openness and responsibility in these firms. Different outside pressures and stakeholder expectations also play a role. Traditional energy firms may work in places with fewer ESG reporting rules than clean energy firms. If stakeholders do not ask for strong ESG reporting, these companies have little reason to use digital technologies for that purpose.

The examination of Hypothesis 4 sheds light on how regional factors affect the link between digital maturity and ESG disclosure quality in energy companies. The findings show that in China and Europe, digital maturity greatly boosts ESG disclosure quality. In the United States, this link is not seen. This difference underscores how regional policies, rules, and cultural attitudes shape how companies use digital technologies for sustainability reporting.

In China, the positive effect of digital maturity on ESG disclosure comes from various related factors. The Chinese government actively encourages digital transformation and sustainability as part of national development. Initiatives like “Internet Plus” and a focus on building a “Digital China” push companies to invest in digital technologies. Meanwhile, China’s regulatory setting focuses more on environmental protection and corporate social responsibility, requiring more thorough ESG disclosures. The mix of government support for digitalization and strict ESG rules creates conditions where digital transformation directly improves ESG disclosure quality. Energy firms in China, reacting to these outside pressures, use digital tools to be more transparent, follow regulations, and satisfy stakeholders.

In Europe, the strong positive link between digital maturity and ESG disclosure quality reflects the region’s deep commitment to sustainability and tech innovation. The

European Union has set up strict regulatory systems that make companies disclose detailed ESG data. Rules like the Non-Financial Reporting Directive (NFRD) and the Sustainable Finance Disclosure Regulation (SFDR) require high levels of clarity and accountability. Also, European societies tend to be very environmentally aware, so consumers, investors, and civil society groups push for responsible corporate actions. Governments in Europe also promote digital innovation through funding programs and policies like the Digital Single Market strategy. These combined demands and supports mean energy companies in Europe use digital transformation to improve ESG disclosures.

The lack of a strong link between digital maturity and ESG disclosure quality in the United States points to different underlying factors. The US regulatory system has fewer required ESG reporting rules compared to China and Europe. Although interest in sustainability is growing, ESG disclosures in the US are often voluntary and less consistent. The Securities and Exchange Commission (SEC) has historically been hands-off, though there are signs of possible changes toward more ESG oversight. Cultural attitudes in the US may stress financial gains and shareholder returns, giving less attention to sustainability unless it clearly helps profits. As a result, energy firms in the US may prioritize digital tools that boost financial metrics instead of ESG reporting. The strong positive effects of company size and financial performance on ESG disclosure scores in the US data support this view, showing that standard financial aspects are more important than digital maturity for ESG reporting.

6.2 Practical Implications

The study shows that digital maturity has a strong positive link with ESG disclosure quality for companies in the energy sector. Companies can use digital tools to improve their ESG reporting, which helps them be more transparent, meet rules, and satisfy stakeholder expectations. Traditional energy companies with lower digital maturity can

rethink their priorities. By investing in technologies like advanced data analytics, blockchain, and artificial intelligence, they can gather data more efficiently, report ESG information with fewer mistakes, and give stakeholders better details about their sustainability efforts. These technologies help companies handle complex ESG data, reduce errors, and offer deeper insights into their performance on environmental and social issues. The study also shows that clean energy and traditional energy companies benefit differently from digital maturity. Traditional energy companies may need to address organizational barriers and resistance to change if they want to improve their ESG reporting through digital tools. This might include creating a culture that supports innovation and sustainability, training workers to improve their digital skills, and using flexible structures that allow for new technology.

In places like China and Europe, where digital maturity strongly improves ESG disclosure quality, energy companies can take advantage of regulations and public interest in sustainability. By matching digital transformation goals with local sustainability goals, these companies can gain a competitive edge, build trust with stakeholders, and help achieve broader environmental targets. In the United States, where the impact of digital maturity on ESG disclosure quality is not as clear, companies may need to watch for changes in sustainability trends. By getting ready for possible rule changes and growing stakeholder concern about ESG issues, US companies can use digital technologies to enhance their ESG reporting and improve their image and appeal to investors.

6.3 Policy Recommendations

The results give useful ideas for policymakers who want to promote digital transformation and innovation in the energy sector to boost ESG disclosure. Governments and regulators can shape the setting in which companies work, and they can strongly affect corporate actions.

Clear regulations that require full ESG reporting can motivate companies to use digital technologies for easier compliance and better reporting accuracy. When information gaps shrink, stakeholders can make better decisions. This creates a culture of trust and accountability. Financial incentives can also push companies to adopt digital approaches for sustainability. Governments can offer tax breaks, grants, or subsidies for digital tools that help ESG performance and disclosure. Collaboration among industry groups, tech providers, and others can push progress, too. Policymakers can set up forums where people share knowledge and solutions, helping companies work together on ESG disclosure challenges.

In the United States, the shifts in political priorities have introduced uncertainty regarding the direction of ESG-related policies. Certain policy stances, including proposals to roll back environmental regulations, may reduce corporate incentives to pursue sustainable development goals. These dynamics could lower stakeholder interest in comprehensive ESG reporting and digital transformation aimed at sustainability. Policymakers in this environment should consider strategies to address potential setbacks in ESG frameworks. Public-awareness efforts that emphasize the long-term economic and environmental benefits of transparent ESG reporting can maintain pressure from investors, consumers, and other stakeholders. Additionally, state-level governments that endorse clean energy and sustainability may continue to implement independent policies that promote ESG practices and digital innovation, even if broader federal support remains limited.

Global cooperation is still key to making ESG reporting standards the same across borders. Policymakers can work with international groups to build shared frameworks that lower regional differences and give global companies consistent rules. When countries align on these approaches, they help push sustainable goals around the world,

even in places where political roadblocks might slow local efforts.

6.4 Theoretical Contributions

This study adds to the academic view of how digital transformation and ESG disclosure connect. First, it shows how digital transformation can improve ESG reporting in the energy sector. By using R&D spending as a measure of digital maturity, the study gives a clear way to see how technology investments relate to sustainability reporting. It also looks at how company type and region change these results. The difference between clean and traditional energy firms helps explain how core strategies and business models shape how well digital transformation works for sustainability goals. This suggests that matching digital efforts with a company's values and goals matters for getting the best results.

The regional analysis builds on institutional theory and how external settings shape what firms do. It shows that rules and culture can change how digital maturity affects ESG reporting. It also blends ideas from technology adoption and sustainability reporting, giving a broad view that strengthens academic debates. It shows that digital transformation does not happen alone. Instead, it depends on company strategies, stakeholder needs, local differences, and rules that all come together to affect business outcomes.

6.5 Limitations of the Study

There are limitations must admit. First, the sample size and data availability may affect the generalizability of the findings. The limited number of companies in only three regions, as well as the limited number of companies, can only represent a specific part of the global energy industry. Including more companies, especially from underrepresented regions or emerging markets, could provide a more comprehensive

perspective. Secondly, the use of R&D expenditure as a proxy for digital maturity, while practical, may not capture all dimensions of a company's digital transformation. R&D spending encompasses a range of activities, and not all may be directly related to digital capabilities. Future research could incorporate additional measures of digital maturity, such as the adoption of specific technologies, digital infrastructure investments, or organizational digitalization indices or use some specify models to evaluate the digital transformation maturity. Thirdly, there may be unobserved variables or external factors not accounted for in the study that could influence the results. For example, corporate governance structures, leadership commitment to sustainability, or economic conditions might affect both digital transformation efforts and ESG reporting practices. Lastly, the scope of the analysis is limited to the energy sector, which has unique characteristics and regulatory environments. While this focus allows for in-depth exploration, it may limit the applicability of the findings to other industries. Different sectors may exhibit varying relationships between digital maturity and ESG disclosure quality due to distinct operational practices, stakeholder expectations, and regulatory pressures.

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