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RESEARCH

The role of alliance portfolio diversity for corporate decarbonization, circular economy and eco-innovation

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Abstract
Amid growing societal and regulatory pressure to demonstrate environmental responsibility, firms are increasingly engaging in environmental alliances to address complex sustainability challenges. However, the implications of having a diverse portfolio of green alliances for a business' progress toward environmental goals remains insufficiently understood and long-term empirical evidence on this relationship is still scant. This study adopts a novel resource-based and knowledge-based perspective to examine how environmental alliance portfolio diversity—across technological, industrial, and functional dimensions—shapes corporate environmental performance. Using data from 280 multinational companies and 1,539 environmental alliances spanning 2002–2023, our analysis reveals that all three dimensions of diversity are positively associated with overall corporate environmental performance, emission reductions, more efficient resource use, and green innovation within firms. These findings underscore the strategic importance of alliance portfolio diversity in advancing sustainability, decarbonization, and circularity goals and provide actionable insights for firms seeking to enhance specific non-financial performance metrics.

Keywords Environmental sustainability · Strategic alliances · Alliance portfolio diversity · Green innovation · Net-zero · Corporate responsibility

JEL Classification Q53 · Q54 · Q55 · L24 · O33

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1 Introduction

In recent years, climate change and environmental concerns have become prominent topics in public and academic discussions, prompting entrepreneurs and businesses to embrace new sustainability practices to minimize their impact (Chu, 2019; Riegler et al., 2023). Acknowledging the inherent complexity of most contemporary environmental challenges, organizations are increasingly recognizing the critical role of business networks and various forms of inter-firm collaborations, extending their focus beyond the confines of individual enterprises (Finke et al., 2016; Gasparini et al., 2024). Private sector partnerships, collaborations, and strategic alliances among different types of firms enable the exchange of competencies, technologies, and ideas between organizations with different characteristics and business models (Goldstein et al., 2019; Todaro et al., 2021). Thus, alliances are instrumental for technology transfers and access to a broad range of expertise, capabilities, and resources (Haim Faridian et al., 2023; Stadtler & Lin, 2017), thereby contributing to a firm's ability to address ecological challenges, move towards sustainable development goals and accelerate their path to net-zero emissions (Carvajal-Camperos et al., 2024).

Strategic alliances, defined as voluntary cooperative agreements between firms aimed at creating value by sharing capital, technology, or firm-specific assets (Niesten & Jolink, 2020), have long been recognized as pivotal for achieving new competitive advantages. In recent years, the number of strategic alliances – especially those with an environmental focus – has surged dramatically, as companies increasingly recognize the value in joining multiple, diverse coalitions (Wassmer et al., 2014). Within the strategic alliance literature, different studies have investigated the role of a diversified network of these collaborative agreements, known as the *alliance portfolio* of a firm (Jiang et al., 2010). An alliance portfolio is an orchestration of various partnerships for the achievement of any specific target, such as minimized risks, enhanced legitimacy, or environmental responsibility (Collins & Riley, 2013). However, thus far the alliance portfolio literature has focused mostly on financial targets. It typically measures the performance of alliance members in terms of profits, long-term resilience, stock market value, and so on (Jacobs & Swink, 2011; Jiang et al., 2010; Lavie & Miller, 2008; Lee et al., 2017). Only few studies have looked at how environmental alliances support non-financial accomplishments in tackling grand challenges such as decarbonization, circular economy, or other aspects of corporate sustainability (Lin, 2012a, 2012b).

A key feature of alliance portfolios is the range and variety of collaborations established by a firm, that is the *alliance portfolio diversity* (APD). This concept captures the variance of alliances within the portfolio of a company and has been identified as a potential driver of corporate performance (Collins & Riley, 2013; Lee et al., 2017; Wuyts & Dutta, 2014). For the purposes of this research, we focus only on various types of diversity at the level of the portfolio and not at diversity within each alliance. The forms of APD examined in the literature capture multiple facets of firm's alliance portfolios across several key dimensions: the types of partner organizations involved in the portfolio's alliances, their geographic scope, the industries involved, the functions of the alliances (e.g., R&D or manufacturing), and the technological capabilities developed or leveraged through these alliances. A substantial body of literature has examined the impact of some of these dimensions of alliance portfolio diversity on firms' financial performance. However, empirical findings remain inconsistent, since a diverse portfolio of alliances can provide access to a broader range of opportunities but also introduces greater complexity in managing heterogeneous partnerships effectively (Lee et al., 2017).

Moreover, and critical for our research, the influence of APD in environmental alliances on firms' non-financial metrics—particularly corporate environmental performance—remains to date largely underexplored (Ashraf et al., 2014, 2019; Le et al., 2021). This gap is particularly significant given the growing emphasis on innovative and multilateral sustainability strategies as key drivers of competitive advantage in today's business landscape (Hermundsdottir & Aspelund, 2021), and considering the need for cooperative approaches to find the appropriate resources and knowledge to enact corporate responsibility. Therefore, understanding how APD is linked to various dimensions of environmental performance is crucial for firms seeking to collaboratively pursue net zero strategies, circularity, green innovation, and other sustainability goals.

Corporate environmental performance is typically evaluated using Environmental, Social, and Governance (ESG) metrics, which provide a structured framework for assessing a firm's relationship with environmental issues— the "E" in ESG—across areas such as carbon emissions, energy efficiency, resource use, and waste management (Eccles et al., 2014; Friede et al., 2015). Despite numerous studies on the drivers of ESG performance (Crace & Gehman, 2023; Martiny et al., 2024), there is still limited empirical evidence on the ESG dynamics that stem from strategic green alliances, collaborations, and inter-organizational partnerships. While some studies suggest that collaborating with external stakeholders and participating in alliances can enhance ESG performance, comprehensive empirical analyses are still scarce (Lin & Darnall, 2015). The existing literature predominantly focuses on firm-level determinants of ESG performance or on the direct relationship with specific stakeholders, leaving a gap in understanding the role of the overall portfolio of external collaborations of a firm in shaping its sustainable practices.

To address this gap, this paper proposes a novel analysis of APD in environmental alliances, considering three key dimensions of diversity at the portfolio level that are particularly relevant for corporate sustainability. Building upon managerial theories of resource-based and knowledge-based views, we consider three dimensions that directly enhance the tangible and intangible resources and knowledge that a firm can access with a diverse alliance portfolio: first, *industry diversity*, namely the range of industries represented in the portfolio of alliances; second, *functional diversity*, namely the varieties of core activity in the portfolio of alliances, for example R&D, manufacturing of specific products, supply and distribution, marketing, etc. (Le et al., 2021); and third, a technological dimension that we introduce specifically to look at the green innovative potential for sustainable solutions, *environmental technology diversity*—defined as the variety of environmental technologies developed or adopted across the portfolio of alliances. By focusing on the relationship between environmental performance and alliance portfolios' diverse resources and knowledge gathered across industries, functions and technologies, we develop and extend existing environmental APD literature. Prior studies have developed important insights on the impact of firms' cognitive frames for sustainability on alliance portfolio diversity (Dzhengiz, 2018, 2020), as well as on firms' capacity to manage stability and change in sustainability transitions (Ashraf et al., 2019; Dzhengiz et al., 2024). Other dimensions of portfolio diversity have also been previously studied in the literature, such as geographic diversity or the size of the organizations involved, but we do not expect them to play a direct role in enhancing the access to resources and knowledge of a firm though a diverse alliance portfolio. Next, we construct three indicators capturing empirically these industrial, functional, and technological dimensions of portfolio diversity using a rich dataset of more than 1,500 alliances with an explicit environmental purpose. Then, we match the dimensions of diversity within alliance portfolios with the overall environmental, social, and governance (ESG) performance of the firms involved, tracking both an aggregate environmental score and more specific outcomes, namely greenhouse gas emissions, resource use, and green innovation.

Our aim is, first of all, to provide a comprehensive characterization of environmental alliances and green alliance portfolios worldwide, which have not been explored systematically in terms of some key diversity dimensions. Second, we seek to understand whether these dimensions of diversity in a company's alliance portfolio are significantly linked to improved environmental performance, climate profile, circularity, and environmental innovativeness. Thus, our contribution to the literature on corporate sustainability strategy is twofold. First, we add to the current debate on the role of business collaborations and specifically look at diverse portfolios of formal alliances with a "green" objective, and their relationship with an understudied set of outcomes, that is companies' non-financial performance.

Second, from a methodological standpoint, we apply panel data techniques to control for time-invariant firm fixed effects, advancing beyond the existing literature, which mostly relied on cross-sectional evidence with only one time period, and thereby providing new and more robust insights into the dynamic nature of alliance portfolio management and corporate environmental impacts. Overall, we shed light on how a combination of different types of green alliance portfolios can drive corporate environmental performance over time, contributing both to the theoretical and empirical understanding of how to leverage collaborations among firms for sustainability—in alignment with the 17th UN Sustainable Development Goal, focused on global partnerships for sustainable development.

The paper is structured as follows. First, we present the theoretical background, followed by our research framework and related hypotheses. Next, we provide a description of the sample and empirical methodology. Subsequently, we illustrate the main results of the analysis. Finally, we conclude with a discussion of the findings, highlighting some limitations and the main implications of the study.

2 Theoretical background

The scale and complexity of transitioning to a more sustainable, low-carbon economy often exceed the capabilities of individual firms (Riegler et al., 2023). The green transition requires transformative changes across industries, supply chains, and technologies, with investments in research and development, infrastructure upgrades, and operational overhauls. The financial burden and technological challenges associated with these transformations can be daunting for single companies, particularly those with limited resources or operating in carbon-intensive sectors (Suk et al., 2016). Moreover, achieving significant improvements in corporate sustainability often involves addressing systemic issues that require collective action, technology transfers, and collaboration across industries and sectors (Groves et al., 2023). Thus, strategic environmental alliances can serve as crucial enablers for harnessing the strengths of different companies and facilitating the sharing of both tangible and intangible resources, thereby contributing to enhanced sustainability outcomes.

The literature on strategic alliances suggests that diverse portfolios of collaborations are vital for companies to effectively achieve any complex performance goal (Lee et al., 2017; H. Lin & Darnall, 2015), and therefore environmental alliances could plausibly contribute to improving companies' sustainability profile, in line with the predictions of well-established management theories of resource-based and knowledge-based views. We build on these theoretical insights to inform our hypothesis development, combining two streams of literature on (i) alliance portfolios and (ii) corporate environmental performance: starting from the evidence on resources and knowledge in strategic environmental alliances in general, we then intersect it with the studies on alliance portfolio diversity and finally with those of ESG performance.

2.1 Diversity of resources and knowledge in alliances

To understand the role of alliance portfolio diversity for companies participating in environmental alliances, we combine the insights from managerial theories of resource-based and knowledge-based views (RBV and KBV, respectively), to develop our theoretical expectations on how different dimensions of diversity can help tackle grand challenges beyond the reach of individual organizations (Falcke et al., 2024; Grant, 1996; Riegler et al., 2023; Wernerfelt, 1984). The RBV and KBV offer a theoretical foundation on the mechanisms that link diverse portfolios of strategic alliances and corporate performance. The key element highlighted by these theories is the importance of accessing unique resources and knowledge (H. Lin, 2012b). The RBV argues that a company's internal resources, which are valuable, rare, inimitable and irreplaceable, are the main source of competitive advantage. Within this set of internal resources, the KBV argues that knowledge is one of the most important sources of competitive advantage for companies (Martín-de Castro, 2015), and strategic alliances are seen as crucial means for the acquisition, creation and utilization of new knowledge.

A substantial body of research has documented the positive impact of accessing resources and knowledge through strategic alliances for firms' financial performance, including improvements in profitability, market share, and innovation outcomes (Chou et al., 2014; Kale & Singh, 2007; Li et al., 2019). The evidence confirms that alliances serve as a versatile platform for organizational learning, enabling the effective transfer of knowledge between partner firms, the integration and recombination of resources, and privileged access to technological and other complex capabilities (Mamédio et al., 2019). In recent years, scholars have expanded their focus beyond purely financial metrics, investigating how alliances affect non-financial performance indicators such as reputational capital, stakeholder engagement, and sustainability outcomes, often through the lenses of ESG performance. Indeed, strategic alliances appear to improve environmental performance through sustainability-specific learning processes and resource-enriching effects (Hübel et al., 2022; Lin et al., 2025).

Building on these considerations, we examine the evidence from the literature on environmental alliances, which has not yet considered diversity in environmental portfolios of inter-firm alliances. We then integrate it with insights from the portfolio diversity literature, which has not focused specifically on environmental alliances thus far, and discuss how portfolio diversity of environmental alliances can leverage resources and knowledge to improve performance. Finally, we bridge the alliance literature with the evidence on the key drivers of ESG performance in an environmental realm, which is again directly linked to specific resources and knowledge availability. From this combination, we derive our central hypotheses on the relationship between portfolio diversity in environmental alliances and corporate sustainability outcomes.

2.1.1 Strategic environmental alliances

A growing strand of research has examined the benefits of strategic environmental alliances (Lin & Darnall, 2015; Riegler et al., 2023; Stadtler & Lin, 2017). Following this literature, we define environmental alliances as voluntary cooperative agreements between firms explicitly aimed at the development, manufacture and/or distribution of green and sustainable products or services, in which partners exchange, share or co-develop environmental resources, knowledge, or technologies (Jolink & Niesten, 2021; Wassmer et al., 2014). Environmental alliances strive to create not only economic value for their participants, but also non-financial value in terms of environmental sustainability, fostering green innovations and sustainable solutions that benefit not only the companies in the alliance but also society at large (Niesten & Jolink, 2020).

Research on environmental alliances has highlighted the key factors that motivate companies to form these alliances and their potential outcomes (Lin, 2012b; Niesten & Jolink, 2020; Stadtler & Lin, 2017). In terms of motivations, the findings of these studies can also be framed within a resource-based view (RBV) and a knowledge-based view (KBV) to explain the main factors for companies that decide to enter these alliances (see for instance Lin & Darnall, 2015, and Niesten & Jolink, 2020). According to this perspective, environmental alliances facilitate companies' access to idiosyncratic resources and competencies, thus stimulating organizational learning and creating new competitive advantage opportunities.

In terms of corporate performance, measured through a range of different outcomes, Lozano et al. (2021) highlight how these collaborative efforts facilitate the pooling of tangible and intangible resources and knowledge, accelerating the development of new green technologies and therefore achieving better environmental performance than isolated initiatives. Although several authors have demonstrated the positive effect of specific environmental alliances and collaborations on environmental performance (Albino et al., 2012; Lin, 2012b; Lopes Cancela et al., 2023), this literature has yet to consider the exponential growth in environmental alliances that is taking place worldwide, and the fact that nowadays many firms have more than one alliance. To date, in the environmental alliance literature, there is still a lack of analysis of the interplay between corporate environmental performance and the characteristics of multiple alliances, namely the overall environmental alliance portfolio of a company. To address this gap, we must also consider the insights from the Alliance Portfolio Diversity (APD) literature.

2.1.2 Alliance portfolio diversity (APD)

Given the instrumental role of environmental alliances in addressing complex ecological challenges through resource and knowledge exchanges, in recent years companies have increasingly engaged in diverse networks of collaborative agreements (Payán-Sánchez et al., 2022). Many companies are choosing to establish various alliances, each serving distinct purposes in advancing their environmental objectives, as no single alliance is sufficient to address the full spectrum of issues necessitating collaborative solutions. However, a critical gap exists in the understanding of the impact of diversity within environmental alliances specifically and their relationship with corporate environmental performance.

The Alliance Portfolio Diversity (APD) literature suggests that different kinds of diversity across alliances can contribute to a firm's efforts in different ways, depending on the dimensions of diversity covered by the portfolio (Jiang et al., 2010). The configuration of the alliance portfolio emerges as a critical factor influencing performance outcomes, like innovation and financial measures, but research suggests that this diversity can be a double-edged sword (Collins & Riley, 2013; Lee et al., 2017; Wuyts & Dutta, 2014). While it offers potential benefits like increased access to new knowledge, enhanced creativity, and improved adaptability to changing market conditions, it can also introduce challenges like increased management complexity, communication difficulties, and potential conflicts due to differing goals and cultures (Lee et al., 2017; Wuyts & Dutta, 2014). These potential drawbacks, coupled with the mixed results observed empirically for the effects of diversity on various performance outcomes, contribute to the ongoing debate and lack of conclusive findings in the literature. To apply these findings to portfolios of environmental alliances, there needs to be careful consideration of the theoretical advantages and disadvantages of different facets of diversity.

The diversity dimensions that have been investigated are manifold, and most of the existing studies on environmental alliance portfolios analyze diversity in terms of a wide variety of organizations, including governments, universities, NGOs, and firms involved in these partnerships (Gutiérrez et al., 2016; Horan, 2019, 2022; Schmutzler et al., 2014). For our study, the unit of analysis are firms and only their portfolios of inter-firm alliances, focusing on diversity dimensions that capture some key attributes of environmental APD that contribute to corporate environmental performance. Furthermore, unlike network studies that emphasize the structural positions of players in the network, our analysis takes a resource- and knowledge-based lens to interpret the role of diversity attributes of a firm’s alliance portfolio, considering that direct access to heterogeneous resources and knowledge is crucial to enable better corporate environmental performance and address complex sustainability challenges.

In this context, the key diversity dimensions considered in the literature are *industry/sectoral diversity*, which captures the various industry sectors represented by the partner firms involved in the portfolio of alliances; *national diversity*, which denotes the different countries of the firms involved; *organizational diversity*, which summarizes the different characteristics of partner organizations, such as size, legal structure, age, etc.; *functional diversity*, which refers to the range of activities covered by the portfolio of alliances (such as marketing, R&D, or manufacturing), and *governance diversity*, which refers to the nature of ownership arrangements, including equity-based or non-equity structures (Lee et al., 2017). There is *technological diversity*, namely the diverse technological capabilities of the partners, or the technological scope of the alliances: this metric can capture the diverse innovative capabilities of individual firms, or the technological profile of the whole alliance, if some joint technology development is in place. These various dimensions are summarized in Table 6 in the Appendix, where we highlight some elements that are theoretically relevant for environmental alliances in light of the insights from RBV and KBV.

The actual effects of each of these dimensions can vary considerably depending on the performance indicator under study,[1] but for non-financial performance and particularly environmental performance, the evidence is still limited. One notable exception is the study of (Le et al., 2021), who explore the mediating role of sustainability collaborations in the relationship between APD and supply chain sustainability performance among Vietnamese firms. Their exploration finds in cross-sectional data a variety of different effects: partner, governance, and functional diversity have U-shaped, inverted U-shaped, and positive linear effects on sustainability collaboration, respectively, which, in turn, indirectly enhances sustainability performance. Other studies have focused on the cognitive frames of firms that guide their interpretation of sustainable practices (e.g., Dzhengiz, 2018). They argue that paradoxical frames, in comparison to business case frames, lead to more diverse portfolios of environmental alliances (Dzhengiz, 2020). A higher diversity of cognitive frames in firms' APD has been shown to have an inverse U-shaped relation with sustainable performance (Ashraf et al., 2019).

Based on our own reading of the literature, we consider the three most important dimensions of diversity for accessing resources and knowledge across a portfolio of inter-firm alliances to be industry, functional and technological diversity. These dimensions are particularly relevant due to their potential to directly influence the access to specific resources and knowledge needed to enhance a firm's capacity to develop and implement innovative environmental solutions, integrate sustainable practices across different business functions, and access diverse expertise and assets from different industry sectors. While other dimensions, such as governance or national diversity, may also play a role, their influence on environmental performance is likely to be less direct and contingent on financial effects and the specific context of the alliances.[2] Given the heterogeneous results seen in the literature in terms of non-linear relations between APD and (environmental) performance, we consider it especially important to move beyond existing studies and take a within-firm approach that considers the variety of knowledge and resources that an individual firm can accumulate over time through its alliance portfolios. We thus combine the RBV and KBV theories discussed in Sect. 2.1 with an APD perspective, considering that the diversity in resources and knowledge represents a key benefit provided by environmental alliances to achieve complex sustainability goals. For this reason, we chose to focus on the three facets of alliance portfolio diversity that most enhance the access to diverse resources and knowledge across industries, functions and environmental technologies, so to unpack some of the dynamics of APD and corporate environmental performance that this literature has not yet reconciled.

For the technological dimension, however, we go beyond the literature that has found a general link between technological diversity and performance (Lin & Chang, 2015), and

[1] For example, Jiang et al. (2010) show that moderate levels of organizational and functional diversity, coupled with lower governance diversity, are linked to higher financial performance. Conversely, industry diversity exhibits a U-shaped relationship with financial outcomes, indicating potential drawbacks at both low and high levels. Other authors found a U-shaped effect of alliance portfolio technological diversity on superior product innovation (Wuyts & Dutta, 2014). Unfortunately, these results have not yet been replicated across different types of alliances and subgroups of partners.

[2] For example, the equity versus non-equity distinction in the governance dimension can have indirect impacts on green trajectories, but we do not expect theoretically a strong direct effect. Equity-based alliances, involving ownership stakes, might provide deeper integration and long-term commitment. Non-equity alliances, such as joint ventures, can offer flexibility and speed in forming green collaborations. However, these are mostly aspects influencing the nature and dynamics of collaborations, rather than the capabilities of partners to directly achieve sustainability targets.

choose to focus specifically on *green* technological diversity, which we expect to play a key role for environmental performance in environmental alliances. The concept of green innovation encompasses the process of developing and deploying new clean technologies (Rennings, 2000), but also the strategic recombination and adoption of diverse environmental technologies (Antonelli et al., 2010). This recombination mirrors the process of recombinant knowledge creation, where new ideas and innovations emerge from the combination of existing knowledge bases (Colombelli, 2016). Despite the ample research confirming the importance of collaborations and exchanges for the generation and diffusion of cleantech (Melander, 2017; Reficco et al., 2018), the specific implications of environmental technology diversity within environmental alliance portfolios remain to be examined. Therefore, we assess APD through the lenses of environmental technology diversity, building a new indicator for different categories of environmental technology.

Finally, we note that this literature suggests that different dimensions of alliance portfolio diversity should be evaluated over an extended time horizon, given that environmental practices often require complex adaptations and organizational changes. The role of APD in corporate sustainability is expected to depend on different mechanisms over time, compared to its impact on financial outcomes, and thus requires a distinct investigation with information for multiple years.

2.2 ESG performance and the need for resources and knowledge

Corporate environmental performance is a multifaceted and broad concept encompassing a wide range of practices, impacts, and evaluative criteria. In the context of this article, we focus more specifically on the 'Environmental' dimension of ESG frameworks, treating it as a narrower and more operationalizable construct within this broader conceptual domain. This 'Environmental' dimension of ESG refers to how firms interact with the natural environment, covering issues such as greenhouse gas emissions, energy and water use, waste management, and pollution. While various initiatives have attempted to standardize environmental disclosures, there is no universal ESG definition or framework (Berg et al., 2022). Nevertheless, ESG standards are widely adopted by financial institutions and investors, who primarily use them to assess and compare firms' environmental impacts and risks (Christensen et al., 2022).

The growing importance of non-financial metrics to capture ESG performance in corporate strategy has attracted significant academic attention in recent years, particularly regarding the factors, resources and capabilities needed for achieving tangible improvements in different ESG areas (Crace & Gehman, 2023; Martiny et al., 2024). While ESG performance is increasingly linked to long-term value creation, its drivers are not always aligned with traditional financial performance metrics. Unlike profitability or market share, ESG outcomes often lack short-term financial incentives and are driven by complex stakeholder expectations, regulatory pressures, and normative commitments (Kotsantonis & Serafeim, 2019). As a result, achieving strong ESG performance may rely more heavily on the availability of strategic resources—such as specialized personnel, resources and infrastructures dedicated to green projects, and robust knowledge systems—than on traditional determinants of firms' success like firm size or access to capital markets (Aragón-Correa & Sharma, 2003).

In this context, knowledge serves as a foundational asset in ESG implementation, particularly given the evolving and non-standardized nature of ESG criteria and regulation across sectors and tasks. Firms with deep internal expertise in sustainability, combined with absorptive and learning capacity to integrate external knowledge, are better positioned to engage in meaningful ESG initiatives (Xia, 2022). This also explains the growing emphasis on collaborative learning and knowledge exchange in cross-sectoral networks that facilitate shared innovation and the co-creation of ESG expertise and value. By pooling technical knowledge, firms can better navigate technical complexities, exchanging and diffusing know-how and best practices in sustainable products and processes (Bodin, 2017). In this view, ESG excellence is as much about accessing resources and knowledge in the ecosystem and through open engagement as it is about individual firm competencies.

The operationalization of environmental performance in our analytical framework is based on this ESG literature and can then be linked to specific environmental ESG metrics relevant also for our empirical analysis. Therefore, we consider environmental performance to be the combination of three key components: emission reduction, resource use optimization, and green innovation. Emission reduction captures a company's commitment and effectiveness towards reducing environmental emissions (especially climate-altering greenhouse gases) in its production and operational processes. Resource use optimization reflects a company's capacity to reduce the use of materials, energy or water, to reuse and recycle them in closed loops, and to find more eco-efficient solutions, also though its supply chain management. Finally, green innovation reflects a company's capacity to reduce the environmental costs and burdens by creating new market opportunities through new environmental technologies and processes, or eco-designed products.

2.3 Hypotheses development

In this section, we combine the insights from the two literatures streams on environmental alliances and APD with the evidence on ESG performance through the lenses of resource- and knowledge-based views. These theoretical lenses imply that diverse alliance portfolios provide firms with access to valuable and complementary resources and knowledge, which in turn are expected to contribute to better environmental performance. Therefore, we derive three testable hypotheses regarding the relationship between environmental performance and the most relevant dimensions of alliance portfolio diversity—environmental technology, industry, and functional diversity.

2.3.1 Environmental technology diversity

Starting from environmental technology diversity, according to the RBV and KBV, the unique resources and expertise that can be gained with a diverse portfolio of environmental alliances covering a broad range of green technologies should allow companies to build a dynamic innovative ecosystem and exploit a wider range of innovative solutions (De Moortel & Crispeels, 2024), which are then the basis for decarbonization, resource and energy efficiency, and further creation of green innovation. This diversity not only provides access to a broader range of green technical solutions but should also foster a dynamic environment for technological exchange, recombination and innovation (König et al., 2011; Martínez Ardila et al., 2020; Weitzman, 1998). The acquisition of diverse and specialized knowledge through a variety of environmental technologies across different alliances can provide individual companies with building blocks that can stimulate innovation and a sustainable growth trajectory coupled with improved environmental performance (Wuyts & Dutta, 2014). This diversified technological base captures an ecosystem of collaboration and knowledge exchange on innovative green solutions and should therefore lead to improved aggregate environmental performance. Hence, we propose the following hypothesis:

Hypothesis 1 A firm's corporate environmental performance is positively associated with the Environmental Technology Diversity of its alliance portfolio.

For the positive association hypothesized above, different specific mechanisms for technological resources and knowledge utilization can underlie the relationship between Environmental Technology Diversity and our three key dimensions of environmental performance: emission reduction, resource use, and green innovation. We discuss each of them in turn.

First, firms engaged in technologically diversified alliances can develop or access advanced solutions for emission control that may not yet be available to each individual company. These may entail the creation and adoption of state-of-the-art techniques, ranging from low-carbon manufacturing processes to sophisticated monitoring and abatement systems (Wang et al., 2022). Second, the combination of physical resources and technical knowledge about complementary technologies—such as integrated carbon capture and storage and energy efficiency improvements—can achieve superior outcomes in reducing pollutants and greenhouse gas emissions relative to the deployment of isolated technologies. The synergistic effect of multiple emission mitigation strategies could significantly outperform single-solution approaches (Feng et al., 2025). Third, technological diversity provides access to a variety of knowledge sources and resources that can represent a form of redundancy hedging: by accessing multiple emission-control pathways, firms reduce their strategic dependency on any single abatement technology that might later underperform, face regulatory setbacks, or become obsolete.

Next, in terms of resource efficiency, environmental technological diversity in APD empowers firms to optimize input consumption across a wider array of operational configurations. Access to varied technologies offers new resources and innovations for energy management, water conservation, and raw material substitution, allowing for more flexible and resilient production systems (Miao et al., 2017). Additionally, partnerships with firms specializing in recycling, reuse, remanufacturing, or circular economy tech solutions increase the likelihood of learning about ways to integrate smarter, closed-loop resource cycles into the firm's operations and having access to specific inputs. A good illustration is the automotive industry's alliances with battery recycling innovators to secure a key resource, critical raw materials, and reduce dependency on virgin resource extraction (Harper et al., 2019). Moreover, acquiring knowledge and integrating multiple technological subsystems—such as coupling waste heat recovery installations with real-time energy monitoring platforms—can enable firms to achieve deeper reductions in resource intensity, combining incremental efficiencies into system-wide gains.

Finally, environmental technological diversity can directly foster green innovation, although the translation into measurable outcomes would often require longer time horizons. Alliance portfolios give access to multiple technological solutions, which enhance the recombinatory potential that is fundamental to complex eco-innovation (Chang et al., 2022). Firms that can combine disparate technologies—such as advanced materials, clean energy systems, and smart logistics—are better positioned to generate new knowledge and breakthrough environmental innovations (Paunov et al., 2025). Additionally, maintaining a range of technologically-oriented alliances exposes firms to different innovation trajectories, which may increase knowledge spillovers, thereby fostering eco-innovations.

2.3.2 Industry diversity

Second, always building upon resource-based and knowledge-based perspectives, we expect that industry diversity within a firm's alliance portfolio should operate as a strategic lever for enhancing aggregate environmental performance. Industry diversity expands the scope of knowledge and resources of a company by incorporating partners from different sectors. Each industry possesses unique environmental challenges, regulatory frameworks, and operational norms. By collaborating in diverse industries, firms gain access to a broader spectrum of environmental resources, knowledge, and best practices. Alliances spanning different industries could further enhance a firm's resource base, providing access to new materials, technologies and even suppliers or other stakeholders that may not be available within a single industry. Moreover, cross-industry learning can result in the transfer of competencies, spark new ideas, challenge existing assumptions, and drive the development of novel approaches to environmental management (Lin, 2012a, 2012b). Therefore, we posit:

Hypothesis 2 A firm’s corporate environmental performance is positively associated with the Industry Diversity of its alliance portfolio.

Similarly to the previous discussion of environmental technological diversity in Hypothesis 1, we identify distinct mechanisms based on RBV and KBV through which industry diversity could improve environmental performance through its core components of emission performance, resource use efficiency, and green innovation.

First, alliance portfolios with firms from diverse industries provide access to the knowledge and resources needed to implement industry-specific best practices in emission control. Different sectors often face distinct regulatory pressures and technological imperatives, resulting in heterogeneous, specialized solutions. Firms in high-emission industries, such as energy, partnering with industries that have had historically strict environmental requirements, such as chemical or pharmaceuticals, could "leapfrog" incremental progress by adopting advanced solutions and compliance strategies without following the slower path of internal development. Moreover, cross-industry alliances can encourage benchmarking by exposing the focal firm to different approaches than those prevailing in its own sector. This knowledge of external practices for comparison can drive firms to tighten their own environmental practices to match or exceed those of their partners in other industries, leading to faster reductions in emissions (Tomar, 2023).

Second, industry diversity in alliance portfolios also plays a crucial role in accessing and optimizing resource use. Cross-industry partnerships expose firms to a broader variety of operational models and tools for managing key inputs like energy, water, and materials. Learning from industries with inherently high resource efficiency (e.g., aerospace, electronics) can inspire firms in resource-intensive sectors to improve their practices and business models (Bocken et al., 2014). Further, certain industries have developed highly specialized models for circularity, such as closed-loop supply chains, reuse systems, and advanced recycling. Collaborating with these industries enables the transfer and adaptation of circular economy practices, allowing firms to discover how to reduce waste and optimize resource loops more effectively. Ultimately, alliances across industries can promote input diversification strategies: firms can access alternative materials, energy sources, or logistics approaches by learning from sectors facing different resource constraints. This diversification reduces reliance on any single resource input and improves overall operational adaptability.

Third, industry diversity can represent a powerful engine for cross-sectoral green innovation, primarily through expanding the technological opportunity space and the knowledge recombination capacity of a firm. Exposure to varied technological paradigms—for instance, the convergence of different sectors like biotechnology, information technology, and advanced materials—creates favorable conditions for radical eco-innovations. Cross-fertilization of ideas becomes particularly potent when partners in the alliance portfolio from distinct sectors contribute complementary, non-overlapping knowledge, methods, and problem-solving heuristics. This variety can enhance firms' ability to recombine ideas into novel, sustainable products and services (Hekkert et al., 2007). Concrete examples include for instance the integration of IT industry innovations (e.g., IoT sensors) into agriculture to reduce pesticide use or the use of advanced material science from aerospace to develop lighter, more energy-efficient vehicles.

2.3.3 Functional diversity

Finally, existing literature suggests that functional diversity within a firm's alliance portfolio is beneficial in terms of both the RBV and KBV perspectives, as it provides access to a wider range of specialized knowledge and capabilities across different business functions (Le et al., 2021). For instance, manufacturing partnerships can lead to the adoption of cleaner production processes and direct access to resources, such as more advanced sustainable materials. Alliances focused on distribution and marketing activities can support complex learning processes about the appropriate forms of advertising for green products and services to reach a wider audience (Jiang et al., 2010). Collaborating in alliances specializing in research and development (R&D) can support the firm in developing cutting-edge environmental practices. Firms that have access to a portfolio of alliances covering many different functions should be able to embed environmental considerations across their whole range of operations and their entire value chains, from product design and development to production, distribution, and marketing. In addition, a portfolio approach will ensure that firms assemble complementary environmental alliances that each address specific knowledge or resource gaps for a company’s functional needs, with marketing focused on translating environmental action into new sales, and R&D on ecological product design (Wassmer et al., 2017, pp.136). This holistic approach to environmental management, facilitated by functional diversity, is expected to yield significant improvements in corporate environmental performance. Therefore, we hypothesize:

Hypothesis 3 A firm’s corporate environmental performance is positively associated with the Functional Diversity of its alliance portfolio.

A wide range of different functional capabilities can complement each other, enabling firms to optimize emissions management, resource efficiency, and green innovation outcomes in an integrated manner and through different levers. First, functional diversity enables firms to expand their knowledge-base about process optimization solutions for emission control and reduction across different stages of their value chain. For instance, manufacturing partners can contribute expertise in improving production efficiency and minimizing energy intensity, while logistics alliances can bring improvements in distribution networks and transportation optimization to cut emission from transportation. These combined efforts could significantly lower a firm's overall carbon footprint thanks to collaborations for environmental management along the whole supply chain (Vachon & Klassen, 2008). Second, by partnering with actors situated at various functional points—upstream R&D, midstream manufacturing, downstream marketing—firms gain end-to-end visibility over emission sources across their operations. Such comprehensive insight into the value chain allows firms to identify and address emission hotspots with targeted interventions, rather than isolated, fragmented initiatives. For example, learning about emissions embedded in product design (upstream) or distribution (downstream) can help a company tackle them more effectively when cross-functional information flows are available.

Second, functional diversity of the alliance portfolio can also foster significant gains in resource use efficiency by enabling firms to implement integrated business models leveraging multiple functions: for instance, accessing the manufacturing and logistics expertise of partners can help implement lean production systems, optimize inventory and packaging, and minimize waste through just-in-time operations. Collaboration with heterogenous distribution partners can provide the logistic resources to streamline transportation networks that reduce both material use and environmental impact. Furthermore, integrating R&D and productive resources with market intelligence could enable firms to adapt product designs to incorporate resource-efficient features, such as reduced packaging, biodegradable materials, or modularity for longer life cycles.

Cross-functional knowledge integration in the alliance portfolio also stands out as a powerful mechanism for accelerating green innovation. The combination of access to R&D's technological exploration capabilities, manufacturing's operational scalability, and marketing's market validation expertise increases the probability of successfully developing and commercializing sustainable products and services. In addition, functional diversity could ensure that eco-innovations do not remain trapped at the ideation or prototyping stage. Manufacturing partners may facilitate the operationalization and scale-up of green technologies, while marketing alliances drive adoption by aligning innovations with market demands and regulatory trends. This cross-functional acceleration mechanism is crucial for overcoming the common bottlenecks between green invention and wide-scale implementation.

Overall, in our analysis of existing literature on environmental alliances, the benefits of these three types of APD seem—at least ex ante—to greatly surpass the costs and complexities of coordinating different alliances, and therefore we expect a positive relationship for all three dimensions. The RBV and KBV offer a variety of examples of theoretical mechanisms for this positive effect to manifest (as summarized in Table 1).

However, this expected positive relationship needs to be tested empirically, to rule out the concern raised in some of the APD literature, that diversity could also lead to inefficiencies and other drawbacks if partners are too heterogenous (Lee et al., 2017). We then test empirically these hypotheses in a rich dataset spanning multiple alliances and two decades of information, so to see exactly how these relationships have evolved for companies with portfolios of environmental alliances.

Table 1 Summary of theoretical insights from resource-based view (RBV) and knowledge-based view (KBV) informing our hypotheses

Hypotheses	Insights from RBV	Insights from KBV
H1—Environmental performance is positively associated with *Environmental Technology Diversity* (ETD) of the portfolio	ETD enhances access to a stock of unique and complementary technological resources for innovative green solutions (carbon-capture and storage technologies, energy efficiency solutions, etc.) State-of-the-art resource-saving techniques, low-carbon processes, monitoring and abatement tools help lowering environmental footprint	ETD endows firms with information and knowledge about diverse green technologies that are at the basis of technical learning, recombination, and knowledge integration Know-how about diverse technologies (materials, clean energy, smart logistics, etc.) foster eco-innovation and breakthrough environmental solutions
H2 - Environmental performance is positively associated with the *Industry Diversity* (ID) of the portfolio	ID enables the use of heterogeneous resources across industries (materials, suppliers, infrastructure, market-specific assets) This broad asset base of complementary industrial resources supports leapfrogging towards cleaner production models by adopting advanced solutions from stricter industries	ID increases exposure to diverse industry logics and knowledge domains and promotes cross-sectoral learning and novel approaches to ESG issues Information about partners' environmental performance in other sectors drives stricter internal practices; knowledge spillovers accelerate cross-sector knowledge transfer
H3—Environmental performance is positively associated with the *Functional Diversity* (FD) of the portfolio	FD creates opportunities to share functional resources along the value chain (R&D, production, distribution, marketing) FD enhances firms' capability to mobilize complementary resources to address sustainability at multiple stages (design, production, distribution) and create more effective end-to-end solutions	Cross-functional learning and knowledge-flows integrate diverse technical, operational, and market knowledge Through knowledge-sharing across diverse functions, FD helps firms identify emission or resource use hotspots and reduces bottlenecks in scaling green solutions for a systemic adoption of eco-efficient practices

3 Methodology

To test the hypotheses developed in the previous section, we need detailed data that covers a wide range of alliances, so to observe a set of companies with relatively well-developed portfolios of environmental alliances. In this section, we explain the choice of our sample, the construction of our key indicators of diversity, and the empirical methodology adopted. Crucially, we illustrate how we use panel data with multiple observations for each firm over 22 years, to advance beyond existing cross-sectional evidence by controlling for firm time-invariant unobservable characteristics.

3.1 Sample and data

To test our hypotheses, we collect data from three databases. First, we use Thomson's SDC Platinum Database to select all the environmental alliances signed from 2002 to 2023 (Stadtler & Lin, 2017). Since we want to focus exclusively on environmental alliances, we leverage the database's search tool to identify, within the 'Deal Synopsis' section of each alliance, a set of keywords explicitly linked to environmental sustainability (such as emission reduction, carbon neutrality, renewable energy, etc.).[3] Second, we gathered corporate environmental performance data from Refinitiv's ESG database for each participating company in the sample of environmental alliances, focusing exclusively on the environmental pillar

[3] We searched for 208 environmental sustainability-related keywords. See the Appendix for details.

of the ESG score and its components. Finally, we used Bureau Van Dijk Orbis' company-level financial data to build control variables at the firm level.

To obtain a tractable size for the network of alliances and ensure a relatively homogenous sample, we select environmental alliances whose key partners are companies operating in high-tech industries, which are most likely to play a substantial role in decarbonization, green innovation and circular economy efforts. Hence, we delimit the perimeter of our analysis by choosing alliances in which at least one participant is an Electrical and Electronic Equipment (EEE) company, considering this a pivotal sector in terms of both opportunities and challenges for environmental sustainability (European Commission, 2020; Rasmussen et al., 2020). We then collect information on all participants in the alliance, many of whom are not from the EEE industry.

The choice of EEE companies as the linchpin for identifying a relevant set of alliances is based on three considerations. First, EEE manufacturers are key enablers of the innovations behind the sustainability transition, contributing to digitalization and electrification processes that are the basis of improving energy efficiency, reducing carbon footprints, and supporting the development of smart, sustainable infrastructures. Second, they have a significant environmental impact, characterized by resource-intensive processes and the generation of substantial electronic waste (Cicerelli & Ravetti, 2024). For these reasons, regulatory institutions are exerting strong pressure on EEE companies to integrate environmental impact considerations into their strategies, urging the adoption of circular economy strategies (Wijethilake et al., 2017). Finally, EEE companies have increasingly started to engage in strategic alliances to leverage collective efforts (Wassmer et al., 2014), and they serve numerous other high-tech supply chains (automotive, energy, appliances, etc.) which are themselves highly relevant for sustainability, decarbonization and circularity. Given these unique features and dynamics, the EEE industry provides a relevant starting point for the definition of our sample.

Applying these selection criteria and merging the data from the three databases, we obtained a sample of 280 companies worldwide participating in 1,539 environmental alliances. To construct firm-level alliance portfolios, we compile, for each company and each year, the set of alliances in which the firm has participated up to that point in time. Environmental alliances are typically characterized by longer-term objectives compared to other types of business collaborations. In our dataset, for those alliances with available duration data, the average length is nearly eight years, with some lasting as long as 15 or 20 years. The resulting sample has global coverage, but most alliances concentrate in the US and China (see Appendix 1). We confirm that these environmental alliances have been growing significantly over the time frame under consideration, as illustrated in Fig. 1: the number of firms with more than one environmental alliance, for which we can have an indication of portfolio diversity, grew dramatically over the two decades, and the average number of alliances for each organization increased with it.

3.2 Diversity indexes, environmental performance and other variables

The main independent variable of interest for our analysis is a measure of alliance portfolio diversity (APD), where diversity is assessed at the overall portfolio level. Following our theoretical reasoning, APD was measured through three dimensions. The first one is the *Environmental Technology Diversity*, which in our data can be defined at the alliance

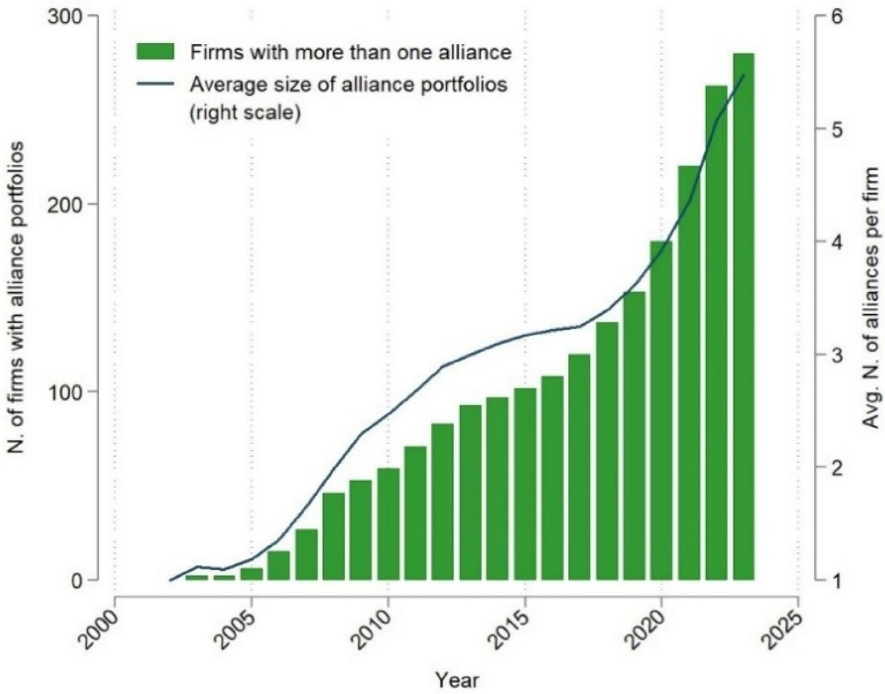

Fig. 1 Growth over time in companies' environmental alliance portfolios

level, reflecting the spectrum of technologies developed by each alliance within the overall portfolio aimed at addressing specific ecological issues. To build this variable, alliances were classified according to five groups of environmental technology: renewable energy, sustainable mobility, energy management, circular economy, artificial ecosystem service, and a final residual category named "other cleantech" which considers all those environmental solutions that do not fall into the previous categories. These categories are based on an elaboration of the IPC Green Inventory and the Green Goods and Services Industries by NAICS Code classifications.

The second measure is *Industry Diversity*, which captures the range within the portfolio of primary industries in which each alliance operates within the portfolio, and it's based on NAIC classification. Given the focus on environmental alliances, unsurprisingly one of the most frequently represented industries is that of electric, gas and water distribution, capturing most renewable activities and water-related services. Table 8 in the Appendix lists the industries represented in this diversity indicator. The last metric is *Functional Diversity*, which considers the array of functional roles undertaken by the alliances and includes the following categories: R&D, manufacturing, distribution and other, as a residual category. The Environmental Technology Diversity and Functional Diversity dimensions were derived from an encoding phase through a semantic analysis of the "Deal synopsis" section of the alliances, provided by Thomson's SDC Platinum Database. Table 2 provides some exemplary cases to illustrate how alliances have been coded for these two dimensions.

Table 2 Examples of coding classification for ETD and FD dimensions

Dimension	Coded category	Examples of deal synopsis text
Environmental Technology Diversity (ETD)	Renewable energy	Engie SA and EDP Renovaveis SA formed a joint venture named Ocean Winds SL to act as the exclusive investment vehicle to capture marine wind energy opportunities around the world
	Sustainable mobility	General Motors Co and LG Corp formed a strategic alliance to develop electric cars
	Energy management	Solvay SA, Marubeni Corp and Ansaldo Energia SpA formed a joint venture to invest in an energy efficiency project at Solvays facility in Rosignano, Italy
	Circular economy Technologies[a]	Honeywell International Inc and TotalEnergies SE formed a strategic alliance. The purpose of the strategic alliance was to supply TotalEnergies with recycled polymer feedstock (RPF) using Honeywell's UpCycle Process Technology at the recently announced Honeywell and Sacyr advanced recycling plant, intended to be built in Andaluca, Spain
	Artificial ecosystem services	General Electric Co and Schlumberger Ltd formed a strategic alliance to provide carbon dioxide sequestration technology and storage development services in the USA
	Other cleantech	Siemens Energy AG and BASF SE formed a strategic alliance. The purpose of the strategic alliance was to accelerate commercial implementation of new technologies designed to lower greenhouse gas emissions
Functional Diversity (FD)	R&D	Mitsubishi Materials Corp, Mitsubishi Corp, and Furuya Metal Co Ltd formed a strategic alliance to provide research and development services in Japan. The alliance was expected to develop a platinum group metals recycling technology using scraps such as disposable catalysts
	Manufacturing	Sharp Corp and Toshiba Corp planned to form a strategic alliance to manufacture solar panels in Japan
	Distribution	Canadian Solar Inc and Lightsource Renewable Energy Holdings Ltd formed a strategic alliance to enter into supply agreement to deliver 1.2 GW of high efficiency polycrystalline solar modules for projects in the US and Australia
	Other functions	Apollo Global Management Inc. and Johnson Controls International plc. formed a strategic alliance for providing sustainability and energy efficiency services to help customers address decarbonization and reach operating cost goals for their buildings

[a]We refer to any initiatives that could be ascribed to the classic 9R framework (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, and Recycle). Many of these refer to recycling initiatives—often the development of advanced recycling facilities or services. However, we also have a variety of other alliances focused on technologies linked to the circular economy: for example, tracing circular supply chains, recovery of specific resources (such as water or sludges, or bio-based materials), productive processes aimed at specific materials reductions (e.g. steel), making innovative products that are recyclable, waste-to-energy projects, just to mention a few

Having classified all alliances into different categories for each diversity dimension, diversity indexes at the portfolio level were calculated through Blau's variability index, according to the formula $D = 1 - \sum p_i^2$, in which p denotes the proportion of alliances within each category (namely, within each green technology, function, or main industry), while i represents the number of distinct categories. The level of diversity D ranges from 0, representing complete homogeneity within the group, to 1, meaning total heterogeneity (Jiang et al., 2010). Our configuration of alliance portfolios in this analysis includes all the alliances formed by the company during the selected period, thus containing both active alliances and alliances that became inactive at some point during the study (Wassmer et al., 2014).

The main dependent variable of our analysis is an index of the firm's environmental performance, considering the environmental pillar of Refinitiv's ESG score, which captures a combination of three scores based on different corporate environmental impacts: 1) an emission reduction score, reflecting corporate's commitment and effectiveness in minimizing production and operational emissions of greenhouse gases; 2) a resource use score, representing efficiency and impact reduction in materials, energy, and water, and proxying the overall circularity of the company; and 3) an innovation score, measuring the development of environmentally friendly solutions. The overall environmental performance score is assigned combining the three scores, normalized with different industry weights depending on the importance of each ESG theme according to Refinitiv's ESG proprietary algorithm and data on the basis of public ESG scores and private analytics. Therefore, the score for this environmental performance pillar represents a company's relative performance in managing its environmental impact based on its emissions reduction efforts, resource use, and environmental innovation, taking into account the materiality of these factors within its specific industry. The overall environmental performance score, as well as the three individual emission, resources, and innovation scores range from 0 to 100, where the higher the value, the better the performance.[4]

We then included some control variables to account for potential confounding effects: the size of the company (proxied by the natural logarithm of net income), its age, and the size of its portfolio of alliances in each year. We also add a control for the time period before the signature of the Paris Agreement and the introduction of the Sustainable Development Goals introduced by the United Nations in 2015: this year represents an important turning point in climate and sustainability commitments worldwide and could have changed the strategy of global companies to environmental alliances and ESG performance, so we include a dummy for the period before and after these events. In the Appendix we present a description of all variables (Table 9) and provide summary statistics (Table 10) and correlations among them (Table 11).

3.3 Empirical model

While previous literature has controlled for a range of observable firm-level characteristics in cross-section specifications, it is implausible that all specific aspects that matter for a company's environmental performance are observable. To better account for intrinsic, immeasurable characteristics such as the values, vocation, or the environmental awareness and sensitivity of a company, we exploit the panel dimension of our data, and control for time-invariant firm fixed-effects. This approach focuses specifically on within-firm effects: any change in the environmental performance of a given company is related in our model to their alliance portfolio in the 22 years of analysis, taking into account all the characteristics of the company that do not change over time (location, sector, year of company's formation, and plausibly its vision and sustainability orientation, and so on).

Our fixed effects model[5] is specified as follows:

[4] For details of the scoring methodology, see https://www.lseg.com/content/dam/data-analytics/en_us/documents/methodology/lseg-esg-scores-methodology.pdf

[5] The choice of a fixed effects model over a random effects one was validated by a Hausman test, which strongly rejected the null hypothesis that the random effects estimator is consistent (that is., that there is no correlation between individual effects and the regressors).

$$y_{it} = \alpha + \beta_1 APD_{it} + \boldsymbol{X}_{it}\gamma + \eta_i + \varepsilon_{it} \quad (1)$$

where y is the environmental performance of company i at time t; APD_{it} represent alliance portfolio diversity, measured through the three dimensions of environmental technology, industry and functional diversity for company i at time t; $\boldsymbol{X}_{it}$ captures time-variant firm-level controls (firm size, age and size of the alliance portfolio per year), and the time dummy for the period before 2015; η_i denotes the firm fixed effects; finally, ε_{it} is the idiosyncratic error term, which we cluster at the firm level to control for heteroskedasticity.[6]

4 Results and discussion

Table 3 reports the results of the baseline model with the analysis concerning the relationship between the three different dimensions of alliance diversity and aggregate environmental performance. The results provide some clear empirical support for the positive link between alliance portfolio diversity (APD) and overall corporate environmental performance within firms. The positive and significant coefficients for all three dimensions of APD – environmental technology diversity, industry diversity, and functional diversity – align with our three hypotheses. We report the result for the within-firm estimators without any controls first (columns 1, 3, 5, 7), and then with controls, in order to refine the identification of relevant effects, noting that the magnitude of the coefficients becomes much smaller (columns 2, 4, 6). Moreover, when we combine all three types of technologies in one equation, we find that their explanatory power overlaps, and functional diversity loses significance even without any additional controls (column 7), while environmental technology diversity loses significance when we add the controls (column 8). Only industry diversity retains some significant explanatory power when the three diversity dimensions are combined in the last, most restrictive model.

This first set of results suggests that firms that engage in a wider range of environmental alliances, spanning either diverse green technologies, industries, or functions, are also the

Table 3 Alliance portfolio diversity and companies' aggregate environmental performance score

	Environmental Performance							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Env. Tech. Diversity	23.75***	11.42***					8.30*	6.06
	(3.95)	(3.93)					(4.58)	(4.76)
Industry Diversity			20.71***	11.36***			14.54***	7.18*
			(2.73)	(3.22)			(3.24)	(3.80)
Functional Diversity					19.68***	9.04***	4.97	4.03
					(3.33)	(3.27)	(3.88)	(3.59)
Obs	2287	1869	2266	1849	2285	1868	2266	1849
Controls	NO	YES	NO	YES	NO	YES	NO	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for firm's net income, age, size of alliance portfolio, and pre-2015 years not reported

[6] We also assess if multicollinearity could be a significant issue in our regressions with a simple calculation of the variable inflation factor (VIF), which for all our different specifications is no higher than 2, far from the problematic multicollinearity threshold of 10.

ones that achieve better environmental performance over a medium-long horizon of more than 20 years. This finding is consistent with the mechanisms highlighted by the resource-based view and knowledge-based view. However, maximizing all three types of diversity does not lead to a compound outcome in terms of environmental performance, but rather it appears that only industry diversity is significant, when different dimensions of portfolio heterogeneity are considered together. This result is in line with the only other study considering multiple APD dimensions in a quantitative environmental performance context, Le et al. (2021), which also observes that different diversity dimensions considered together do not all present significant effects.

We also check for any diminishing marginal effects of these relationships using quadratic diversity dimensions (Table 23 in the Appendix). At the within-firm level, we do not see many non-linear trends, except for functional diversity, which on its own displays a significant inverted U-shape relationship with respect to the environmental innovation score, indicating that too much functional diversity may at some point become counterproductive for achieving innovative results. This result emphasizes that, while it is important to combine the knowledge and resources deriving from different functions, like R&D, manufacturing and marketing to cover all aspects of the innovation development and application process, at some point the complexities introduced by managing a too diverse portfolio of alliances do not improve green innovation.[7]

We can then further break down the results for specific environmental performance indicators, namely the score for carbon emissions, resource use and green innovation, which all capture different facets of environmental performance and thus different mechanisms, as discussed in the development of our hypotheses. Table 4 illustrates the different effects – for brevity we only report the results with the inclusion of controls, in the more conservative specification. We observe that the different types of alliance portfolio diversity are also relevant for these specific environmental dimensions, but with some exceptions. Diversity in environmental technologies, for instance, is the only dimension of diversity significantly linked to our proxy of circularity, the Resource Use Score (column 5). This effect indicates that environmental technological diversity within APDs may enhance firms' ability to optimize input consumption by granting access to a broader array of technological resources and specialized knowledge related to materials, energy, water and to other natural resources. Firms may be integrating diverse technological subsystems (e.g., smart energy monitoring platforms and waste heat recovery systems, or closed-loop water recycling installations paired with sensors for leak detection, or advanced material sorting technologies integrated with AI-based quality control) to achieve more substantial reductions in resource intensity.

Once again, when considering jointly the three dimensions of diversity (columns 4, 8, and 12) we see that only Industry Diversity is significant, and only for one specific environmental score, the Environmental Innovation one. These findings suggest that industry diversity has a

[7] Unfortunately, most of our results do not have a direct counterpart in the literature: for example, the fact that we observe an inverted U-shaped relationship for functional diversity is different from Le et al. (2021), one of the few other papers looking at multiple APD dimensions and sustainability, but in their case the dependent variable is sustainability collaboration (i.e., the alliances themselves), not a measure of environmental performance; thus, we have no reason to presume that functional forms would be comparable. Conversely, Ashraf et al. (2019) have a dependent variable that, like our study, captures environmental performance (namely, carbon emissions) and find non-linear, diminishing returns to diversity like us, but they use a measure of portfolio diversity that we could not reproduce in our data, organizational cognitive frames, so once again any comparison should be approached cautiously.

Table 4 Alliance portfolio diversity and different dimensions of environmental performance

	Emissions Score				Resource Use Score				Environmental Innovation Score			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Env. Tech. Diversity	8.55**			3.92	7.77*			6.36	12.52**			3.11
	(4.24)			(5.49)	(4.15)			(5.06)	(5.52)			(7.01)
Industry Diversity		8.80***		5.13		4.68		0.12		16.84***		12.72**
		(3.24)		(4.35)		(3.64)		(4.45)		(4.75)		(6.13)
Functional Diversity			8.91***	5.30			6.60	4.71			14.33**	7.59
			(3.35)	(3.85)			(4.03)	(4.88)			(5.90)	(5.75)
Obs	1866	1846	1865	1846	1869	1849	1868	1849	1870	1850	1869	1850
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for time trend, n. of employees, age and size of alliance portfolio per year

robust role as a catalyst for cross-sectoral green innovation, favoring the interaction of distinct technological paradigms—such as those emerging from biotechnology, information technology, and advanced materials—fostering an environment conducive to eco-innovations. Such industry diversity seems to enhance firms' recombinant capacity to produce novel, sustainable products and services (Hekkert et al., 2007), as suggested in our second hypothesis.

4.1 Post hoc analysis: lagged APD, age, and sectors

In interpreting the above results, we should be cautious in making any causal claims because, despite the firm fixed effects, which eliminate the issue of omitted time-invariant characteristics of each company, it is still possible that other sources of endogeneity may be at play. Among these, the most plausible is some form of reverse causality. Portfolio diversity is the outcome of all alliances built over the years, while the environmental performance corresponds to the specific actions and metrics of the company in a given year, so we are inclined to assume that environmental alliances precede and to some extent enable better environmental performance; but the opposite could also hold, that more environmentally conscious firms are the ones that join more environmental alliances across a broader range of purposes, sectors and technologies. To move one step further in the direction of understanding how alliance diversity can be an antecedent of better environmental performance, we present a check with one-year-lagged metrics of APD, to find some suggestive evidence of the direction of the causal effects. Even if we lose some observations when taking lagged values, in Table 5 we show that the individual dimensions of portfolio diversity are still all significantly related to environmental performance, confirming our three hypotheses. However, while all other results remain robust, when we look at the three joint dimensions of APD jointly, the coefficient of industry diversity is no longer significant (column 8).

Similarly, when looking at three separate components of environmental performance with lagged APD metrics (Table 6), we lose the significance of industry diversity in the Environmental Innovation Score with all dimensions of diversity together (column 12) and we see that environmental technology diversity is no longer significant for the Emission Score and Resource Use Score (columns 1 and 5). These cases could indicate some degree of reverse causality, such that only companies with high scores in these environmental areas (that is, companies already implementing emission reduction and circularity strategies) are the ones that pursue a diverse portfolio of environmental alliances.

These lagged positive associations between the dimensions of diversity and environmental performance are largely confirmed when looking at further lags, even if effects are not always significant when moving back in time. In Table 13 to Table 20 in the Appendix we extend the lags back to 8 years, the average duration of an environmental alliance for those that report the duration of the deal. We notice that some specific dynamic patterns emerge: industry diversity has longer term significant positive coefficients, covering multiple years in the past, both for aggregate environmental performance and particularly for resource use and green innovation scores. Thus, overall, industry diversity seems to be the broader-spectrum type of alliance diversity that provides positive results consistently over time. Interestingly, functional diversity again presents some non-linearities, with lags farther back in time showing a significant negative sign, confirming from another angle that more functional diversity is not always beneficial. In this case, particularly for emissions and resource use, it is possible that that time is the key mechanism for this effect, as it takes several years for the functional diversity

Table 5 Lagged alliance portfolio diversity and companies' aggregate environmental performance score

	Environmental Performance							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
L1.Env. Tech. Diversity	20.90***	9.70**					7.90*	4.97
	(4.10)	(4.30)					(4.73)	(5.05)
L1.Industry Diversity			18.02***	9.23***			11.76***	5.35
			(2.86)	(3.48)			(3.49)	(4.10)
L1.Functional Diversity					17.77***	8.72***	6.13	4.89
					(3.05)	(3.31)	(4.47)	(4.48)
Observations	2068	1692	2049	1674	2067	1692	2049	1674
Controls	NO	YES	NO	YES	NO	YES	NO	YES
Firm_FE	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

coefficient to turn from negative to insignificant to positive. The payoffs in terms of learning and additional resources provided derived by heterogenous alliances across multiple functions are therefore not visible over short time horizons, but require a maturation period to be fully incorporated and put into action to deliver better environmental outcomes.

Finally, we look for any significant heterogeneity in our results on the basis of the firm's age and macro-sector. Table 21 in the Appendix shows that environmental technology diversity is most relevant for the environmental performance of the youngest quintile of firms, while industry diversity is a significant dimension of APD for companies older than the average in our sample (see Fig. 3 for the age distribution of our companies). This suggests that young firms are likely to be important technology providers within alliances, while the more mature ones may leverage more cross-industry synergies. With respect to sectoral differences (Table 22 in the Appendix), environmental technology diversity is key in manufacturing (even when considering all three dimensions of diversity jointly), while industry diversity is significant in the service sector in particular (again, even when considering all three dimensions of diversity jointly).

Overall, our findings confirm across a broad range of specifications that diversity in alliance portfolio is positively linked with environmental performance within firms. This link is not always statistically significant when considering intra-firm changes, but it broadly confirms our three hypotheses that, in general, having more diverse alliance portfolios goes hand in hand with greater corporate environmental sustainability.

5 Conclusion

This study explores the previously unexamined relationship between alliance portfolio diversity (APD) for environmental alliances and corporate environmental performance. Recognizing the growing importance of environmental alliances in addressing sustainability challenges, we examine how diversity in environmental technologies, industry sectors and functional roles within the alliance portfolio of a firm relates to its environmental ESG performance. By employing panel data analysis on a sample of 280 companies over 22 years, we find that all three dimensions of APD go hand in hand with better environmental performance. Overall, our study confirms that, even when looking at variation in APD within firms, over the past two decades there has been a significant link between dimensions of diversity in alliance portfolios and environmental scores.

Table 6 Lagged alliance portfolio diversity and different dimensions of environmental performance

	Emissions Score				Resource Use Score				Environmental Innovation Score			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
L1.Env. Tech. Diversity	7.08			1.74	4.93			2.40	9.90*			3.70
	(4.48)			(5.43)	(4.34)			(5.49)	(5.89)			(7.69)
L1.Industry Diversity		8.42***		5.26		4.21		1.25		11.30**		6.49
		(3.16)		(3.99)		(3.64)		(4.67)		(5.56)		(6.97)
L1.Functional Diversity			10.09***	6.98			6.95	5.53			13.34**	9.23
			(3.57)	(4.44)			(4.26)	(5.12)			(5.69)	(5.84)
Obs	1689	1671	1689	1671	1692	1674	1692	1674	1693	1675	1693	1675
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

5.1 Theoretical contributions

At a theoretical level, our research contributes to the understanding of collaborative managerial strategies to achieve green corporate transitions and enriches the field of alliance portfolio theories in several ways. First, by applying a resource-based and knowledge-based theoretical perspectives to the context of environmental alliances and the environmental pillar of ESG performance, we expand existing theories on APD in a case where resources and knowledge are expected to play a central role. Unlike previous network-focused studies that emphasized cognitive frames (Dzhengiz, 2018, 2020) and/or multilateral collaborations including actors outside the private sector like universities, NGOs, governments, etc. (Gutiérrez et al., 2016; Horan, 2019; Schmutzler et al., 2014), this research narrows the lens to inter-firm alliances. This sharper focus enables a clearer view of the significance of APD for companies developing specific sustainability objectives.

In particular, we inform theoretical debates about the role of APD for environmental performance testing our hypotheses with disaggregate corporate environmental performance distinguishing three key components—emissions, resource use, and green innovation—providing a more fine-grained understanding of how different types of alliance portfolio diversity relate to distinct environmental ESG scores. By doing so, the study addresses a significant gap in the literature, enriching the theoretical arguments on APD in an environmental context with detailed evidence for within-firm relationships between diversity in technologies, industries and functions across alliances and environmental performance over a long time frame, evidence that confirms the theoretical importance of having access to diverse partnerships, but not necessarily with the same importance for all environmental targets.

5.2 Practical contributions: managerial and policy implications

From a managerial perspective, our findings underscore the importance of a strategic, goal-oriented approach to building environmental alliance portfolios. Rather than indiscriminately maximizing the diversity of alliances across all dimensions, firms can align their alliance strategy with specific long-term environmental objectives, choosing priorities amongst reducing emissions, improving resource efficiency, or fostering green innovation. The analysis reveals that the benefits of different APD dimensions may not necessarily be additive. This suggests a need for selective prioritization—managers may, for instance, focus on industry diversity to enhance systemic environmental performance on a broader spectrum, or technological diversity to encourage more specifically the implementation of resource use optimization. Moreover, some effects, particularly those linked to cross-industry partnerships, may unfold over several years, suggesting that environmental alliance strategies require a long-term horizon to yield meaningful results. Functional diversity, in this context, may even present negative effects at some points, for instance as the alliances have just begun, or when functional diversity becomes exceedingly high. Specific types of companies can participate in heterogeneous alliances tactically also depending on their sector and firm characteristics: for instance, younger companies that are developing new green innovations might prefer to participate in a range of alliances with different environmental technology projects, more than older companies.

At the policy level, the study highlights the need to support and incentivize cross-sector environmental collaborations with a nuanced understanding of portfolio dynamics. Policy initiatives should go beyond encouraging the growth of the sheer number of alliances and instead promote diversity in functions, industries and technological scope, which can accelerate knowledge diffusion and resource synergies across the corporate ecosystem. Additionally, the findings indirectly suggest that ESG evaluation frameworks—often used by investors, regulators, and rating agencies—could begin to incorporate alliance portfolio diversity as a forward-looking indicator of proactive corporate environmental engagement. Recognizing the strategic role of diverse green alliances in shaping sustainability outcomes could provide an additional predictive measure of firm-level environmental responsibility and access to relevant resources and knowledge.

5.3 Limitations and future research

While this study offers some valuable new insights, it also has limitations that present interesting opportunities for further exploration. First, for the sake of tractability, our sample considers only environmental alliances where at least one company belonged to the electric and electronic sector, as explained in the sample construction. This choice focuses the analysis on a wide range of high-tech sectors, but it might be interesting for future research to take either a narrower focus on specific sectors (i.e. only alliances in the automotive industry or those in energy industries), or a broader scope also including "low tech" industries and partnerships. Moreover, one key challenge of working with official international alliances in high-tech industries is that our sample is strongly dominated by large multinationals and relatively old firms. Therefore, we can provide only suggestive evidence and some initial indications regarding young companies. Future works could test the validity of our results focusing specifically on startups, possibly also integrating the analysis with some primary data collection, to understand the exact role of early entrepreneurial decisions in terms of partnerships and environmental performance.

Finally, although our post-hoc analysis incorporating extended time lags offers some reassurance regarding the directionality of effects, it does not eliminate all concerns related to endogeneity. In particular, the possibility remains that firms first commit to enhancing their environmental profile and subsequently design alliance strategies aligned with this objective, thereby creating a sequential process that may confound causal interpretation. Moreover, the analysis may be subject to omitted variable bias if unobserved factors—such as managerial orientation toward sustainability, firm culture, or stakeholder pressures—influence both alliance portfolio diversity and environmental performance. Future research could seek to address these limitations by employing some form of exogenous variation, such as instrumental variables, natural experiments, or difference-in-differences designs in the presence of policy or regulatory shocks. Moreover, collecting richer firm-level data, particularly on internal environmental governance structures or managerial incentives, would further enhance the ability to control for confounding factors and better isolate causal relationships.

In conclusion, our findings underscore the pivotal role of engaging in diverse environmental alliances for corporate sustainability. Scholars, policymakers and industry leaders should recognize that fostering such collaborations provides an opportunity to enhance environmental performance by sharing resources and knowledge amongst environmentally conscious organizations. By promoting initiatives that encourage strategic alliances with diverse technological, industrial, and functional characteristics, we can accelerate progress towards net zero emissions and broader sustainability objectives, ensuring that different types of firms contribute effectively to global environmental challenges.

Appendix 1: Summary of theoretical dimensions of alliance portfolios

See Table 7.

Table 7 Dimensions of alliance portfolio diversity from the APD literature. *Source*: Author's own elaboration

Portfolio diversity dimension	Definition	Theoretical relevance for *environmental* performance through the lenses of RBV and KBV	Key references
Industry/Sectoral	The various industries represented in an alliance portfolio. E.g. an alliance portfolio with energy firms and transportation firms	Direct relevance to establish partnerships along and across supply chains (e.g., an integrated sustainable supply chain approach between cement and steel producers, and construction companies). Leverage complementary strengths (e.g. tech companies for ESG data analytics and monitoring, financial firms for the funding, and manufacturers to produce green products)	Collins and Riley (2013); Jiang et al., (2010); Lee et al., (2017)
National	Geographic coverage of the firms in the alliance portfolio. E.g., portfolio with alliances between French and Indian firms	Indirect relevance, potentially useful to exchange knowledge about environmental regulations across different countries or to access different international markets	Jiang et al., (2010); Lavie and Miller (2008); Lee et al., (2017)
Organizational/Partner	The variation in the characteristics of organizations involved in then portfolio (by size, legal status, position in the supply chain, etc.)	Indirect relevance, insofar as firm characteristics relate to different resources and knowledge and can translate into complementary assets useful for environmental outputs	Dzhengiz (2018, 2020); Dzhengiz et al., (2024); Gutiérrez et al., (2016); Jiang et al., (2010); Le et al., (2021); Lee et al., (2017)
Functional	Alliance function and/or activity. E.g. a portfolio with alliances for marketing purposes and for R&D purposes	Direct relevance, both in terms of shared resources and shared knowledge, to create cross-functional synergies and tackle complex ecological issues from multiple angles (e.g. doing R&D to develop new green technology, then manufacturing it, and then marketing the new product)	Jiang et al., (2010); Le et al., (2021); Lee et al., (2017)
Governance	Alliance ownership arrangement. E.g. a portfolio with equity-based alliances and non-equity based ones	Indirect relevance, most important for financial outcomes	Jiang et al., (2010); Le et al., (2021); Lee et al., (2017)

Table 7 (continued)

Portfolio diversity dimension	Definition	Theoretical relevance for *environmental* performance through the lenses of RBV and KBV	Key references
Technological	The different technologies deployed by each firm in the alliance or developed in the whole alliance. E.g. alliances with solar and wind manufacturers, or a portfolio with one alliance to develop solar farms and one for hydroelectric energy distribution	Direct relevance, as (green) tech solutions can be transferred, shared and leveraged across the partners and/or developed in the alliances themselves. The advantages for environmental alliances specifically from green tech diversity are numerous: green innovations can be scaled up across different businesses, cross-industry technology transfer can lead to wider adoption, pooling intellectual property costs and R&D risks can enable more ambitious green innovations	Lee et al., (2017); Wuyts and Dutta (2014)

Appendix 2: Geographical, industry and age distribution of firms in the alliances

Most alliances are concentrated in the USA, where we observe more than 200 of them, followed by China, with more than 100 alliances. Beyond the high concentration in these two countries, some environmental alliances are appearing in several other countries around the globe, especially in Europe, Japan, and India. Overall, 47 countries worldwide have more than one green alliance in our dataset (Fig. 2).

See Fig. 3 and Table 8.

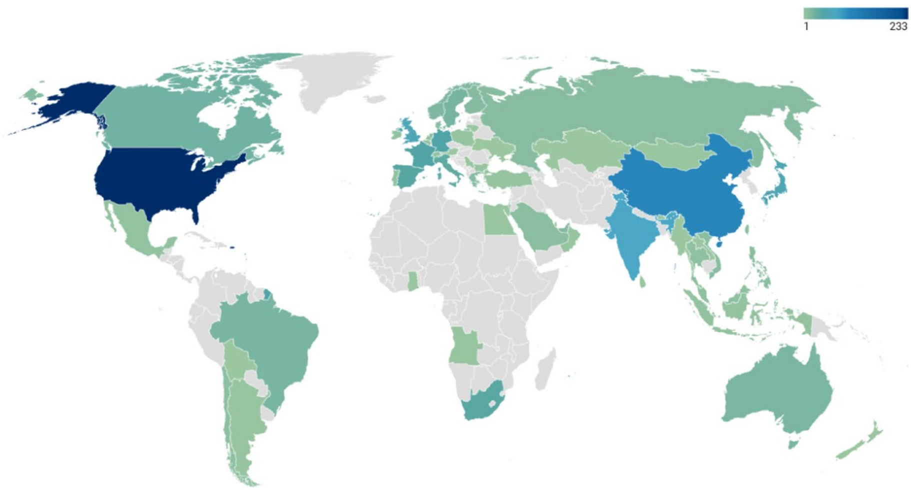

Fig. 2 Geographical distribution of the number of environmental alliances in the sample, 2002–2023

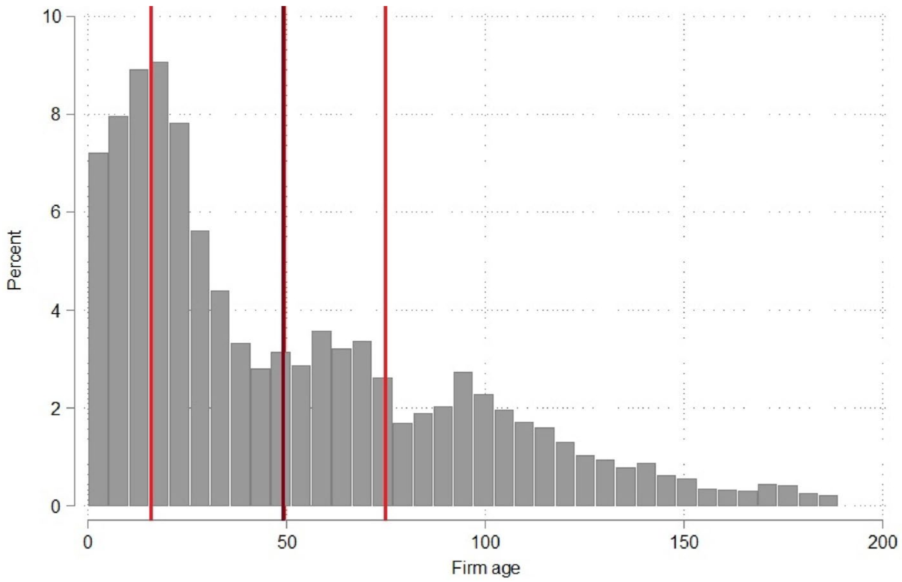

Fig. 3 Distribution of firms' age. The vertical lines indicate the bottom quintile, the mean and the top quintile, from left to right

Table 8 Number of industries represented in the environmental alliances considered between 2002 and 2023

Industry	Frequency
Electric, Gas, and Water Distribution	405
Wholesale Trade-Durable Goods	143
Business Services	124
Repair Services	94
Construction	92
Oil and Gas, Petroleum Refining	66
Electronic and Electrical Equipment	55
Miscellaneous Manufacturing	36
Machinery	30
Investment & Commodity Firms; Transportation Equipment	27
Public Administration	19
Chemicals and Allied Products; Sanitary Services	14
Prepackaged software	8
Measuring, Medical, Photo equipment; Transportation and Shipping (excluding air)	7
Air Transportation and Shipping	6
Metal and Metal Products	5
Agriculture, Forestry, and Fishing; Mining; Real Estate; Mortgage Bankers and Brokers	4
Health Services	3
Credit Institutions; Misc. Retail Trade; Stone, Clay, Glass, and Concrete Products; Wholesale Trade Non-Durable Goods	2
Amusement and Recreation Services; Commercial Banks and Holdings; Communications Equipment; Drugs; Personal Services; Retail; Telecommunications	1

Appendix 3: Summary and description of the dataset

See Tables 9, 10, 11 and 12.

Table 9 Description of the variables

Variable type	Variable name	Description	Range of values
Dependent Variable	Environmental Performance	A combination of three scores based on different corporate environmental impacts	0–100
Dependent Variable	Emissions	Corporate commitment and effectiveness in minimizing production and operational emissions	0–100
Dependent Variable	Resource use	Efficiency and impact reduction in materials, energy, and water	0–100
Dependent Variable	Eco-Innovation	The development of sustainable solutions and creation of green market opportunities through new technologies	0–100
Independent Variable	Environmental Technology Diversity (ETD)	The spectrum, within the portfolio, of technologies developed by each alliance aimed at addressing specific ecological issues	0–1
Independent Variable	Functional Diversity (FD)	The array of functional roles undertaken by the alliances	0–1
Independent Variable	Industry Diversity (ID)	The range of primary industries in which each alliance operates within the portfolio	0–1
Control Variable	Employees	The number of a company's employees	1–1.608
Control Variable	Firm age	The number of years since the firm's foundation date (in log)	1.10–5.24
Control Variable	Portfolio size per year	The firm's total number of alliances within the selected period	1–38

Table 10 Summary statistics—firm level

	Count	Mean	SD	Min	Max
Year of company foundation	4642	1953.668	40.802	1834.000	1999.000
Net income	3690	13.506	1.874	3.519	18.419
Employees	3560	69.387	104.534	0.003	1608
Age	4642	3.789	0.810	1.099	5.242
AP size	2410	3.654	4.140	1.000	38.000
Environmental Performance	3449	62.052	25.077	0.000	99.140
Emissions	3445	67.340	28.800	0.000	99.870
Resource Use	3449	65.412	29.497	0.000	99.920
Environmental Innovation	3449	50.018	34.206	0.000	99.890
ETD	2410	0.213	0.256	0.000	1.000
ID	2390	0.326	0.299	0.000	0.880
FD	2410	0.275	0.252	0.000	1.000
Observations	4642				

Table 11 Variables' correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Year of company foundation	Net income	Employees	Age	AP size	Environmental Performance	Emissions	Re-source Use	Environ-mental Innovation	ETD	ID	FD
Year of firm foundation	1.00											
Net income	-0.14^{***}	1.00										
Employees	-0.19^{***}	0.47^{***}	1.00									
Age	-0.93^{***}	0.16^{***}	0.17^{***}	1.00								
AP size	−0.05	0.20^{***}	0.20^{***}	0.08^{**}	1.00							
Environmental Performance	-0.22^{***}	0.28^{***}	0.25^{***}	0.24^{***}	0.22^{***}	1.00						
Emission Score	-0.15^{***}	0.24^{***}	0.15^{***}	0.19^{***}	0.15^{***}	0.81^{***}	1.00					
Resource Use Score	-0.18^{***}	0.34^{***}	0.23^{***}	0.23^{***}	0.17^{***}	0.79^{***}	0.74^{***}	1.00				
Environmental Innovation Score	-0.19^{***}	0.14^{***}	0.23^{***}	0.17^{***}	0.20^{***}	0.74^{***}	0.35^{***}	0.34^{***}	1.00			
ETD	−0.03	0.16^{***}	0.15^{***}	0.04	0.39^{***}	0.17^{***}	0.11^{***}	0.10^{***}	0.15^{***}	1.00		
ID	-0.10^{***}	0.23^{***}	0.29^{***}	0.14^{***}	0.55^{***}	0.32^{***}	0.24^{***}	0.17^{***}	0.33^{***}	0.55^{***}	1.00	
FD	-0.13^{***}	0.22^{***}	0.21^{***}	0.17^{***}	0.39^{***}	0.29^{***}	0.25^{***}	0.24^{***}	0.21^{***}	0.20^{***}	0.48^{***}	1.00

$^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

Table 12 Variation within and between firms in the dataset

Variable		Mean	Std. Dev	Min	Max	Observations
Environmental Performance	overall	61.66	25.35	0.00	99.14	N = 4042
	between		21.56	0.00	90.39	n = 280
	within		16.97	−17.01	121.51	bar = 14.4357
Emission Score	overall	66.80	29.29	0.00	99.87	N = 4038
	between		26.28	0.00	99.04	n = 280
	within		18.32	−21.34	135.67	bar = 14.4214
Resource Score	overall	64.68	29.82	0.00	99.92	N = 4042
	between		25.39	0.00	99.22	n = 280
	within		19.31	−20.89	127.61	bar = 14.4357
Environmental Innovation Score	overall	49.90	33.84	0.00	99.89	N = 4042
	between		24.92	0.00	97.74	n = 280
	within		24.36	−36.40	119.54	bar = 14.4357
Portfolio Size	overall	3.54	3.93	1.00	38.00	N = 2867
	between		2.56	1.08	19.63	n = 280
	within		2.73	−15.09	28.04	bar = 10.2393
Environmental Technology Diversity	overall	0.20	0.25	0.00	1.00	N = 2867
	between		0.20	0.00	1.00	n = 280
	within		0.16	−0.51	0.76	bar = 10.2393
Industry Diversity	overall	0.32	0.30	0.00	0.90	N = 2844
	between		0.20	0.00	0.74	n = 278
	within		0.22	−0.42	0.96	bar = 10.2302
Functional Diversity	overall	0.28	0.25	0.00	1.00	N = 2864
	between		0.20	0.00	0.67	n = 279
	within		0.16	−0.33	0.82	bar = 10.2652

Appendix 4: Additional regressions with lagged APD diversity

See Tables 13, 14, 15, 16, 17, 18, 19 and 20.

Table 13 Further lags of alliance portfolio diversity and companies' aggregate environmental performance score

Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs
L2.Env. Tech. Diversity	6.88 (4.32)	1529	L2.Industry Diversity	6.34* (3.40)	1512	L2. Functional Diversity	7.25** (3.23)	1529
L3.Env. Tech. Diversity	7.81* (4.38)	1377	L3.Industry Diversity	6.64* (3.40)	1361	L3. Functional Diversity	5.13* (3.06)	1377
L4.Env. Tech. Diversity	8.62* (4.39)	1231	L4.Industry Diversity	10.18*** (3.33)	1216	L4. Functional Diversity	5.87** (2.90)	1231
L5.Env. Tech. Diversity	5.90 (4.67)	1102	L5.Industry Diversity	10.58*** (3.36)	1088	L5. Functional Diversity	3.99 (2.93)	1102
L6.Env. Tech. Diversity	2.54 (4.74)	986	L6.Industry Diversity	9.51*** (3.30)	973	L6. Functional Diversity	2.88 (3.36)	986
L7.Env. Tech. Diversity	1.06 (4.26)	876	L7.Industry Diversity	10.26*** (3.24)	864	L7. Functional Diversity	1.02 (3.18)	876
L8.Env. Tech. Diversity	−1.54 (4.23)	773	L8.Industry Diversity	8.49*** (3.10)	762	L8. Functional Diversity	−1.91 (3.30)	773

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported. Each coefficient is for a separate regression. All regressions include company fixed effects. Standard errors clustered at the firm level

Table 14 The effects of the three joint dimensions of alliance portfolio diversity (lagged) on aggregate environmental performance score

	Environmental performance						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L2.Env. Tech. Diversity	3.35						
	(4.92)						
L3.Env. Tech. Diversity		4.44					
		(5.16)					
L4.Env. Tech. Diversity			2.45				
			(5.83)				
L5.Env. Tech. Diversity				−1.36			
				(6.48)			
L6.Env. Tech. Diversity					−5.12		
					(6.86)		
L7.Env. Tech. Diversity						−8.13	
						(6.77)	
L8.Env. Tech. Diversity							−10.83
							(6.68)
L2.Industry Diversity	3.29						
	(4.02)						
L3.Industry Diversity		3.98					
		(4.12)					
L4.Industry Diversity			8.48*				
			(4.66)				
L5.Industry Diversity				11.02**			
				(5.09)			
L6.Industry Diversity					11.85**		
					(5.57)		
L7.Industry Diversity						14.61**	
						(5.88)	
L8.Industry Diversity							14.80**
							(5.73)
L2.Functional Diversity	4.91						
	(4.31)						
L3.Functional Diversity		2.48					
		(4.28)					
L4.Functional Diversity			2.34				
			(4.19)				
L5.Functional Diversity				0.55			
				(3.98)			
L6.Functional Diversity					0.01		
					(4.29)		
L7.Functional Diversity						−2.19	
						(4.01)	
L8.Functional Diversity							−5.13
							(3.80)
Observations	1512	1361	1216	1088	973	864	762
Controls	YES	YES	YES	YES	YES	YES	YES
Firm_FE	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

Table 15 Further lags of alliance portfolio diversity and companies' emission score

Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs
L2.Env. Tech. Diversity	5.10 (5.01)	1527	L2.Industry Diversity	5.17 (3.46)	1510	L2. Functional Diversity	8.31** (3.30)	1527
L3.Env. Tech. Diversity	7.09 (5.68)	1375	L3.Industry Diversity	3.98 (3.75)	1359	L3. Functional Diversity	5.13 (3.59)	1375
L4.Env. Tech. Diversity	9.53 (5.90)	1230	L4.Industry Diversity	5.44 (3.97)	1215	L4. Functional Diversity	2.93 (3.54)	1230
L5.Env. Tech. Diversity	8.72 (5.45)	1102	L5.Industry Diversity	6.10 (3.90)	1088	L5. Functional Diversity	−0.29 (3.30)	1102
L6.Env. Tech. Diversity	9.04 (5.85)	986	L6.Industry Diversity	7.14 (4.46)	973	L6. Functional Diversity	0.24 (4.00)	986
L7.Env. Tech. Diversity	9.62* (5.33)	876	L7.Industry Diversity	10.11** (4.41)	864	L7. Functional Diversity	−1.90 (4.20)	876
L8.Env. Tech. Diversity	7.18 (4.84)	773	L8.Industry Diversity	7.30* (4.28)	762	L8. Functional Diversity	−5.46 (4.11)	773

*p<0.10, **p<0.05, ***p<0.01. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported. Each coefficient is for a separate regression. All regressions include company fixed effects. Standard errors clustered at the firm level

Table 16 The effects of the three joint dimensions of alliance portfolio diversity (lagged) on the emission score

	Emission score						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L2.Env. Tech. Diversity	1.71						
	(5.53)						
L3.Env. Tech. Diversity		5.46					
		(6.38)					
L4.Env. Tech. Diversity			7.62				
			(7.43)				
L5.Env. Tech. Diversity				6.14			
				(7.53)			
L6.Env. Tech. Diversity					5.86		
					(8.08)		
L7.Env. Tech. Diversity						4.01	
						(7.90)	
L8.Env. Tech. Diversity							2.31
							(7.25)
L2.Industry Diversity	2.24						
	(4.01)						
L3.Industry Diversity		0.52					
		(4.46)					
L4.Industry Diversity			1.95				
			(5.41)				
L5.Industry Diversity				4.09			
				(5.89)			
L6.Industry Diversity					4.87		
					(6.53)		
L7.Industry Diversity						9.17	
						(6.85)	
L8.Industry Diversity							7.98
							(6.51)
L2.Functional Diversity	6.69*						
	(3.82)						
L3.Functional Diversity		3.62					
		(3.98)					
L4.Functional Diversity			0.87				
			(4.08)				
L5.Functional Diversity				−2.56			
				(4.03)			
L6.Functional Diversity					−1.82		
					(4.32)		
L7.Functional Diversity						−4.78	
						(4.38)	
L8.Functional Diversity							−8.11**
							(4.08)
Observations	1510	1359	1215	1088	973	864	762
Controls	YES	YES	YES	YES	YES	YES	YES
Firm_FE	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

Table 17 Further lags of alliance portfolio diversity and companies' resource use score

Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs
L2.Env. Tech. Diversity	6.95 (4.62)	1529	L2.Industry Diversity	4.11 (3.91)	1512	L2. Functional Diversity	5.84 (4.28)	1529
L3.Env. Tech. Diversity	8.94* (4.73)	1377	L3.Industry Diversity	3.86 (3.94)	1361	L3. Functional Diversity	3.07 (3.89)	1377
L4.Env. Tech. Diversity	10.54** (5.15)	1231	L4.Industry Diversity	6.74* (3.77)	1216	L4. Functional Diversity	2.57 (3.54)	1231
L5.Env. Tech. Diversity	8.65* (4.91)	1102	L5.Industry Diversity	8.70** (3.83)	1088	L5. Functional Diversity	1.61 (3.72)	1102
L6.Env. Tech. Diversity	5.46 (4.95)	986	L6.Industry Diversity	8.99** (3.97)	973	L6. Functional Diversity	−0.22 (4.09)	986
L7.Env. Tech. Diversity	2.22 (4.38)	876	L7.Industry Diversity	8.89** (3.94)	864	L7. Functional Diversity	−3.89 (3.56)	876
L8.Env. Tech. Diversity	−2.85 (4.54)	773	L8.Industry Diversity	7.89* (4.22)	762	L8. Functional Diversity	−7.72* (4.02)	773

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported. Each coefficient is for a separate regression. All regressions include company fixed effects. Standard errors clustered at the firm level

Table 18 The effects of the three joint dimensions of alliance portfolio diversity (lagged) on the resource use score

	Resource Use Score						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L2.Env. Tech. Diversity	5.28						
	(5.93)						
L3.Env. Tech. Diversity		8.47					
		(6.36)					
L4.Env. Tech. Diversity			8.40				
			(7.18)				
L5.Env. Tech. Diversity				4.28			
				(7.19)			
L6.Env. Tech. Diversity					−0.29		
					(7.52)		
L7.Env. Tech. Diversity						−5.04	
						(7.60)	
L8.Env. Tech. Diversity							−11.86
							(7.74)
L2.Industry Diversity	0.42						
	(5.31)						
L3.Industry Diversity		−0.20					
		(5.65)					
L4.Industry Diversity			3.14				
			(5.66)				
L5.Industry Diversity				7.18			
				(5.78)			
L6.Industry Diversity					9.82		
					(6.34)		
L7.Industry Diversity						12.75*	
						(6.90)	
L8.Industry Diversity							16.02**
							(7.06)
L2.Functional Diversity	4.38						
	(5.31)						
L3.Functional Diversity		1.42					
		(4.94)					
L4.Functional Diversity			0.06				
			(4.48)				
L5.Functional Diversity				−1.30			
				(4.08)			
L6.Functional Diversity					−3.08		
					(4.45)		
L7.Functional Diversity						−6.99*	
						(4.13)	
L8.Functional Diversity							−11.18***
							(3.96)
Observations	1512	1361	1216	1088	973	864	762
Controls	YES	YES	YES	YES	YES	YES	YES
Firm_FE	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p 0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

Table 19 Further lags of alliance portfolio diversity and companies' green innovation score

Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs	Lag in APD dimension	Coefficient	Obs
L2.Env. Tech. Diversity	2.61 (5.82)	1530	L2.Industry Diversity	6.52 (5.22)	1513	L2.Functional Diversity	9.56* (5.09)	1530
L3.Env. Tech. Diversity	2.58 (4.88)	1377	L3.Industry Diversity	7.53 (4.99)	1361	L3.Functional Diversity	5.90 (4.91)	1377
L4.Env. Tech. Diversity	3.74 (5.02)	1231	L4.Industry Diversity	13.40*** (5.03)	1216	L4.Functional Diversity	7.81 (4.76)	1231
L5.Env. Tech. Diversity	−2.49 (5.81)	1102	L5.Industry Diversity	10.51** (5.08)	1088	L5.Functional Diversity	6.15 (4.83)	1102
L6.Env. Tech. Diversity	−7.42 (6.14)	986	L6.Industry Diversity	8.19 (5.05)	973	L6.Functional Diversity	7.38 (5.21)	986
L7.Env. Tech. Diversity	−6.85 (6.08)	876	L7.Industry Diversity	9.35* (4.91)	864	L7.Functional Diversity	6.79 (5.19)	876
L8.Env. Tech. Diversity	−5.78 (7.23)	773	L8.Industry Diversity	9.13* (5.17)	762	L8.Functional Diversity	4.33 (5.57)	773

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported. Each coefficient is for a separate regression. All regressions include company fixed effects. Standard errors clustered at the firm level

Table 20 The effects of the three joint dimensions of Alliance Portfolio Diversity (lagged) on the Green Innovation score

	Environmental Innovation Score						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L2.Env. Tech. Diversity	−2.64						
	(7.55)						
L3.Env. Tech. Diversity		−3.55					
		(6.92)					
L4.Env. Tech. Diversity			−7.51				
			(7.19)				
L5.Env. Tech. Diversity				−13.34			
				(8.33)			
L6.Env. Tech. Diversity					−18.42**		
					(8.72)		
L7.Env. Tech. Diversity						−19.07**	
						(9.03)	
L8.Env. Tech. Diversity							−17.82
							(10.79)
L2.Industry Diversity	5.16						
	(6.65)						
L3.Industry Diversity		8.17					
		(6.42)					
L4.Industry Diversity			15.74**				
			(6.64)				
L5.Industry Diversity				15.58**			
				(7.07)			
L6.Industry Diversity					15.49**		
					(7.45)		
L7.Industry Diversity						17.70**	
						(7.93)	
L8.Industry Diversity							17.40*
							(9.06)
L2.Functional Diversity	7.48						
	(5.39)						
L3.Functional Diversity		2.83					
		(5.45)					
L4.Functional Diversity			3.10				
			(5.79)				
L5.Functional Diversity				2.77			
				(5.40)			
L6.Functional Diversity					5.01		
					(5.58)		
L7.Functional Diversity						3.89	
						(5.76)	
L8.Functional Diversity							1.17
							(6.36)
Observations	1513	1361	1216	1088	973	864	762
Controls	YES	YES	YES	YES	YES	YES	YES
Firm_FE	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

Appendix 5: Additional regressions

See Tables 21, 22, 23.

Table 21 Alliance portfolio diversity and environmental performance by firms' age groups

	Environmental performance															
	Youngest 20%				Younger than the mean				Older than the mean				Oldest 20%			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Env. Tech. Diversity	11.91*			5.60	2.80			0.13	5.05			1.35	6.15			3.90
	(6.88)			(10.18)	(6.08)			(7.46)	(4.83)			(5.20)	(4.87)			(6.03)
Industry Diversity		5.51		−3.30		2.78		3.53		7.07**		5.13		5.64		3.63
		(9.34)		(9.57)		(6.26)		(7.29)		(3.43)		(3.93)		(3.66)		(5.04)
Functional Diversity			20.89*	19.39			2.77	−1.70			6.93**	5.27			4.42	1.00
			(11.27)	(13.35)			(6.18)	(7.27)			(3.15)	(3.78)			(4.99)	(5.60)
Obs	143	140	142	140	841	821	840	821	1028	1028	1028	1028	468	468	468	468
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

Table 22 The relationship between alliance portfolio diversity and environmental performance: distinction between manufacturing and service industries

	Environmental performance															
	Primary sector				Manufacturing				Services				Energy			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Env. Tech. Diversity	11.20			15.39	15.73***			13.39**	4.99			−6.28	2.28			−1.97
	(8.03)			(10.42)	(5.10)			(6.17)	(8.36)			(8.38)	(10.36)			(12.22)
Industry Diversity		5.86		−2.56		9.67**		2.08		22.71***		25.83***		6.75		3.60
		(4.78)		(6.18)		(4.01)		(4.53)		(6.40)		(8.24)		(9.33)		(10.20)
Functional Diversity			0.78	−4.64			8.16**	4.62			16.68*	−1.84			11.06	9.35
			(8.58)	(8.80)			(4.07)	(4.57)			(8.43)	(9.38)			(8.23)	(8.50)
Obs	126	126	126	126	938	937	937	937	342	342	342	342	463	444	463	444
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

Table 23 The relationship between alliance portfolio diversity and different metrics of environmental performance: non-linear effects

	Environmental Performance				Emissions Score				Resource Use Score				Environmental Innovation Score			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Env. Tech. Diversity	19.27*			13.39	17.30			15.67	22.16			19.75	17.36			2.71
	(11.06)			(12.19)	(11.05)			(12.36)	(13.75)			(15.25)	(15.50)			(17.47)
(Env. Tech. Diversity)2	−14.07			−12.85	−15.66			−20.15	−25.80			−23.66	−8.68			−0.34
	(17.50)			(18.77)	(18.60)			(19.09)	(23.23)			(24.82)	(24.22)			(27.13)
Industry Diversity		12.73		6.42		1.00		−5.62		9.64		1.96		23.09*		15.62
		(8.32)		(8.52)		(7.88)		(9.40)		(8.22)		(8.56)		(11.90)		(12.69)
(Industry Diversity)2		−2.34		1.65		13.29		18.94		−8.45		−2.60		−10.65		−6.40
		(11.40)		(11.27)		(12.37)		(12.74)		(13.09)		(13.35)		(15.97)		(16.49)
Functional Diversity			15.49**	1.74			8.97	−1.13			8.99	1.95			32.43**	18.04
			(7.52)	(10.38)			(9.83)	(11.64)			(11.04)	(12.50)			(13.35)	(16.15)
(Functional Diversity)2			−11.03	3.23			−0.11	10.67			−4.07	3.23			−30.91*	−17.29
			(9.54)	(12.79)			(13.14)	(15.25)			(17.39)	(19.11)			(17.85)	(19.62)
Obs	1869	1849	1868	1849	1866	1846	1865	1846	1869	1849	1868	1849	1870	1850	1869	1850
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

*$p<0.10$, **$p<0.05$, ***$p<0.01$. Controls for net income, age and size of alliance portfolio, and pre-2015 years not reported

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Data availability The data that support the findings of this study were used under a licence of SKEMA Business School, Université Côte d'Azur and so are not publicly available.

Declarations

Conflict of interest The authors declare no competing interests.

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