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Regional Environmental Protection Investments, Cluster Ecosystems, and Firm Innovation: Evidence From Germany

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ABSTRACT

This paper presents an exploration of how regional environmental protection investments (EPIs) and cluster ecosystems affect the innovation performance of research and development (R&D) firms versus non-R&D firms across regions in Germany. We develop a conceptual framework to elucidate the relationship between regional EPIs, cluster ecosystems, R&D decisions, and innovation performance of firms. We test this framework by employing ordinary least squares (OLS) and fixed effect regressions to analyze a unique sample of panel data from ORBIS and DESTATIS for the period 2009–2017. We find that in regions in which there are higher EPIs, R&D firms outperform their non-R&D counterparts in terms of intangible assets formation. We also find that the relationship between cluster ecosystem and firm innovation performance is contingent on firm R&D engagement and specific types of regional EPIs. Additional insights reveal that there are spillover effects on firm innovation performance for non-R&D firms belonging to business clusters and at the same time, in proximity to geographical areas that are populated by higher numbers of other cluster constituents. The results of this study contribute to our nascent understanding of innovation ecosystems and hold important implications for policymakers in terms of how to formulate effective environmental policies to promote firm innovation.

1 | Introduction

Since the early 1970s, the scope of environmental protection measures in most developed countries has been significantly extended, resulting in increased environmental control investments (Li et al. 2018; Li et al. 2023). Even though climate change has been recognized as a critical global challenge, that requires global action, most adverse consequences are localized, that is, the South European and North American wildfires of 2021. Hence, policy intervention at the regional level becomes significantly more relevant and important as the climate crisis deepens (Hurlimann and March 2012; Sun et al. 2024; Vlaisavljevic et al. 2020).

Recently, there is a growing attention in regional studies and related literature streams to whether regional environmental protection investments (EPIs) enhance firms' innovation performance (Carayannis et al. 2018; Chang et al. 2016; Hewes and Lyons 2008). EPIs are defined as corporate investments by firms for the protection and improvement of environmental quality and prevention of ecological environment deterioration (Hong et al. 2022; Lu 2021). Hence, EPIs are indicative of firm engagement in environmental sustainability (Xie et al. 2019). Recently, various high-profile names have actively engaged in environmental protection initiative to contribute to sustainable natural ecosystems. For example, Amazon launched a US$2 billion Climate Pledge Fund dedicated to sustainable technologies and services in 2020. This is part of the company strategy to reach net-zero carbon by 2040. Another example can be seen in Tesla's Renewable Energy and Battery Storage Projects that help stabilize the grid and promote renewable energy adoption.

On the one hand, the significance of environmental protection support policies on firms' innovation have long been recognized (Liao 2018a; Qiu et al. 2020; Shao et al. 2020; Yang et al. 2024). Environmental protection support policies create institutional pressures on firms to improve their green innovation (Liao 2018a; Qiu et al. 2020). Furthermore, firms located in regions with high levels of environmental protection measures benefit from "the availability of scientific and technological knowledge" and "environmental awareness" (OECD 2013, 84). These lead to the creation and accumulation of knowledge by firms at the regional level, which allow them to transform technological output into market value (Liao 2018a; Yang et al. 2024). By the same token, Maskell (2001) emphasizes knowledge as the most crucial strategic resource to ensure sustainable differentiation and competitive advantages of organizations. Besides, greater input in regional environmental governance can amplify social connections among actors who perform environmental innovation and activate regional innovation networks, which further contributes to the rise of firm innovation efficiency (Arranz et al. 2019; Qiu et al. 2020; Ramanathan et al. 2017; Weber and Reardon 2015).

On the other hand, it remains unclear whether operating in an ecosystem with a great focus on environmental protection is likely to be beneficial for a firm (Tang et al. 2018). Actually, firms have to make considerable changes to technology and innovation practices to adapt to the institutional environment with a great focus on environmental protection (Cleff and Rennings 1999; Hilliard and Jacobson 2011). In addition, when engaging in green innovation, firms encounter the substantial upfront investment required (Xie et al. 2019), that is likely to take up a large proportion of firms' budget. After that, firms need to cover considerably operational cost of facilities for the treatment of unwanted materials (i.e., waste) (Qiu et al. 2020, Tang et al. 2018). Besides, the extra cost of compliance with increasingly environmental standards and regulations are highly likely to reduce firms' spending towards enhancing firm innovation (Lee 2009; Skawińska and Zalewski 2009). Hence, the relationship between regional environmental measures and innovation outcomes remains inconclusive in the existing literature.

Parallel to that, the role played by cluster ecosystems is increasingly at the forefront of the international policy agenda. A business cluster is recognized as an ecosystem that contains "geographically proximate groups of inter-connected firms and associated institutions in a particular field, linked by commonalities and complementarities" (Porter 1998, 254). The ecosystem is suited to support the interaction and cooperation between members within the community (Boschma and Fornahl 2011; Cruz and Teixeira 2010; Isaksen and Onsager 2010; Luong et al. 2025; Porter 1998), thus stimulating interactive learning and innovation activities in the network (Du and Vanino 2020). Furthermore, knowledge sharing allows cluster members to constantly combine resources to persistently engage in innovation (Vlaisavljevic et al. 2020). However, at the same time, studies have identified a set of cluster disadvantages that can adversely affect firm innovation activities, such as intensive competition (Porter 1998; Porter and Miranda 2009; Zucker et al. 1998), or costs to access required external capital (Beaudry and Breschi 2003; Larty et al. 2017; Lee 2009; Myles Shaver and Flyer 2000; Trippl et al. 2015). Hence, a question arises whether cluster ecosystems are better organizational forms in providing firms with favorable conditions to boost their innovation performance compared to noncluster areas.

There is an extensive literature that is mainly focused on large firms and innovative sectors (Hervas-Oliver et al. 2018; Hervas-Oliver et al. 2022), whereas much less is known about non-R&D performers, a significant lacuna given that a number of firms successfully innovate and at the same time do not engage in R&D (Hervas-Oliver et al. 2011; Hilliard and Jacobson 2011; Rammer et al. 2009). Furthermore, given the debatable results concerning the relationship between EPIs and firm innovation performance (Lee 2009; Liao 2018a; Skawińska and Zalewski 2009; Yang et al. 2024) and between cluster ecosystem and firm innovation performance in prior research (Du and Vanino 2020; Lee 2009; Myles Shaver and Flyer 2000; Trippl et al. 2015; Vlaisavljevic et al. 2020), we argue that these competing conceptual perspectives may be reconciled together in research on the EPIs–innovation performance relationship in the context of clusters. In fact, there is little evidence on the impact of regional EPIs on firm innovation performance in the context of cluster ecosystems (Bell 2005; Díez-Vial et al. 2023; Tsenina et al. 2022).

We aim at filling these gaps by drawing on the knowledge-based view (Hoskisson et al. 1999; Maskell 2001) that considers knowledge as the most crucial strategic resource to ensure sustainable differentiation and competitive advantages of organizations. We link this view to insights from the regional environmental protection perspective (Lambert and Boons 2002; Weber and Reardon 2015) and the innovation literature (Cleff and Rennings 1999; Jaffe et al. 2002). Hence, we are able to explain whether R&D firms in regions with higher EPIs are more innovative (in terms of intangible assets). Furthermore, we shed light on the interaction between R&D status, membership of a business cluster, and regional EPIs. It turns out that the sign of regional EPIs effect varies with the different types of EPIs. Lastly, we establish a novel result for non-R&D firms that the membership in populous business clusters improves their innovation performance.

We test the resulting hypotheses empirically using a large firm-level data on location, industry classification, R&D expenditure, intangible assets, and other firms level controls from ORBIS by Bureau van Dijk, that is linked with a dataset on region-level EPIs (NUTS1) sourced from the German Federal Statistical Office (DESTATIS). Using ordinary least squares (OLS) and fixed effect models, we find that R&D firms outperform non-R&D ones, in regions with higher levels of EPIs. We extend the literature on the effect of cluster ecosystems on firm innovation by uncovering two conditioning factors, namely, R&D engagement of cluster firms and specific types of regional EPIs. Furthermore, we find evidence of positive spillovers on innovation performance of non-R&D firms who are part of a cluster ecosystem and concurrently in close proximity to larger pools of cluster constituents.

Our study offers three contributions. First, we theoretically develop the interrelationship between regional EPIs, cluster ecosystems, and innovation performance of R&D firms vis-à-vis that of non-R&D ones. Empirically, our detailed and novel dataset enables us to provide statistical insights on the role played by regional EPIs and cluster ecosystem in firm innovation for German firms during the period 2009–2017.

Second, our results complement three distinct strands of literature (environmental protection, business cluster, and innovation) to uncover the conditions needed for all types of firms to improve their innovation performance in the context of cluster ecosystem.

Third, we outline numerous implications based on our results and some important avenues for future investigation, which are all at the intersection of innovation ecosystems such as environmental protection support and cluster ecosystems, and how these influence firm-level innovation trajectories across different regions. In particular, we provide evidence that the effect of regional EPIs for firms that do R&D and at the same time are members of a business cluster is heterogeneous in terms of its sign. More specifically, only regional Waste Management Investment increases the innovation performance of R&D firms in business clusters. Hence, regional environmental policy and more specifically regional environmental investment that has as an objective to help firms reach their innovation potential should consider specific types of EPIs. Furthermore, regional governments interested in improving innovation for non-R&D firms, should encourage or even provide financial incentives to these firms to locate in populous business clusters.

This paper is organized as follows. Section 2 provides a review of the literature and hypotheses development. In Section 3, research design is presented. Section 4 reports and discusses the empirical results. Section 5 discusses theoretical and policy implications. Finally, we provide the concluding remarks coincided with limitations and suggestions for future research in Section 6.

2 | Literature Review and Hypotheses Development

Our paper draws insights from three distinct literature streams (environmental protection, business clusters, and innovation) to develop a conceptual framework that links them in explaining how regional EPIs and cluster ecosystems affect the innovation performance of firms across regions in Germany. The first literature strand is on environmental protection, which has hitherto mostly focused on the impact of regional EPIs on firm innovation performance (Becker 2019; Li et al. 2018; Schot and Steinmueller 2018). The second strand of literature focuses on business clusters, highlighting the heterogeneity in empirical evidence regarding the ways in which cluster ecosystems impact firm innovation performance (Arranz et al. 2019; Abukabarr and Mitra 2017; Porter and Miranda 2009; Wennberg and Lindqvist 2010). The third literature strand is on innovation, which discusses the determinants of firm innovation success (Brancati et al. 2022; Zawislak et al. 2014). In the following sections, we discuss and outline each literature strand in greater detail prior to deriving our hypotheses.

2.1 | Regional EPIs and Firm Innovation Performance

In the context of the emerging knowledge-based economy, business managers use their significant resources and innovation capacity to make their business activities more efficient and less polluting (Forsberg and Von Malmborg 2004; Kabongo and Boiral 2017; Li et al. 2023). Environmental management has become a strategic business issue as it could potentially allow firms to achieve economic advantages such as reduced environmental control costs, material savings, and process efficiencies (Carayannis et al. 2018; Chang et al. 2016; Hilliard and Jacobson 2011). In particular, the regions with a high focus on environmental protection have a strong tendency to apply innovative principles to achieve greater environmental potentials (Jiang et al. 2018) and to support "innovative planning practices" with ambitious environmental goals (Chapple et al. 2011, 6). Parallel to this, a firm who is more likely to engage in innovation will significantly improve its resource efficiency over time by optimizing product design and manufacturing processes, thereby making firms more competitive (Dangelico and Pontrandolfo 2015). In addition, green innovation can enhance brand value and increase customer loyalty by signaling a firm's sense of social responsibility and, hence, help firms achieve sustainable competitive advantages (Carfora et al. 2021; Dangelico 2016).

Nevertheless, several contributions focused on environmental innovation support the notion that environmental processes demand firms to make considerable changes to technology and innovation practices (Cleff and Rennings 1999; Hilliard and Jacobson 2011; Jaffe et al. 2002; Mazzanti and Zoboli 2009; Truffer and Coenen 2012). As a consequence of the externalities associated with environmental technology, regional actors are requested to implement a range of joint activities to aim at developing innovations in sustainability and to achieve the advancement and diffusion of more environmental technologies (Skawińska and Zalewski 2009). Firms that are not able to implement effective environmental management find it challenging to obtain official approval for planning permission or independent production companies (IPC) license (Hilliard and Jacobson 2011), thereby constraining their "flexibility of action" (Hoffman 1997, 6). Besides, evidence has shown that firms may be reluctant to engage in green innovation activities due to the substantial costs related to environment engagement and environmental management (Qiu et al. 2020; Xie et al. 2019). In particular, firms have to initially allocate a large portion of their budget to the upfront investment required (Xie et al. 2019). Furthermore, firms have to show continuous improvement in environmental performance and support this with environmental management procedures. These firms are required to constantly advance their technical capabilities for technology adoption and environmental management overtime. Hence, firms have to cover the extra costs to meet the regional environmental requirements (Ford et al. 2014; Lee 2009; Liao 2018b). Despite the growing interest in environmental innovation, it is not clear whether regional environmental investments stimulate technological development and innovation of firms in the regions (Hewes and Lyons 2008; Liao 2018b; Yang et al. 2023).

Evidence has shown that R&D collaboration is among the most important determinants in firms' pursuit of innovation

(Ardito et al. 2019; Audretsch and Belitski 2020; Mazzanti and Zoboli 2009). Firms that aim to remain competitive must invest in R&D and adopt sustainable practices to enhance their technological capabilities. These types of investments will result in new and innovative solutions and hence strengthen the firms' competitive advantages (Bataineh et al. 2024; Kumar et al. 2024). Besides, R&D firms are more likely to collaborate with other R&D firms by perceiving that incoming knowledge sharing from that specific type of partners are relevant for their innovation effort (Holloway and Parmigiani 2016). Bossink (2007) highlights that the innovative organizations within the interaction patterns are more likely to be able to manage the balance between the exploitation and exploration of innovative possibilities, and between competition and cooperation with their counterparts. Furthermore, some case study analyses have indicated that innovative organizations are more inclined to cooperate with research centers, universities, national labs, and governmental organizations to promote environmental innovation processes (Mazzanti and Zoboli 2009; Vallés-Giménez and Zárate-Marco 2022). Ramanathan et al. (2017) find that innovative firms are generally more capable of innovatively responding to environmental processes and managing their environmental performance. Hilliard and Jacobson (2011) reach a similar conclusion that R&D sectors appear associated with more innovative activities coincided with a less negative environmental impact. Therefore, we deemed it reasonable to hypothesize that R&D firms significantly benefit from regional EPIs by effectively exploring and exploiting any available resources to further develop innovation both individually and interorganizationally with the other members of the regions.

Although it is widely accepted that R&D activities affect a firm's innovation performance (Iammarino et al. 2009; Miotti and Sachwald 2003), there is a dearth of empirical studies on the effects of regional EPIs on the innovation performance of R&D firms versus non-R&D firms (Hervas-Oliver et al. 2018; Hervas-Oliver et al. 2022; Ramanathan et al. 2017). In this paper, we choose Germany as the setting for our empirical study on both R&D performers and their non-R&D counterparts, and we argue that the innovation performance of R&D firms is more pronounced compared to that of non-R&D firms in regions with higher EPIs. That leads us to formulate our first hypothesis:

Hypothesis 1. *R&D firms experience greater innovation performance (compared to non-R&D firms) in regions with higher EPIs.*

2.2 | Mechanisms Behind the Relationship Between Cluster Ecosystems, R&D Engagement, and Regional EPIs on Firm Innovation Performance

It remains largely unresolved whether cluster location enhances innovation performance of member firms (Lee 2009; Mudambi and Swift 2012). On the one hand, it is highlighted that clustering is an effective way of facilitating innovative activities (Laursen et al. 2016; Porter and Miranda 2009). In cluster ecosystems, there are two crucial dimensions, namely, geographical proximity and industrial specification (Kelchtermans et al. 2020; Porter and Miranda 2009). Geographical proximity, which facilitates contacts and interactions among a cluster's constituent firms (Isaksson et al. 2016), stimulates access to knowledge among the firms (Vlaisavljevic et al. 2020). At the same time, the economic activities conducted within the same or related industries among cluster members facilitate accelerated knowledge sharing, primarily driven by personnel interactions, cooperation, and competition (Delgado et al. 2014; Laursen et al. 2016; Luong et al. 2025). Porter (1998) argues that innovation dynamics are stimulated by peer pressure among members in networks and that cluster members are aware of their peers' initiatives and activities. Thus, cluster ecosystems are conducive to intracluster cooperation among their constituent firms, and then, firms can learn from one another to enhance their own innovation practices.

On the other hand, some studies have shown that geographical agglomeration is not statistically correlated with firms' innovation performance (Larty et al. 2017; Lee 2009; Myles Shaver and Flyer 2000; Trippl et al. 2015). Zucker et al. (1998) find evidence that intense competition for R&D resources among firms located in a cluster would raise the costs of R&D and limit the availability of better quality R&D resources for a number of local players. Besides, cluster firms become more vulnerable if they are locked in technology obsolescence (Beaudry and Breschi 2003; Lee 2009; Mudambi and Swift 2012). These results indicate that intracluster cooperation emanating from geographical proximity alone may not be sufficient to be conducive to clustered firms' innovation performance. Mechanisms or channels through which geographical proximity may influence firms' innovation performance remain largely unexplored (Audretsch and Feldman 2004; Lee 2009).

The extant literature has shown that the effect of cluster location on firm innovation activities is moderated by R&D engagement of cluster firms (Beaudry and Breschi 2003; Temouri et al. 2025). More specifically, Beaudry and Breschi (2003) have found that only firms located in clusters that are more densely populated by other R&D firms in the same industry tend to be more innovative than firms located in clusters with a plethora of non-R&D firms. The internal R&D effort promotes the "absorptive capacity" of firms, which is the ability to identify, assimilate, and exploit the knowledge coming from external sources (Cohen and Levinthal 1990, 129). Furthermore, collaboration among R&D firms can be developed because effective learning takes place through repeated cooperation and hence builds trust and supports the exchange of tacit knowledge (Cruz and Teixeira 2010; Staber and Sautter 2011).

In recent years, heterogeneous environmental protection measures (waste treatment, water resources and air, and air pollution) have been implemented in business clusters in an effort to enhance firm innovation activities (Skawińska and Zalewski 2009). Environmental innovation requires higher cooperative efforts and higher complementarities among the networking activities performed by network players (Mazzanti and Zoboli 2009; Foxon and Andersen 2009). Hilliard and Jacobson (2011) show that cluster ecosystems include environment-related and supporting institutions, such as the environmentally aware civil society, research centers, and local authorities who are in charge of environmental governance. Nevertheless, some other conflicting results show that the weight of economic instruments in business cluster ecosystems is continuously growing, for example, fees for complying with environmental regulation in business clusters (Jiang et al. 2018). Hence, the high cost of environmental governance, to some extent, can directly limit innovation activities of cluster firms.

The diverse empirical results on the clustering–innovation relationship above imply that there should be some conditioning factors or mechanisms through which being located in a cluster influences firm innovation performance. We contribute to a greater clarity and better understanding of how firms operating in a business cluster can enhance their innovation performance, which we argue is contingent upon two conditions: (1) firm R&D engagement and (2) specific types of regional EPIs. Hence, we propose:

Hypothesis 2. *R&D firms in cluster ecosystems experience greater innovation performance (compared to non-R&D and not in cluster ecosystems firms) in regions with higher regional EPIs.*

2.3 | Spillovers Among Non-R&D Firms in Business Clusters

There is a broad consensus that both competition and cooperation in clusters stimulate innovation and technological development (Carayannis et al. 2018; Porter and Miranda 2009; Temouri et al. 2025). One the one hand, firms in clusters are often confronted with tougher competition, forcing cluster members to continuously improve their practices and engage with sustained innovations (Temouri et al. 2025). On the other hand, interfirm cooperation continuously enhances a knowledge environment in clusters, thereby improving clusters' knowledge base (Lazzeretti and Cinti 2009) and create new knowledge quickly and freely among members (Spigel and Harrison 2018). In cluster ecosystems, the cooperative constellation is strengthened because there is a strong collaboration among not only businesses but also support organizations and regional governments (Boschma and Fornahl 2011; Porter 1998). Moore (1993, 76) highlights that firms in such communities as clusters "work co-operatively and competitively to support new products, satisfy customer needs and eventually incorporate the next round of innovations."

Some studies suggest that cluster ecosystems should be viewed as a digital economy phenomenon due to their emphasis on cutting-edge technology that facilitates innovation opportunities (Autio et al. 2018). Technology-intensive firms have high visibility in a cluster, driving innovation, digitalization and valuable knowledge spillovers (Porter and Miranda 2009). In addition, the visible and invisible modes of governance and structure systems in cluster ecosystems set the processes for the clusters to follow appropriate structural frameworks that support innovation (Spigel and Harrison 2018). Furthermore, empirical evidence has shown that intracluster cooperation in business clusters results in learning and demonstration effects (Amdam et al. 2020). Therefore, firms within the same regions and industries can learn from better performing organizations in terms of innovation activities specifically.

Complementary resources are a key driver of interorganizational cooperation that is an integral part of innovation process (Miotti and Sachwald 2003; Marchi 2012). Firms who are in close proximity to a pool of cluster constituents are strongly incentivized to integrate their networks and to pool their resources to reduce the costs and risks. Furthermore, technology and innovation form a large part of the success of cluster ecosystems (Porter and Miranda 2009). Hence, cluster ecosystems help member firms to strengthen their ongoing ability to improve their innovation (Grillitsch and Nilsson 2017; Li et al. 2018; Tether 2002; Rugman and Verbeke 2003; Vlaisavljevic et al. 2020). This points to the attractiveness of the ecosystems and to the fact that firms in geographically bounded settings can significantly benefit from their partners' resources and should not need to expend much effort to absorb the knowledge outcomes of other entities (Isaksen and Onsager 2010; Storper and Venables 2004).

There are some research attempts to discover the role played by spillover effects on R&D firms to enhance their innovation performance (Laursen et al. 2016; Romijn and Albu 2002). However, the discussion on non-R&D performers in this literature strand have been largely neglected (Thomä and Zimmermann 2020). At the same time, evidence has shown that some firms develop innovations without performing R&D activities (Hervas-Oliver et al. 2011; Hervas-Oliver et al. 2018). We therefore focus on firm innovation without R&D in this hypothesis to investigate the conditions for non-R&D firms that will enhance their innovation performance in the context of cluster membership and geographical proximity to pools of complementary resources of clusters. We argue that non-R&D firms operating in cluster ecosystems are close to pools of cluster firms and hence increasingly strive to expand their own resources base by gaining access to those of such pools' members. As a result, non-R&D firms that are close to the networks of cluster ecosystems are inclined to cooperate with the pools' members to scale up their innovation performance. Therefore, non-R&D firms that are close to the pools of cluster firms and belong to such pools have favorable conditions to evolve by strengthening the indigenous innovative activities carried out in the networks. This leads to our third hypothesis:

Hypothesis 3. *Non-R&D firms operating within densely populated cluster ecosystems experience higher innovation performance, via spillover effects.*

Overall, we develop three hypotheses, as discussed above, to address literature gaps in terms of the relationships among regional EPIs, cluster ecosystems, R&D decisions, and firms' innovation performance. We develop the first hypothesis to address the inconclusive literature on the relationship between regional environmental measures and innovation outcomes. The second hypothesis is proposed to reconcile insights from fragmented literature on the effect of cluster ecosystems on firm innovation performance. Finally, we devote the third hypothesis to examine conditioning factors for non-R&D firms to innovate, given that the discussion on non-R&D performers in this literature strand has been largely neglected, even though in many cases, firms develop innovations without performing R&D activities.

The above discussion and derivation of our hypotheses culminates in our conceptual framework depicted in Figure 1. It shows two boxes that operationalize our hypotheses and map them to our empirical strategy. In the upper box, we start with the comparison between R&D firms versus non-R&D firms,

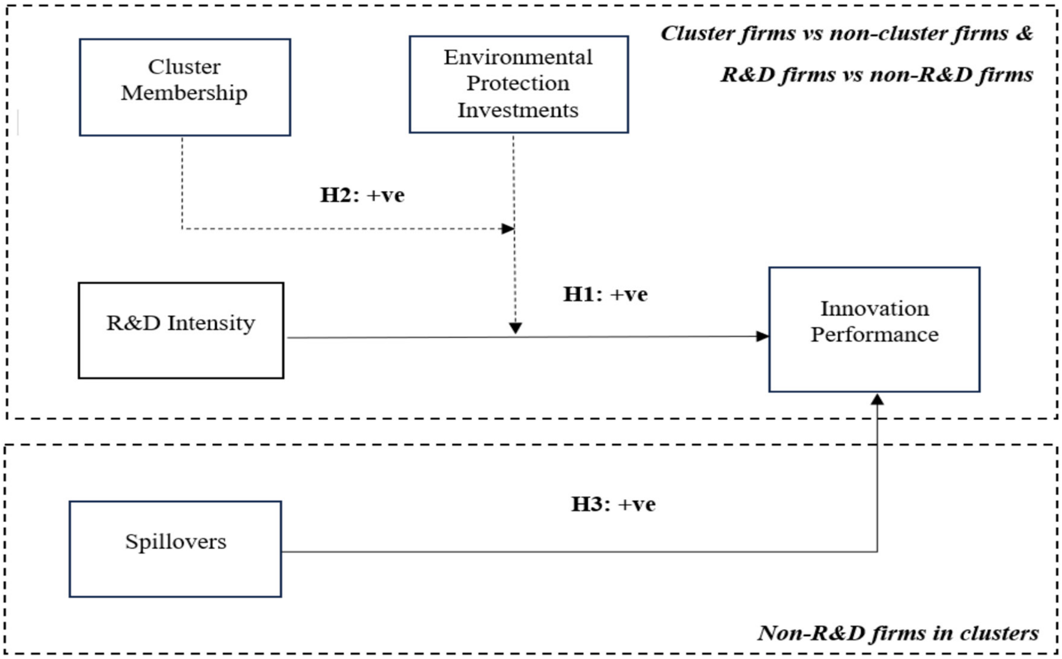

FIGURE 1 | Conceptual framework.

and cluster firms versus noncluster firms, discussing the link between R&D intensity and innovation performance in the context of EPIs and cluster membership. This forms the basis for Hypotheses 1 and 2. In the lower box of our conceptual framework, we focus on uncovering the conditions deriving from cluster ecosystems for non-R&D performers to enhance innovation performance (Hypothesis 3). Hence, we contribute to a greater clarity and better understanding of the intersection between EPIs, the effects of being located in cluster ecosystems, and innovation performance for both R&D firms versus non-R&D firms.

3 | Research Design

Data used in this paper are secondary in nature and is drawn from two main sources, including ORBIS by Bureau van Dijk and Federal Statistical Office of Germany (Statistisches Bundesamt DESTATIS). Data on firm location, financial status, industrial specialization, and other firm-level data come from ORBIS. This database remains one of the most popular firm-level databases used in the literature due to its coverage and representativeness. Data on regional level EPIs are from DESTATIS. In total, our dataset includes 63,366 firms from different groups based on firm-specific characteristics (i.e., firm assets, firm age, no. of employees, MNE vs. non-MNE, and export revenue) and across various groups geographic subdivisions of Germany's economic regions from 2009 to 2017 that are used to empirically analyze the effects of EPIs and cluster ecosystem on firms' innovation performance. The flowchart of the research design we use in this paper is represented in Figure 2.

The lack of comprehensive lists of identified business clusters in specific countries or jurisdictions plagues the empirical studies in this literature strand (Martin and Sunley 2011). To tackle this problem, we use the list of business clusters in Germany available from the German Federal Ministry for Economic Affairs and Energy. This list provides information on location and industry specialization for each cluster (see Graphs S1 and S2 and Table S1 in the Supporting Information).[1]

We base our cluster classification on the definition by Porter (1998) that cluster firms are located in close geographic proximity and operate in similar industry markets. Hence, we follow the two-dimension method (Du and Vanino 2020; Kelchtermans et al. 2020) to identify firms who are part of cluster ecosystems. First, we use a reference location (city/municipality) as a geographically territorial unit for each business cluster. Second, we combine two-digit NACE codes as industry specialization with reference locations to group firms to be in the same business clusters. This procedure is well suited with the quantitative econometric analysis developed therein.

We then complement our cluster classification with regional level EPIs at the NUTS1 level. They were introduced by the government to incentivize sustainable firm innovation and growth across German regions, including cluster and noncluster ecosystems. Statistics on EPIs are recorded annually for companies and operations in the environmental economic accounts. Such accounts are added as satellite systems in each state (Länder) and then are centralized to the national accounts. EPIs are indicative of firm engagement in the regions with the intention to implement environmental treatments, achieving sustainable growth, and securing regional development.

Our data include a representative sample of German firms in terms of sectors, size, foreign ownership, and age. Our original sample contains 207,820 firm-year observations drawn from 63,366 firms across the various geographic subdivisions of Germany's economic regions (Länder) for the period 2009–2017.

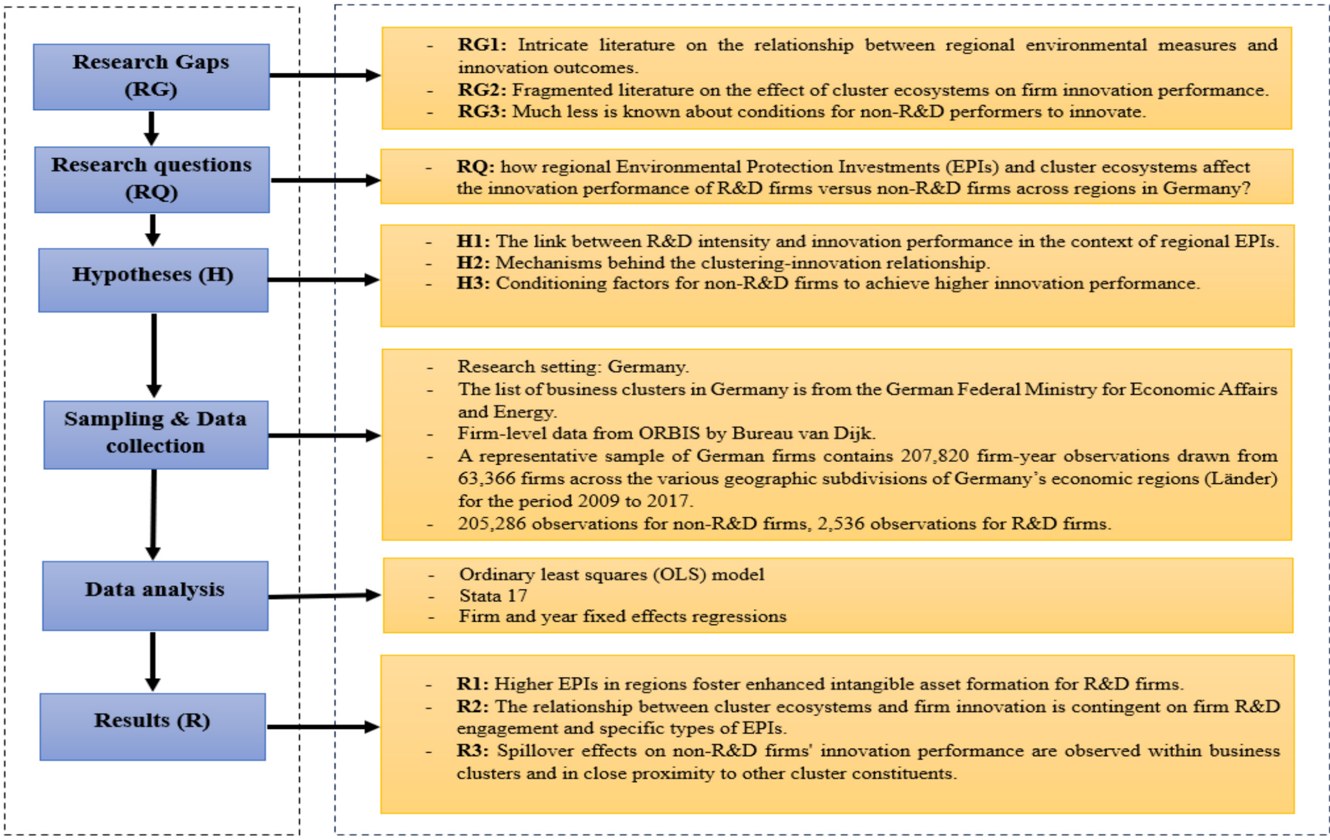

FIGURE 2 | Flowchart of the research design.

Detailed descriptions of variables used in our study are shown in Table 1.

3.1 | Empirical Model and Specifications

We performed the OLS model in Stata 17 to test our hypotheses. We chose firm- and year-fixed effects regression, as these effects represent a more stringent form of fixed effects, which control for bias from time-invariant firm heterogeneity, that is consistent with the prevailing trend in the recent innovation literature (Li et al. 2022; Xie et al. 2019; Yang et al. 2023).

Various innovation proxies are used in the existing literature, such as patent counts, trade market applications, and new product launches (Jensen and Webster 2009; Montresor and Vezzani 2016). Each of these innovation proxies has relative strengths and weaknesses in terms of coverage. Following Bagna et al. (2021), we use intangible fixed assets as a proxy for our dependent variable *innovation performance*, as listed in the balance sheet account of the companies sourced from ORBIS. The variable *intangible fixed assets* is commonly used as a proxy for firm innovation performance because such assets capture formation expenses, research expenses, goodwill, development expenses, and all other expenses with a long-term effect that reflect the investments tied to a firm's innovative activities (Du and Temouri 2015; Jensen and Webster 2009; Montresor and Vezzani 2016).

We use Equation (1) to test the first hypothesis regarding the relationship between the innovation performance of R&D and non-R&D firms in regions with different levels of EPIs:

$$\begin{aligned} & Performance_{ijt} = \beta_0 + \beta_1\, R\&D\ dummy_{ijt} \\ & + \beta_2\, Länder\ Environmental\ Investment_{jt} \\ & + \beta_3\, R\&D\ dummy_{ijt} * Länder\ Environmental\ Investment_{jt} \\ & + \sum_{k=1}^{3} \beta_{4k} Firm_{ijt}^{k} + a_i + \gamma_t + \varepsilon_{it}, \end{aligned} \tag{1}$$

where i denotes firm, t denotes time (i.e., year), j denotes region (Länder), and k denotes the number of different firm-level variable controls. The dependent variable *Performance* represents the innovation performance of firm i in region j at time t, proxied by its intangible fixed assets. *R&D dummy* is a binary variable set to one if a firm invested in R&D and zero otherwise. *Länder Environmental Investment* measures the amount each region spends on diverse types of EPIs. $Firm_{ijt}^{k}$ captures a number ($k = 3$) of firm characteristics such as firm age, fixed assets, and number of employees. Those variables are discussed in the work by Andries and Czarnitzki (2014), Kalay and Lynn (2015), Protogerou et al. (2017), and Yildiz et al. (2021) as determinants of firm innovation performance. Finally, ε denotes an idiosyncratic error term, while α_i and γ_t denote the firm- and time-fixed effects, respectively.

TABLE 1 | Variable definition.

Variable name	Variable description	Source
Dependent variables		
Firm innovation performance	Intangible fixed assets are listed in the balance sheet account. Intangible fixed assets include all intangible assets such as formation expenses, research expenses, goodwill, development expenses, and all other expenses with a long-term effect.	ORBIS
Independent variables		
Business cluster	A firm's membership in a cluster is based on the analysis of the authors, see Research Design Section and Appendix S1. Dummy variable (equals 1) indicating that a firm is located in a recognized business cluster. Dummy variable (equals 0) indicating that a firm is not located in any recognized business cluster.	DESTATIS and ORBIS
Total regional environmental protection investments	Total investments in environment by all firms in each Länder. The total investment sums up investments on waste management, wastewater management, noise and vibration protection, air pollution control, species and landscape protection, protection and remediation of soil, ground and surface water, and climate protection.	DESTATIS
Regional waste management investment	Investments in waste management by all firms in each Länder. This is one of the eight subcategories of Total regional environmental protection investments.	DESTATIS
Regional climate protection investments	Investments in climate protection by all firms in each Länder. This is one of the eight subcategories of Total regional environmental protection investments.	DESTATIS
Share spillover (Länder level)	A ratio of the number of firms that are part of a cluster in a Länder, over the total number of firms in a Länder.	ORBIS and author's calculation
Share spillover (city level)	A ratio of the number of firms that are part of a cluster in a city, over the total number of firms in the city.	ORBIS and author's calculation
R&D dummy	Dummy variable that takes the value of 1 if a firm has positive R&D expenditure and 0 otherwise	ORBIS
Control variables		
Firm age	The age of a firm calculated since the year when the company was incorporated.	ORBIS
Fixed assets	Fixed assets are company-owned, long-term tangible assets, such as forms of property or equipment.	ORBIS
Number of employees	The total number of employees of a company.	ORBIS

(Continues)

TABLE 1 | (Continued)

Variable name	Variable description	Source
MNE	Dummy variable (equals 1) indicating that a firm is a multinational enterprise. Dummy variable (equals 0) indicating that a firm is a domestic firm.	ORBIS
Export revenue	The earnings of a company that are generated through the export of goods or services.	ORBIS

In terms of regional EPIs, we use *total EPIs* of a state (Länder). These are the sum of regional EPIs in eight environmental subcategories, including (1) waste management, (2) wastewater management, (3) noise and vibration protection, (4) air pollution control, (5) species and landscape protection, (6) protection and remediation of soil, (7) ground and surface water, and (8) climate protection by all firms in each Länder. We are able to access comprehensive data for two of these subcategories at the regional aggregate, namely, *regional waste management investments* and *regional climate protection investments*. Hence, by using these two, we are able to delve into a more detailed analysis regarding the impact of different types of regional EPIs in Germany. Thus, we use three regional level variables to capture the heterogeneity in different EPIs. Academic work on this topic has been challenging due to the lack of information on regional EPIs over time. The three regional environmental variables we use are available for nine consecutive years from 2009 to 2017. The data sources for the EPIs made by firms in each Länder are listed in Appendix S2.

The second empirical model examines the effect of two conditioning factors (R&D engagement and regional EPIs) on the relationship between the cluster membership and firm innovation performance. The modeling for testing Hypothesis 2 is as follows:

$$\begin{aligned} Performance_{ijt} &= \beta_0 + \beta_1\ R\&D\ dummy_{ijt} + \beta_2\ L\ddot{a}nder\ Environmental\ Investment_{it} \\ &+ \beta_3\ Cluster_{ijt} + \beta_4 R\&D\ dummy_{ijt} * L\ddot{a}nder\ Environmental\ Investment_{jt} \\ &+ \beta_5 R\&D\ dummy_{ijt} * L\ddot{a}nder\ Environmental\ Investment_{jt} * Cluster_{ijt} \\ &+ \sum_{k=1}^{3} \beta_{6k} Firm_{ijt}^{k} + a_i + \gamma_t + \varepsilon_{it}, \end{aligned} \tag{2}$$

$Cluster_{ijt}$ is a dummy that is set to 1 if a firm belongs to a cluster and to 0 otherwise (based on geographical proximity [cities/municipalities] and industrial specialization for 80 business clusters in Germany as explained in Section 3). Here, we extend the previous estimation approach and allow for triple interaction between R&D engagement, cluster membership, and regional EPIs. This enables us to model statistically the complex relationship of these three variables and their impact on firm innovation performance.

The third empirical model focuses on firms that do not engage in R&D. In this empirical approach, we exclude from the estimation sample all firms that conduct R&D investment. We try to estimate the potential spillover effect on innovation of non-R&D firms within business clusters that arises from cluster size (share spillover) in a regional location (*Länder* or *city*). The following augmented specification is used:

$$\begin{aligned} Performance_{ijt} &= \beta_0 + \beta_1\ Share\ spillover_{jt} \\ &+ \beta_2\ L\ddot{a}nder\ Environmental\ Investment_{jt} \\ &+ \beta_3\ Cluster_{ijt} + \beta_4 Share\ spillover_{jt} * Cluster_{ijt} \\ &+ \sum_{k=1}^{3} \beta_{5k} Firm_{ijt}^{k} + a_i + \gamma_t + \varepsilon_{it}, \end{aligned} \tag{3}$$

In this model, for the share spillover, we use two different geographical locations: (a) *Länder* and (b) *city*. Following the work of Song and Son (2020), we define the variable *Share spillover* (Länder level) as the ratio of the number of firms in a Länder that are part of a cluster over the total number of firms located in a Länder. While *Share spillover (city level)* is defined as the ratio of the number of firms that are part of a cluster in a city over the total number of firms located in a city. The interaction term between share spillover and business clusters is included to test whether non-R&D firms who are cluster members and are in close proximity to a larger pool of member firms in business clusters experience an increase in their innovation performance.

For the robustness of our results, we include two variables—MNE and export revenue—in our baseline models, and the overall result did not change (these results are available upon request). The data sources for all firm-level and region-level variables used in our study are noted in Table 1.

3.2 | Descriptive Statistics

Table 2 provides the descriptive statistics for the variables used in our analysis.

We also present descriptive statistics for both non-R&D (Table 3) and R&D firms (Table 4). There are significant differences in the summary statistics between the two groups of firms for all variables. Specifically, for non-R&D firms, there are 205,286 observations while the figure for R&D firms is only 2536 observations. On average, the innovation performance is found to be significantly higher for R&D firms. Similarly, such firms are on average older than their non-R&D counterparts, with their average age values being 51 and 25, respectively. Also, *fixed assets* values of R&D firms are found to exponentially exceed those of non-R&D ones. Interestingly, around 30% of the firm-year observations of R&D firms in our sample are part of business clusters, compared to only 5% for non-R&D ones that are located in business clusters. For the *MNE* variable, the figures show that 79% of the firm-year observations of the R&D firms are found

TABLE 2 | Descriptive statistics.

Variables	Observation	Mean	SD	Min	Max
Innovation performance	207,820	20,950	662,688.9	0	76,100,000
R&D dummy	207,820	0.012	0.109	0	1
Share spillover (Länder level)	207,820	0.051	0.123	0	0.66
Share spillover (city level)	207,820	0.052	0.137	0	1
Total environmental protection investments	207,820	657,807	388,163.5	8723	1,455,419
Waste management investments	207,820	97,796	85,167.05	84	370,527
Climate protection investments	207,820	223,704	149,981.8	2277	618,443
Firm age	207,820	25.67	26.772	0	651
Fixed assets	207,820	107,488	2,074,368	0	314,000,000
No. of employees	207,820	468	5769.663	1	642,300
Business cluster	207,820	0.048	0.2142	0	1
MNE	207,820	0.16	0.37	0	1
Export revenue	207,820	14,597	649,541	0	179,000,000

TABLE 3 | Descriptive statistics (R&D intensive = 0).

Variables	Observation	Mean	SD	Min	Max
Innovation performance	205,284	5150.70	90,990.48	0	13,300,000
Share spillover (Länder level)	205,284	0.05	0.12	0	0.66
Share spillover (city level)	205,284	0.05	0.14	0	1
Total environmental protection investments	205,284	657,000	388,000	8723	1,460,000
Waste management investments	205,284	97,674.71	85,248.57	84	371,000
Climate protection investments	205,284	224,000	150,000	2277	618,000
Firm age	205,284	25.37	26.09	0	441
Fixed assets	205,284	58,843.30	596,000	0	54,100,000
No. of employees	205,284	297.99	2418.30	1	209,000
Business cluster	205,284	0.05	0.21	0	1
MNE	205,284	0.16	0.37	0	1
Export revenue	205,284	14,777.85	654,000	0	179,000,000

to be multinational enterprises, as opposed to only 16% for the non-R&D ones.

Table 5 shows correlations for all our variables used in the empirical analysis. The correlation coefficients are relatively low, and therefore, multicollinearity appears not to be a likely statistical consideration in our analysis.

4 | Results

Our results suggest that R&D firms are benefiting in terms of higher innovation performance in regions that have higher EPIs. We also show the channels behind the cluster—firm innovation relationship, namely, R&D engagement of constituent firms in business clusters and heterogeneous regional EPIs in each state (Länder). In addition, we provide evidence for conditions for non-R&D firms to enhance their innovation performance in the context of cluster ecosystems.

For all estimation models, we exploit the longitudinal dimension of the dataset and estimate the econometric specifications using linear regressions with firm- and year-fixed effects. For each one of the three models, we focus on three variables suited to measure EPIs by German regions (Länder) and hence present three columns of the same specifications.

TABLE 4 | Descriptive statistics (R&D intensive = 1).

Variables	Observation	Mean	SD	Min	Max
Innovation performance	2536	1,300,000	5,800,000	0	76,100,000
Share spillover (Länder level)	2536	0.05	0.10	0	0.66
Share spillover (city level)	2536	0.11	0.22	0	1
Total environmental protection investments	2536	732,000	378,000	8723	1,460,000
Waste management investments	2536	108,000	77,681.44	84	371,000
Climate protection investments	2536	240,000	134,000	2277	618,000
Firm age	2536	51.00	54.28	0	651
Fixed assets	2536	4,050,000	1,760,000	160	314,000,000
No. of employees	2536	14,231.64	45,426.79	2	642,300
Business cluster	2536	0.30	0.46	0	1
MNE	2536	0.79	0.41	0	1
Export revenue	2536	0.000	0.000	0.000	0.000

TABLE 5 | Correlation matrix.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) R&D dummy	1									
(2) Share spillover (Länder level)	−0.0005	1								
(3) Share spillover (city level)	0.0496	0.8911	1							
(4) Total	0.0212	−0.1320	−0.1181	1						
(5) Waste management	0.0128	−0.2071	−0.1882	0.6192	1					
(6) Climate protection	0.0122	0.1604	0.1416	0.7823	0.2289	1				
(7) Firm age	0.1051	−0.0611	−0.0391	0.0627	0.0543	0.0189	1			
(8) Fixed assets	0.2110	0.0022	0.0246	0.0128	0.0010	0.0122	0.0404	1		
(9) No. of employees	0.2651	0.0005	0.0502	0.0187	0.0080	0.0147	0.0785	0.7198	1	
(10) Business cluster	0.1326	0.3756	0.4642	−0.0439	−0.0707	0.0546	0.0202	0.0594	0.0866	1

Furthermore, for the third model (Equation 3), we have created two measures of the spillover magnitude. This calculation includes only non-R&D firms. Accordingly, we remove from the sample all the R&D firms to identify which conditions enhance innovation performance in the context of cluster ecosystems for non-R&D firms. The first measure accounted for the proportion of the region's (Länder) firms that belong to cluster ecosystems, while the second captured the same information at the much more geographically restricted city level. Here, the implicit assumption is that firms operating in a business cluster can indirectly affect the performance of other firms in the same region or city.

Results for Hypothesis 1: the link between R&D intensity and innovation performance in the context of regional EPIs.

We present our results for the first model in Table 6, which shows the R&D dummy variable with the strongest statistically significant effect for all three types of regional environmental investments. In particular, when we use *total regional environmental investments* (Column 1, Table 6), we find that a firm that engages in R&D experiences a 71,468 USD increase in its intangible assets. We find this effect to be highly statistically significant at the 1% level and to be in line with the existing literature (Iammarino et al. 2009; Miotti and Sachwald 2003) that R&D activities have a large and significant impact on a firm's innovation performance. We also found that regional EPIs have a negative and highly statistically significant effect on innovation performance for the firms that do not engage in R&D. This effect is found to be rather small in magnitude; an increase of 1000 USD in regional EPIs was found to cause an 8 USD drop

TABLE 6 | Fixed effect regression (Hypothesis 1)

Dependent variable: Intangible assets	(Total)	(Waste management)	(Climate protection)
R&D dummy	71,468.9***	199,213.9***	223,095.1***
	(12,587.9)	(10,190.6)	(10,673.0)
Regional environmental protection investments	−0.00834***	−0.000241	−0.00707*
	(0.00276)	(0.0125)	(0.00394)
R&D dummy * regional environmental protection investments	0.220***	0.376***	0.0313
	(0.0131)	(0.0504)	(0.0275)
Firm age	404.5***	367.5***	363.1***
	(110.2)	(113.4)	(111.1)
Fixed assets	0.244***	0.244***	0.243***
	(0.000586)	(0.000604)	(0.000591)
No. of employees	38.36***	38.43***	38.72***
	(0.275)	(0.284)	(0.277)
Constant	−16,477.7***	−21,533.9***	−21,294.6***
	(3434.0)	(3309.1)	(3249.8)
Observations	219,773	207,820	216,458
R^2	0.693	0.693	0.693
Firm-fixed effects	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes

Note: (1) Results with *total environmental protection investments* are presented in model (1). Results with *regional waste management investments* are presented in model (2). Results with *regional climate protection investments* are presented in model (3). (2) The dependent variable is intangible assets in all models; clustered standard errors at the firm level to account for heteroskedasticity. (3) A full set of year and industry dummies are included in models. (4) Monetary values are in US dollars and are deflated using GDP deflators. (5) Standard errors in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

in the value of a firm's intangible assets. This result, to some extent, follows the literature strand that firms' innovation performance may not be achieved if they are unable to offset the expenditure on technical innovations to meet the regional environmental requirements (Ford et al. 2014; Lee 2009; Skawińska and Zalewski 2009).

However, it is worth noting that such a negative effect is reversed when regional EPIs increase by one unit for firms that are also engaging in R&D. In this case, the effect is highly statistically significant, showing that an increase of a thousand USD in regional EPIs for firms that do R&D will result in an increase of 220,000 USD in intangible assets. This result shows that on the one hand, the effect of such spending on the value of a firm's intangible assets could be negative, which may be due to the fact that regions with higher environmental spending introduce distortions in their attempt to finance the related programs. This could potentially put firms off from "producing" intangible assets. On the other hand, regional environmental investments increase the intangible asset stock of those firms that are already engaged in R&D. This result supports the argument in the literature that R&D firms are more likely to collaborate with other R&D firms and then knowledge sharing takes place with that specific type of partners to encourage their innovation effort (Holloway and Parmigiani 2016). In addition, R&D sectors appear to be associated with more innovative activities coincided with a less negative environmental impact (Hilliard and Jacobson 2011; Ramanathan et al. 2017).

Firm-level controls, namely, fixed assets, number of employees, and firm age are found to have the expected sign (positive) and to be highly statistically significant. Each subsequent year of firm operations is found on average, to result in a 404,000 USD increase in intangible assets, while the hiring of an extra employee is found to yield 38,000 USD intangible assets, and finally, a 1000 USD increase in a typical firm's fixed assets is found to increase its intangible ones by 244 USD.

These results mostly hold for the two other columns of Table 6, which, respectively, present regional level *waste management investments* and *climate protection investments*. We find some degree of heterogeneity in the magnitude of the effect of regional EPIs on firm innovation performance, depending on the type of regional EPIs. Particularly, in Columns 2 and 3 of Table 6, we see that the individual effect of regional environmental investments for firms with no R&D engagement is still found to be negative but to be either not statistically significant (Column 2) or to exhibit a reduced level of significance of 10% (Column 3). Equally, the interaction between the R&D dummy and regional EPIs is found to be positive, albeit statistically significant only in the penultimate one. This could be interpreted as evidence that not all types of regional EPIs benefit firms engaged in R&D activities. In particular, regional investment in *waste management* increases an R&D firm's intangible assets by 376 USD, while *climate protection* seems to yield no additional benefits for a R&D firm's formation of intangible assets.

Overall, the results shown in Table 6 contain highly significant estimates and reasonable R^2 values, showing evidence that R&D firms outperform non-R&D ones, in terms of innovation performance in regions with higher investments in *total environmental protection* and *waste management*. The inclusion of firm- and time-fixed effects further increased our confidence for these estimates to control for potential endogeneity that might arise in our estimation.

Results for Hypothesis 2: mechanisms (i.e., R&D engagement and types of regional EPIs) behind the clustering–innovation relationship.

Table 7 presents the estimates for the second econometric model. In Table 7, we see in all three columns that engaging in R&D results in increasing intangible assets of firms, from 65,496 USD (total EPIs control) to 222,439 USD (climate protection investments control). As before, we find that different types of regional EPIs (except for Column 2) for non-R&D firms that are not part of business clusters have highly statistically significant and negative, albeit economically small effects on a firm's intangibles.

A new variable that we add is whether a firm is in a business cluster. As reported in Table 7, it is evident that belonging to a

TABLE 7 | Fixed effect regression (Hypothesis 2).

Dependent variable: Intangible assets	(Total)	(Waste management)	(Climate protection)
R&D dummy	65,496.0***	204,924.0***	222,439.2***
	(12,667.0)	(10,318.4)	(10,689.3)
Regional environmental protection investments	−0.00836***	−0.00263	−0.00881**
	(0.00289)	(0.0126)	(0.00417)
Business cluster	77,702.0***	26,382.4	53,379.3***
	(18,052.7)	(17,768.1)	(17,367.9)
R&D dummy*regional environmental protection investments	0.250***	0.277***	0.0708**
	(0.0141)	(0.0600)	(0.0299)
R&D dummy*business cluster*regional environmental protection investments (0, 1)	0.00108	0.0577	0.0152
	(0.00859)	(0.0455)	(0.0118)
R&D dummy*business cluster*regional environmental protection investments (1, 1)	−0.0994***	0.289***	−0.154***
	(0.0188)	(0.0887)	(0.0487)
Firm age	372.7***	406.7***	350.5***
	(110.7)	(113.8)	(111.5)
Fixed assets	0.244***	0.244***	0.243***
	(0.000587)	(0.000605)	(0.000591)
No. of employees	38.37***	38.43***	38.76***
	(0.275)	(0.284)	(0.277)
Constant	−19,711.7***	−23,574.1***	−23,515.2***
	(3595.3)	(3461.9)	(3397.8)
Observations	219,773	207,820	216,458
R^2	0.694	0.694	0.693
Firm-fixed effects	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes

Note: (1) Results with *total environmental protection investments* are presented in model (1). Results with *regional waste management investments* are presented in model (2). Results with *regional climate protection investments* are presented in model (3). (2) The dependent variable is intangible assets in all models; clustered standard errors at the firm level to account for heteroskedasticity. (3) The interaction terms between R&D dummy, business cluster, and regional environmental protection investment are included in all models. (4) A full set of year and industry dummies are included in models. (5) Monetary values are in US dollars and are deflated using GDP deflators. (6) Standard errors in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

business cluster is found to increase a firm's intangible assets but only when we controlled for *total regional EPIs* and *climate protection investments*. The magnitude of this effect is found to be the highest in the case of *total EPIs* (77,702 USD) and the lowest for *climate protection* (53,379 USD) among the statistically significant effects, as seen in Columns 1 and 3 of Table 7. In the literature, some empirical analyses have shown that networking activities are a major driver of innovation performance (Du and Vanino 2020; Mazzanti and Zoboli 2009) and environmental innovation requires stronger cooperative efforts with network partners (Foxon and Andersen 2009).

Being positive and statistically significant for all three columns, the interaction of a firm's R&D engagement and regional EPIs is found to verify our earlier results. The overall regional environmental effect is found to be positive for those firms that have engaged in R&D activities. Hence, this again indicates that regional EPIs, while possibly not having positive effects in terms of the acquisition of intangible assets for the average German firm, do have the desirable effects for those that engage in R&D.

The next two sets of interactions are between R&D status, participation in clusters and regional environment protection investments. For the first interaction between non-R&D firms that are in business clusters, the effect of *regional environment protection investments* on intangible assets is found to be not statistically significant in all three models. For the second interaction between R&D firms that are in business clusters, the effect of regional environment protection investments is found to be statistically significant for all three specifications, although the sign is found to vary from negative, when regional investments are aimed at *total environmental protection* and *climate protection*, to positive, when it is aimed at *Waste management*. The results highlight that the average R&D firm in a business cluster will be more comfortable and capable of investing in R&D related to *waste management* and hence can benefit from regional waste management investments to enhance their innovation performance. In other words, we have provided evidence that R&D engagement and regional investments on *waste management* act as conditioning factors in the relationship between the clustering and firm innovation.

As in the previous set of results, the firm-level controls are found to have the expected signs and magnitudes and are highly statistically significant. Overall, we are of the view that the results presented in Table 7 suggest that Hypothesis 2 is supported, albeit in a nuanced way. We find that, for some R&D firms that are both part of clusters and in regions engaged in *total EPIs* and *climate protection investments*, the results show a negative effect on the level of intangibles, while for the type of regional investments that are focused on *waste management*, the results show a positive effect on such levels. Put it another way, the crucial factor that determines the sign of this effect is the types of regional EPIs.

Results for Hypothesis 3: conditioning factors (i.e., cluster membership and spillover effects) for non-R&D firms to achieve higher innovation performance.

In Tables 8 and 9, we restrict our sample to firms that do not engage with R&D to discover conditions for non-R&D firms to achieve enhanced innovation performance in the impact of cluster ecosystems. Results in the topic for non-R&D firms have been ambiguous and fragmented and most of the samples are based solely on R&D innovators (Thomä and Zimmermann 2020). The results in our study will, therefore, provide a comprehensive discussion on the innovation performance of non-R&D firms with the spillover effects. In Tables 8 and 9, we see that for both definitions of spillovers (*Länder* or *city*), their effect is negative and statistically significant for the formation of a firm's intangible assets. In Table 8, we found that, for firms that are not part of a business cluster, a 1% increase in the number of business cluster firms relative to the total number of firms in their Länder will result in a reduction of intangible assets of non-R&D firms by between 57,771 USD (Waste management) to 66,656 USD (Climate protection). Furthermore, non-R&D firms experience a decrease in intangible assets performance when they are part of a business cluster. The effect varies from just above 57,000 USD to just below 64,000 USD for *climate protection* control and *waste management* control, respectively. Hence, being either part of a cluster or in proximity to geographical areas that are populated by higher numbers of other cluster constituents reduces the generation of intangible assets of non-R&D firms. But non-R&D firms gain substantially, between 97,780 USD and 112,652 USD in intangible assets formation, when two conditions take place simultaneously: (1) Non-R&D firms are part of a cluster ecosystem and (2) they are surrounded by an increasing number of other cluster firms in their location. That is, non-R&D firms appear to benefit in terms of innovative performance only when they are members of growing business clusters. In terms of regional investments, the effect of regional EPIs on the intangible capital formation of non-R&D firms is found to be positive and significant only when we control for *climate protection*.

In Table 9, we see that the above analysis mainly remains intact. The coefficients for the interaction term between Share spillover (city level) and business cluster in all three columns are positive and statistically significant, indicating that our specifications are valid. Overall, all the effects have the same sign, but their magnitudes are smaller. In particular, the spillover effects are more nuanced when the geographical area is smaller (city). A slight difference is that here the effect of all types of regional EPIs are not statistically significant.

Overall, we find empirical evidence that is consistent with Hypothesis 3. When non-R&D firms are part of a business cluster, and at the same time are surrounded by an increasing number of other cluster firms, they then experience higher intangible assets performance. This result is in line with the argument that firms in cluster ecosystems can be very attractive partners for firms that are spatially proximate due to access to pools of complementary resources (Isaksen and Onsager 2010; Rugman and Verbeke 2003). It could be said that for these firms, because they do not engage in one of the main factors driving intangible assets formation, which is R&D activities, they will need to satisfy two additional requirements, that is, participation in business cluster and geographical proximity to other firms located in clusters, in order to be able to create intangible assets. Thus, the result confirms that there are spillover effects on firm innovation performance of non-R&D firms belonging to business clusters and in geographical areas that are populated by higher numbers of such firms.

TABLE 8 | Fixed effect regression (Hypothesis 3—Länder level).

Dependent variable: Intangible assets	(Total)	(Waste management)	(Climate protection)
Share spillover (Länder level)	−60,898.0***	−57,771.6***	−66,656.5***
	(12,276.7)	(13,974.0)	(12,469.9)
Business cluster	−58,077.3***	−63,839.7***	−57,305.6***
	(7377.8)	(7857.5)	(7431.2)
Share spillover*business cluster	97,780.2***	112,652.9***	98,779.5***
	(20,845.5)	(22,956.0)	(20,998.4)
Regional environmental protection investments	−0.000431	0.00366	0.00210**
	(0.000732)	(0.00326)	(0.00105)
Firm age	−1905.5***	−2050.5***	−1919.9***
	(111.8)	(117.3)	(112.9)
Fixed assets	0.138***	0.140***	0.138***
	(0.000486)	(0.000502)	(0.000489)
No. of employees	11.20***	11.13***	11.20***
	(0.213)	(0.219)	(0.214)
Constant	45,820.6***	49,155.3***	46,153.6***
	(2538.3)	(2733.3)	(2563.5)
Observations	217,200	205,284	213,895
R^2	0.378	0.381	0.379
Firm-fixed effects	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes

Note: (1) Results with *total environmental protection investments* are presented in model (1). Results with *regional waste management investments* are presented in model (2). Results with *regional climate protection investments* are presented in model (3). (2) Share spillover is calculated at (Länder level). (3) R&D firms are excluded from the dataset. (4) The dependent variable is intangible assets in all models; clustered standard errors at the firm level to account for heteroskedasticity. (5) The interaction terms between R&D dummy, business cluster, and regional environmental protection investment are included in all models. (6) A full set of year and industry dummies are included in models. (7) Monetary values are in US dollars and are deflated using GDP deflators. (8) Standard errors in parentheses.
*$p<0.1$.
**$p<0.05$.
***$p<0.01$.

5 | Results Summary

It is useful at this point to summarize our key results. In the upper box, we show that regional EPIs, while possibly not having positive effects in terms of the acquisition of intangible assets for an average German firm, do have the desirable effects for those that engage in R&D (Hypothesis 1). We also find evidence that R&D engagement and regional investments on *waste management* act as conditioning factors in the relationship between the clustering and firm innovation (Hypothesis 2). In the lower box, we have provided evidence that non-R&D firms gain substantially in intangible assets formation, when two conditions take place simultaneously: (1) Non-R&D firms are part of a cluster ecosystem and (2) they are surrounded by an increasing number of other cluster firms in their location (Hypothesis 3). Again, we find that types of regional EPIs do matter for non-R&D firms to achieve higher levels of innovation performance. In particular, the effect of regional EPIs on the intangible capital formation of non-R&D firms is found to be positive and significant only when we control for *climate protection*.

Although it is important to be cautious when comparing the effect of different types of regional EPIs, our results do indicate some heterogeneity in the effect of sector-specific environmental investments on firm innovation. It seems that not all types of regional EPIs benefit firms engaged in R&D activities. In particular, regional investments in *waste management* increases an R&D firm's intangible assets. Also, in the context of a cluster ecosystem, we find that, for some R&D firms that are both part of clusters and in regions engaged in *waste management*, the results show a positive effect on the level of intangibles. Whereas the positive effect on such levels is shown for non-R&D firms that are in regions engaged in *climate protection investments*. Clearly, these results warrant further research and are perhaps indicative of sector-specific environmental investments in each country.

6 | Theoretical and Policy Implications

In this paper, we advance our understanding of the links between EPIs, cluster ecosystems, R&D performance, and firm innovation. We elaborate on the implications of our study below.

TABLE 9 | Fixed effect regression (Hypothesis 3—city level).

Dependent variable: Intangible assets	(Total)	(Waste management)	(Climate protection)
Share spillover (city level)	−12,100.8***	−11,399.2**	−12,774.3***
	(4451.6)	(4700.5)	(4511.6)
Business cluster	−52,759.4***	−55,840.1***	−52,604.1***
	(6871.1)	(7248.4)	(6920.2)
Share spillover * business cluster	17,725.9***	18,102.2***	18,212.4***
	(5787.6)	(6100.5)	(5859.7)
Regional environmental protection investments	−0.000776	0.00393	0.00136
	(0.000723)	(0.00325)	(0.00103)
Firm age	−1908.6***	−2057.7***	−1921.5***
	(111.7)	(117.2)	(112.8)
Fixed assets	0.138***	0.140***	0.138***
	(0.000485)	(0.000502)	(0.000489)
No. of employees	11.21***	11.14***	11.22***
	(0.213)	(0.219)	(0.214)
Constant	42,672.2***	46,186.6***	42,545.7***
	(2411.7)	(2547.7)	(2426.4)
Observations	217,200	205,284	213,895
R^2	0.378	0.381	0.378
Firm-fixed effects	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes

Note: (1) Results with *total environmental protection investments* are presented in model (1). Results with *regional waste management investments* are presented in model (2). Results with *regional climate protection investments* are presented in model (3). (2) Share spillover is calculated at city level. (3) R&D firms are excluded from the dataset. (4) The dependent variable is intangible assets in all models; clustered standard errors at the firm level to account for heteroskedasticity. (5) The interaction terms between R&D dummy, business cluster, and regional environmental protection investment are included in all models. (6) A full set of year and industry dummies are included in models. (7) Monetary values are in US dollars and are deflated using GDP deflators. (8) Standard errors in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

6.1 | Theoretical Implications

Our study contributes to the literature by theoretically developing a conceptual understanding of the interrelationships between regional EPIs, cluster membership, and R&D participation of firms in driving the formation of intangible asset. Our results build on recent literature to corroborate the fact that the innovation performance of R&D firms is more pronounced compared to that of non-R&D firms in regions with higher expenditure on EPIs. We also provide insights into how R&D firms are influenced by different types of regional EPIs to achieve higher levels of innovation performance.

Second, our conceptual framework extends insights from knowledge-based perspective (Hoskisson et al. 1999; Maskell 2001) in showing the role played by cluster ecosystems on firm innovation performance. We uncovered several underexplored channels through which cluster location influences firm innovation performance: (1) firm R&D engagement and (2) specific types of regional EPIs. Hence, we are able the reconcile the diverse empirical findings on the clustering–innovation relationship in the current literature.

Third, our study contributes to the literature on EPIs, cluster membership and firm innovation by examining particular conditions for non-R&D firms. Prior research offers some attempts to discover the role played by spillover effects on R&D firms to enhance their innovation performance (Laursen et al. 2016; Romijn and Albu 2002). Given that innovation can be developed without R&D activities, our study offers a nuanced perspective by uncovering two conditions for non-R&D firms to enhance their innovation performance, including (1) non-R&D firms are part of a cluster ecosystem and (2) they are surrounded by an increasing number of other cluster firms in their location. More importantly, we provide evidence that non-R&D firms need to meet these two conditions simultaneously to be able to gain innovation performance. Overall, in our conceptual framework, we show that not only firm efforts but also environmental and locational aspects play a role in improving firm performance over time.

6.2 | Policy Implications

The results from this paper have important policy implications with regard to the support for firms in the various German states (Länder) and cluster ecosystems. First, the results in our study show that regional EPIs are crucial for R&D firms to achieve their higher innovation performance. Policymakers can therefore consider the plan to establish *eco-districts* (Weber and Reardon 2015) that are seen as sites of innovation for their member firms to pursue greater environmental sustainability and innovative activities.

In addition, our findings show that cluster ecosystems can bring conditions favorable to firms if some specific requirements are met, for example, specific types of regional EPIs for R&D firms or the vicinity of an increasing number of other business cluster firms for non-R&D firms. Therefore, regional and central governments with an interest in boosting firm innovation performance should think of the types of supported firms (engaged in R&D and members of clusters) that contribute largely to the dynamics of regional development (de Noronha Vaz et al. 2015). Relevant policies should be in place to improve cluster ecosystems by focusing on such conditioning factors and to provide strong incentives for firms in the regions to engage in innovation enhancement.

More importantly, the results clearly imply some important implications regarding sector-specific environmental investments. We show that policymakers must carefully consider specific types of regional EPIs to design effective policies that foster environments conducive to enhancing firms' innovation performance. In the case of Germany, investments in *waste management* appear to create favorable conditions for R&D firms. Also, in the context of a cluster ecosystem, we find that for some R&D firms that are both part of clusters and in regions engaged in *waste management*, the results show a positive effect on the level of intangibles. However, the positive effect on such levels is shown for non-R&D performers that are in regions engaged in *climate protection investments*. This means that policymakers should consider particular environmental protection programs that are implemented regionally. One would propose that in the case of Germany, those policymakers that intend to raise revenue to fund the provision of public goods would do well to encourage R&D firms in the regions to invest in *waste investment* and non-R&D firms in the regions to invest in *Climate Protection* to increase the innovation performance of firms in the regions.

7 | Conclusions

We set out to explore the roles played by different regional EPIs in Germany, cluster membership and the intensive margin of firm innovation performance. Our results confirm that German regions with higher EPIs enable R&D firms to generate higher intangible assets than their non-R&D counterparts (Hypothesis 1). Furthermore, we find that R&D engagement by firms located in business cluster and the specific types of regional EPIs are two mechanisms that yield different effects on the relationship between the cluster membership and firm innovation performance (Hypothesis 2). This is a very important result that, to our knowledge, had not been hitherto documented in the literature.

Another key result is related to spillover effects for the innovation performance of non-R&D firms belonging to business clusters and at the same time, in geographical areas that are populated by higher numbers of business cluster firms (Hypothesis 3). In the case that only one of these two conditions holds, then the innovation performance of non-R&D firms is reduced. Our explanation for this result is that (as we demonstrated in Hypothesis 1) the most important determinant of innovation performance is R&D activity. Hence, for firms that do not engage in R&D activity, the route to a successful innovation performance has very high requirements, namely, to be part of a cluster and at the same time in the vicinity of an increasing number of other business cluster firms.

7.1 | Limitations and Future Research

It is important to note that our paper is not free from limitations and there are potential extensions that could be addressed by future research. First, it is worth noting that our choice to focus on one developed country may limit the generalizability of our findings to other contexts. Developing countries may have different institutional and regulatory environments that could impact the behaviors of firms in clusters. Hence, future research could investigate how EPIs affect firms' innovation performance in the context of industrial clusters with broader sampling frames across countries, which would in turn improve the external validity of our results. This would require disaggregated data availability not only for different types of firms in cluster locations but crucially the different levels of environmental protection policies across heterogeneous regions within a country. These aspects would then allow future studies to uncover the generalizability of our results. However, we would expect the magnitude of coefficients to potentially differ depending on the country of investigation, which could then lead to policy recommendations that can be more tailored to the specific environmental policy but also the level of support from the government.

Second, we based our classification of "cluster" and "noncluster" firms on a comprehensive map and lists of recognized clusters sourced from the government website. In the future, one could use geolocation data to identify more precise cluster locations that add even greater precision to measuring clusters. This would allow more fine-grained analysis of clusters that are associated with higher NACE (digit) industries and capturing network effects from one cluster to another cluster.

Third, in terms of the results for non-R&D firms, we believe that our research provides some insights related to two conditions (i.e., cluster membership and spillovers effects) for those firms. We understand that these interesting results warrant further investigation by future research. For example, practical challenges or potential trade-offs for non-R&D firms operating under stringent environmental policies can open up a new line of enquiry in terms of research that investigates conditions for non-R&D firms to achieve innovation performance. Another limitation related to results for non-R&D firm is the use of the variable *share spillover*. In particular, we use a relatively coarse though widely applied indicator; the ratio of the number of firms in a region that are part of a cluster over the total number of firms located in the region. Future studies may address this limitation with improved data that can somehow capture the *share spillover* effect more accurately.

Lastly, we also highlight the importance of sector-specific environmental incentives for policymakers to design and implement effective policies. Future research may adopt a qualitative approach to investigate the behaviors of firms in terms of sector-specific environmental incentives and innovation practices. One could perhaps build on the existing econometric studies in the literature by interviewing managers to gain further insights into the mechanisms through which cluster firms invest in environmental protection and enhance innovation performance, in order to discover what are the key drivers of the relationship.

Endnotes

[1] The Supporting Information includes Appendix S1 (Graph S1: German business clusters map; Graph S2: business clusters in and around the city Berlin; Table S1: German business clusters list) and Appendix S2 (sources for data on regional EPIs).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.