

## **SPATIAL EMBEDDEDNESS, BRANCH CONFIGURATION, AND STRATEGIC DEPLOYMENT IN GERMAN WIND ENERGY: MANAGEMENT AND REGIONAL PLANNING IMPLICATIONS**

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*This article examines how the spatial configuration of corporate branches shapes strategic deployment patterns in the German wind energy sector and why these patterns matter for management and regional planning. The analysis draws on the published spatial evidence reported for the German market over 2000–2019, using the turbine-level MaStR registry and branch-location information for Enercon, Nordex Group, Siemens Gamesa Renewable Energy (SGRE), Vestas, and GE Wind Energy. Rather than presenting a new causal dataset, the manuscript develops a management-oriented synthesis of that empirical base in order to clarify the strategic meaning of branch configuration, firm embeddedness, and operational geography. The central analytical measure is a localization coefficient comparing each firm’s installed capacity within branch-centered distance bands to its national installed-capacity share. The evidence supports three consistent descriptive conclusions. First, knowledge-generation sites and installed capacities are positively co-located in the German wind sector. Second, the strength and meaning of co-location depend on embeddedness: embedded firms such as Enercon and Nordex display the strongest short-range alignment between R&D, headquarters, and installed capacity, while foreign firms display the highest co-location at production sites rather than innovation units. Third, the 50-km band emerges as the most decision-relevant range for localized coordination and short-cycle learning. For embedded firms, 50-km co-location coefficients for R&D rise from 2.08 to 2.38 for Enercon and from 1.60 to 2.09 for Nordex between 2000–2009 and 2010–2019, whereas Vestas records values near zero for R&D at the same radius. Taken together, these findings clarify how branch-location strategy, territorial embeddedness, and regional innovation systems shape operating conditions and policy choices in complex renewable-energy industries. The article concludes with measured implications for branch placement, cluster-oriented industrial policy, and medium-scale regional planning.*

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## INTRODUCTION

Location is not only a geographical fact; it is a managerial decision with consequences for knowledge creation, operational coordination, market access, and long-run competitive positioning. In industries where complex engineering, iterative testing, and field-level troubleshooting remain central, the spatial relationship between innovation units and deployed products becomes especially consequential. Wind energy is a clear case. Turbine design, siting, installation, and maintenance depend on repeated feedback loops between engineers, production teams, service functions, and operating assets. For that reason, branch-location strategy in wind energy is best understood as both a management question and a planning question.

The German wind sector provides an especially informative setting. Germany combines a large domestic market, strong institutional support for renewable-energy deployment, and a corporate landscape that includes highly embedded domestic firms as well as globally organized foreign manufacturers. The sector is therefore well suited to evaluating whether branch configurations are anchored in local learning systems, in demand-led market access, or in some combination of both. Published evidence for Germany shows that the locations of company branches and installed wind capacity are not randomly distributed. Instead, they form a structured geography in which embedded firms are more tightly co-located with deployment than foreign firms at innovation sites, while foreign firms exhibit stronger co-location at production sites [13].

This article develops a management-centered synthesis of that evidence and addresses a practical gap between spatial-economic description and organizational interpretation. The published coefficients show where branches and installed assets overlap, but they do not by themselves specify what those patterns imply for branch design, coordination, and regional planning. By recasting the evidence in terms of branch function, embeddedness, and operating radius, the manuscript speaks directly to questions of organizational design and applied planning relevance [8, 9].

Rather than advancing unsupported causal claims, the article remains anchored in the empirical record reported for 2000–2019 and develops three substantive contributions. First, it clarifies the operational meaning of the localization coefficients reported for R&D departments, headquarters, and production sites. Second, it interprets firm differences through the lens of embeddedness and branch function. Third, it translates the empirical findings into concrete implications for corporate branch placement and regionally differentiated industrial policy. To strengthen interpretive validity, the discussion tests whether the same managerial reading is supported across radii, across branch functions, and across the two decadal periods. The result is a transparent, evidence-led synthesis that is theoretically coherent and practically relevant.

## CONCEPTUAL BACKGROUND

### *Tacit knowledge, embeddedness, and branch strategy*

A large body of research in economic geography and innovation studies argues that not all knowledge travels equally well. Codified knowledge can often be transferred through formal documentation, standardization, and remote coordination. Tacit knowledge, by contrast, is difficult to formalize and is learned through doing, using, and interacting. In the influential distinction developed by [7], STI knowledge is formalized, science-based, and more easily mobile, whereas DUI knowledge is practical, interaction-based, and strongly shaped by proximity.

This distinction is directly relevant to managerial branch decisions. When innovation depends heavily on tacit problem solving, locating R&D, service, and production activities near the operational environment can reduce coordination costs and improve learning quality. In such settings, branch placement becomes part of

the firm's knowledge architecture. Conversely, when firms rely more heavily on codified or globally sourced knowledge, local branch placement may be driven less by learning and more by market access, logistics, or administrative convenience [1, 2, 4].

The German wind sector exhibits this tension clearly. Wind-energy innovation contains both synthetic engineering knowledge and practical experiential learning. It is not a purely laboratory-based activity. Turbine design and performance optimization require feedback from installation and use, which makes localized interaction strategically valuable. Prior work on wind-energy innovation therefore emphasizes the continuing importance of tacit knowledge, engineering routines, and regional resource formation, even within increasingly globalized value chains [3, 6, 12, 14].

Firm embeddedness intensifies this logic. Embedded firms are those whose historical development, organizational routines, and market orientation are more tightly tied to a local or national environment. Such firms can internalize localized learning more effectively because managerial authority, technical experimentation, and production coordination are often nested within the same territorial system. In contrast, transnational or foreign firms may distribute those functions across countries, drawing on broader STI channels while locating some branches primarily in response to demand [5, 13].

#### *Why this is a management and planning problem*

The empirical question is not merely whether branches are near installed turbines. The deeper issue is how firms configure their branch networks to balance learning, coordination, and market reach. That is a classic management problem. At the same time, these firm decisions aggregate into regional development patterns, affecting where supply chains thicken, where specialized labor accumulates, and where local innovation systems become self-reinforcing. That is a planning problem.

An analysis centered on branch configuration in wind energy therefore belongs within management and planning research for three reasons. First, it examines strategic organizational choices regarding the placement of innovation, management, and production functions. Second, it evaluates how those choices interact with regional demand and localized knowledge systems. Third, it identifies practical implications for public and private decision makers concerned with cluster development, industrial specialization, and renewable-energy deployment. The combination of organizational strategy and territorial consequence gives the topic clear applied relevance for both scholars and decision makers. [8, 10]

## **DATA AND ANALYTICAL APPROACH**

### *Empirical base*

The empirical base consists of published spatial evidence for Germany's wind-energy market over 2000–2019. The underlying study uses the MaStR registry, which records the locations, capacities, and manufacturers of wind turbines installed in Germany since 1990. It combines those turbine-level records with branch-location information for five manufacturers that collectively account for almost the entire German market: Enercon, Nordex Group, Siemens Gamesa Renewable Energy (SGRE), Vestas, and GE Wind Energy [13].

The corporate profiles reported in the underlying evidence are strategically distinct. Enercon is the most strongly embedded domestic manufacturer and has roughly 40% of the German market. Vestas and SGRE each hold more than 20% of installed capacity, but their organizational geographies differ sharply. Nordex remains locally important but more internationally oriented than Enercon. GE has a smaller market presence,

approximately 6%, and does not maintain German headquarters or R&D centers in the reported branch set [13].

The study period is split into two equal phases, 2000–2009 and 2010–2019. This design makes it possible to evaluate whether the role of co-location changes as the industry matures. It also aligns the analysis with the period in which Germany’s renewable-energy expansion was shaped by the Renewable Energy Sources Act and sustained policy support for wind deployment [11, 13].

### *Localization coefficient*

The central analytical device is a branch-centered localization coefficient. For a given company branch and a given radius, the measure compares the firm’s share of installed capacity inside that radius with the firm’s share of installed capacity nationwide. In compact form:

$$L_n = \frac{C_n/G_n}{C_a/G_a}, \quad (1)$$

where  $C_n$  is the company’s installed capacity within radius  $n$ ,  $G_n$  is total installed capacity within radius  $n$ ,  $C_a$  is the company’s installed capacity nationwide, and  $G_a$  is total installed capacity nationwide. Values substantially greater than 1 indicate that the firm’s installed capacity is more concentrated around the branch than would be expected from its national market share. Values below 1 indicate relative spatial separation [13].

This formulation is especially useful for management analysis because it converts a diffuse spatial pattern into a decision-relevant signal. High values suggest that a branch is embedded in an operational territory where the firm deploys a disproportionate share of its products. The interpretation differs by branch type. High co-location around an R&D unit signals a tight learning loop. High co-location around a headquarters suggests strategic and managerial concentration. High co-location around a production site can indicate either local supply-side learning or strong demand-led market servicing.

### *Analytical framing used here*

The published evidence reports coefficients for three branch types: R&D departments, headquarters, and production sites. It also compares multiple radii (25, 50, 75, 100, 125, and 150 km). The present manuscript reinterprets these published values to answer a focused management question: which branch configurations are most consistently associated with localized deployment, and what does that imply for branch strategy and regional planning?

Because the published evidence is descriptive across two decadal windows rather than event-dated at the branch-opening level, the analysis presented here does not claim causal sequencing. Its contribution is instead interpretive and comparative. The argument is strengthened by three internal validation checks already present in the source evidence: comparison across branch types, comparison across six radii, and comparison across two decadal windows. Agreement across those descriptive lenses supports the managerial interpretation, even though causal identification remains outside the design.

## RESULTS

### *R&D co-location and the managerial significance of the 50-km radius*

Table 1 presents the published R&D co-location coefficients across the six reported radii. Three consistent descriptive patterns emerge.

First, embedded firms show the strongest R&D co-location at short distances. Enercon records coefficients of 2.21 and 2.66 at 25 km in the two respective periods, and 2.08 and 2.38 at 50 km. Nordex shows a comparable pattern, with 2.18 and 2.40 at 25 km and 1.60 and 2.09 at 50 km. In strategic terms, these values mean that the local operating environment around embedded firms' innovation units contains far more of the firms' installed capacity than national market shares alone would predict.

Second, the evidence points to 50 km as the most decision-relevant radius for localized coordination. For Enercon and Nordex, the 50-km values remain high and strengthen in the later decade. At larger distances, however, the coefficients drop materially, indicating that the strategic value of proximity weakens as the branch's immediate operating field becomes more diffuse.

Third, weakly embedded or foreign firms show a different innovation geography. SGRE still exhibits positive R&D co-location, but at lower short-range intensity than Enercon and Nordex, and its 50-km value falls from 1.73 to 1.37 in the later decade. Vestas shows near-zero values at 25 and 50 km in 2010–2019, indicating that its German R&D footprint is not embedded in the same local deployment pattern.

Table 1: R&D co-location coefficients by radius and period (adapted from published evidence)

Radius (km)	Enercon		Nordex Group		SGRE		Vestas	
	2000–2009	2010–2019	2000–2009	2010–2019	2000–2009	2010–2019	2000–2009	2010–2019
25	2.21	2.66	2.18	2.40	0.66	1.44	0.16	0.00
50	2.08	2.38	1.60	2.09	1.73	1.37	0.19	0.00
75	1.89	1.59	1.42	1.09	1.80	1.24	0.52	0.35
100	1.79	1.16	1.43	0.94	1.79	1.20	0.60	0.43
125	1.61	1.24	1.56	1.02	1.58	1.13	0.58	0.51
150	1.42	1.07	1.35	0.87	1.46	1.24	0.62	0.50

Note: Values greater than 1 indicate that the firm's installed capacity is more concentrated around the R&D site than would be expected from its national market share. The underlying coefficients are reported for the German market in [13].

The managerial implication is direct: when a firm's innovation model depends on localized experiential learning, persistent co-location at short radius can be interpreted as a strategic asset. The empirical concentration around 25 and 50 km is therefore more than a descriptive curiosity; across both periods, it consistently signals an organizational model that keeps design, testing, and deployment in close operational dialogue.

Figure 1 makes the same point visually. Enercon and Nordex peak sharply at short range and then fall as distance increases. SGRE remains above 1 across all reported radii in the later decade, but its profile is flatter and less concentrated. Vestas remains structurally disconnected from local deployment at innovation sites. For branch strategy, these profiles imply distinct organizational models rather than minor quantitative variation.

### *Headquarters, production sites, and branch-function asymmetry*

R&D is not the only branch function that matters. Management units and production units interact with the local environment differently, and the published coefficients show that this distinction is strategically important.

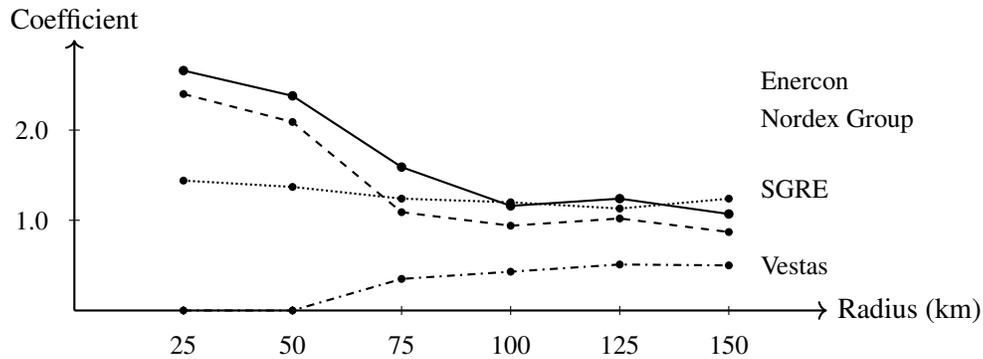


Figure 1: R&D co-location profiles in 2010–2019. The 50-km threshold separates the strongest embedded-firm concentration from the flatter or weakly embedded profiles.

Table 2 consolidates the 50-km coefficients for the three branch types. The 50-km radius is highlighted because it is where the clearest and most consistent management signal emerges in the published evidence. For Enercon and Nordex, R&D and headquarters are tightly aligned with installed capacity, and both firms also retain strong production-site co-location. The identical R&D and headquarters values reported for these firms should be read cautiously: they indicate overlapping territorial concentration in the published matrix, not necessarily two independently estimated spatial processes. Even with that caveat, the joint pattern supports an integrated branch model in which knowledge creation, management, and production remain territorially coordinated.

SGRE’s profile is more mixed. Its R&D and production-site coefficients remain above 1 at 50 km, but both weaken in the later decade, especially headquarters, which falls below 1. This is descriptively consistent with a transnational organizational structure in which managerial coordination is less strongly tied to the same local operating environment as deployment.

The foreign firms display the clearest functional asymmetry. Vestas records negligible R&D co-location at 50 km in 2010–2019, modest headquarters alignment, and very strong production-site co-location. GE, which has no German R&D or headquarters in the reported branch set, records exceptionally strong production-site co-location. Descriptively, this means that foreign firms are not absent from German industrial geography; rather, they participate through a different spatial logic. Their German footprint is organized more strongly around production and market servicing than around locally embedded innovation.

Table 2: 50-km co-location coefficients by branch type (adapted from published evidence)

Firm	Embeddedness profile	R&D 2000–2009	R&D 2010–2019	HQ 2000–2009	HQ 2010–2019	Production 2000–2009	Production 2010–2019
Enercon	Strongly embedded	2.08	2.38	2.08	2.38	1.47	1.96
Nordex Group	Embedded / internationalizing	1.60	2.09	1.60	2.09	1.60	2.09
SGRE	Transnational hybrid	1.73	1.37	1.79	0.97	1.79	1.02
Vestas	Foreign	0.19	0.00	1.24	0.60	2.16	2.06
GE Wind Energy	Foreign	–	–	–	–	1.84	2.74

Note: Dashes indicate that the published branch set reports no German headquarters or R&D center for GE Wind Energy. Values are taken from the 50-km rows of the published coefficient matrices reported by [13].

This asymmetry matters for management because it separates two different location logics. High R&D and headquarters co-location suggests a territorially integrated knowledge-and-control model. High production-site co-location without high R&D co-location suggests a demand-led service and manufacturing model. The German wind sector contains both patterns, and the comparative evidence indicates that firms adopt them

differently according to embeddedness, history, and strategic orientation.

#### *Temporal change and the maturity of the industry*

A second important result concerns temporal change. One might expect the importance of proximity to weaken as the wind industry matures and processes become more standardized. The evidence shows a more nuanced pattern.

For embedded firms, co-location weakens at larger radii over time but strengthens within the 50-km band. The reported evidence summarizes this clearly: at the most relevant short range for embedded firms, co-location coefficients rise from approximately 1.6–2.5 in 2000–2009 to 2.1–2.7 in 2010–2019 [13]. This means that industry maturation has not eliminated the value of local proximity. Instead, it has sharpened it. The broader spatial footprint becomes less decisive, while the immediate operational territory becomes more strategically important.

For management, this is an important descriptive finding. Mature industries are often assumed to move toward placeless efficiency, with knowledge becoming increasingly codified and organizational functions becoming more geographically separable. The German wind case shows that this assumption is only partially valid. In a complex engineering sector, maturity can reduce the value of broad spatial dispersion while increasing the value of short-range coordination between innovation, managerial oversight, and operational deployment.

## **MANAGEMENT AND REGIONAL PLANNING IMPLICATIONS**

#### *Implications for corporate branch placement*

The first implication concerns branch-network design. Firms operating in complex renewable-energy sectors should distinguish explicitly between the strategic functions of R&D, headquarters, and production sites. The German evidence suggests that embedded firms benefit from an integrated territorial model in which R&D and managerial control remain close to operating assets. This can improve learning speed, facilitate troubleshooting, and support the incremental innovation that characterizes engineering-intensive industries.

For firms with a more transnational structure, the evidence suggests that headquarters and production can be decoupled from locally embedded R&D. This is not necessarily a weakness. It may reflect a deliberate strategy in which innovation is coordinated through broader, multinational knowledge networks while production and service functions are located where the market is strongest. The key managerial lesson is that branch placement should follow branch function, not a uniform location rule.

A practical decision rule follows. When the organizational goal is rapid learning from field operations, firms should prioritize tight co-location between R&D and installed assets, ideally within a 50-km operating field. When the goal is logistics, servicing, and market response, production-site placement can be justified even in the absence of local R&D concentration. This is especially relevant for multinational firms entering large national markets where demand is strong but local innovation anchoring is weaker.

#### *Implications for industrial and regional planning*

The second implication concerns public planning and industrial policy. If policymakers treat all renewable-energy activity as if it responds to generic R&D incentives alone, they risk missing the territorial mechanisms through which learning actually occurs. The German evidence indicates that embedded regional innovation

systems matter most where tacit engineering knowledge is continuously recycled among firms, service functions, and installed assets.

This supports a planning approach focused on strengthening existing regional trajectories rather than relying exclusively on spatially blind innovation subsidies. For wind energy, policy is likely to be more effective when it reinforces local supplier networks, engineering-service ecosystems, and medium-distance coordination around established deployment territories. The empirical importance of the 50-km radius suggests that planning should pay close attention to subregional rather than purely national scales.

The evidence also has implications for medium-scale regions, especially in northwestern Germany. Regions that are not the largest metropolitan centers can still become powerful innovation territories when they combine deployment density, production capacity, and embedded firms. From a planning perspective, this means that policy should not focus only on major agglomerations or only on basic R&D expenditures. It should also cultivate specialized operational ecosystems in which local firms, suppliers, and technical labor pools can interact repeatedly and efficiently.

#### *Implications for JMPR's practice-oriented audience*

The value of the analysis for a practice-oriented readership lies in its ability to translate a technical localization metric into concrete managerial and planning guidance. [9] The manuscript contributes in three specific ways.

First, it shows how a simple but powerful localization metric can convert branch geography into a managerial diagnostic. Second, it demonstrates that embeddedness is not merely a contextual descriptor but a strategic condition associated with different branch configurations. Third, it connects firm-level branch decisions to region-level planning outcomes, making the evidence useful to both managers and policymakers.

## **CONCLUSION**

The German wind sector demonstrates that branch configuration is a consequential determinant of how innovation, management, and deployment are organized in space. Using published evidence for 2000–2019, this article shows that knowledge-generation sites and installed capacities are positively co-located, but that the strength and interpretation of co-location vary sharply by firm embeddedness and branch type. Because the analysis is based on reported coefficients rather than newly estimated models, its contribution lies in structured interpretation rather than causal identification.

The most important managerial result is that the 50-km radius functions as a practical operating threshold for embedded firms. Within that distance, Enercon and Nordex show strong and strengthening R&D co-location, a pattern consistent with a tightly coupled learning system even though the evidence remains descriptive rather than causal. The most important planning result is that regional innovation policy should reinforce territorially embedded engineering ecosystems rather than assume that broad, generic innovation support will produce the same effect everywhere.

For foreign firms, the evidence points to a different but equally coherent strategy: weaker local innovation anchoring paired with strong production-site alignment to demand. The broader lesson is that location strategy in complex renewable-energy industries must be matched to branch function, organizational embeddedness, and the knowledge requirements of the value chain. Future work should test these inferred mechanisms with event-dated branch changes, direct performance outcomes, and explicit measures of knowledge exchange.

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