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Research article

# Fostering just transition in the Italian automotive ecosystem: Firm-level insights on EV transition risks and pathways

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A B S T R A C T

The global automotive industry is undergoing a profound transformation driven by the shift to electromobility, which is reshaping supply chains and reallocating value from traditional European and U.S. suppliers toward emerging Asian firms specializing in batteries and electric components. This transition raises pressing concerns about job losses and economic disruption in established automotive regions, particularly in Europe, highlighting the urgent need for a "just transition." Despite its importance, fragmented stakeholder approaches and limited academic attention have hindered cohesive debate and actionable policy guidance. This study advances understanding by proposing a novel methodological framework that links firms' product portfolios and economic characteristics to their exposure to the technological and market risks associated with the green transition with an innovative composite indicator. The purpose is to cluster firms using an original dataset of Italian automotive suppliers to assess their occupational outlooks in the context of the electric vehicle transition. The findings provide new insights into the dynamics of the automotive ecosystem, identify key challenges for suppliers, and offer evidence-based recommendations to support a sustainable and equitable transition toward electromobility.

## 1. Introduction

The global automotive industry is a paradigmatic case of a "brown" industry undergoing a profound ecological transformation driven by the rise of electromobility (Cassetta et al., 2017; Santos and Davies, 2020). This transition requires not merely the substitution of internal combustion engines with electric powertrains, but a radical reconfiguration of vehicle architecture, production systems, core components, inter-firm dependencies, and the industry's underlying knowledge base (Jacobides, MacDuffie, and Tae, 2016; Sovacool et al., 2019; Perri et al., 2025).

This process is affecting the global and local supply-chains, whose value is moving from the "core" suppliers and countries that produce components related to the incumbent technology and are concentrated in USA and Europe, to those once considered to be in the "periphery" of the automotive perimeter and geography, namely the suppliers specialized in the electrical equipment and the battery development, that are mainly located in China and Asian countries (Schulze, Paul MacDuffie, and Täube, 2015).

Despite the emergence of innovative actors and the expansion of adjacent industries (Garcia et al., 2020) as well as the growth of green exports (Novaresio and Patrucco, 2025), serious concerns remain regarding the negative externalities of the EV transition on

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production and employment in the traditional automotive countries, especially in Europe, where the automotive industry is experiencing a persistent yet uneven stagnation in productive and market performance and is now also exposed the potentially adverse effects of controversial international trade policies (Llano et al., 2021). The shift to the EV paradigm reopens the long-standing "job vs environment" dilemma (Alic, 1997; Pichler et al., 2021a), as the destruction of "brown jobs" may not be fully compensated by the creation of "green ones" (Vandeplas et al., 2022), and the path towards a *just transition* remains highly contested (Galgóczi, 2020). While industry associations, consulting firms, and policymakers have produced divergent projections on employment effects, these estimates are often based on top-down approaches focused on OEMs or sectoral aggregates (Cassetta et al., 2017). As a result, the debate remains fragmented and lacks systematic firm-level evidence on how suppliers are differentially exposed to technological and market risks associated with mobility electrification. Moreover, while a growing body of literature examines the employment effects of electrification through macroeconomic projections, input–output models, or sectoral analyses, limited attention has been devoted to developing firm-level analytical frameworks capable of assessing suppliers' differentiated exposure to electrification risks. In particular, existing studies rarely link firms' product portfolios to their technological compatibility with EV architectures, nor do they systematically combine technological exposure with market-related vulnerabilities. This leaves a methodological gap in assessing how suppliers may experience heterogeneous labor impacts during the transition.

In this paper, we address this specific gap by developing a product-based technological risk index that measures suppliers' exposure to electrification according to the EV compatibility of their components. We then combine this indicator with firm-level economic and productivity variables to construct a composite assessment of technological and market vulnerability. We argue that this approach is crucial for fostering a more informed and grounded analysis of firms' vulnerabilities, particularly regarding potential job losses.

This study pursues this goal by analyzing an original dataset with micro data on the Italian automotive suppliers, which are classified by means of an unsupervised clustering approach according to three key dimensions of their activities, namely the product specialization and diversification, the financial and labor size and the labor productivity. The Italian supply-chain provides an ideal research setting, as Italy is among the European countries most exposed to the consequences of the EV transition. This is due to two main factors: (1) Italy hosts a deeply embedded local supply chain whose production remains heavily dependent on Stellantis (formerly Fiat Chrysler Automobiles), which has made only limited investments in new sustainable powertrain technologies; and (2) following a sharp decline in automotive assembly in Italy, and a significant reduction in employment at Stellantis (from 55,000 to about 40,000 over the past four years), the impact of technological transformation on suppliers — who currently employ around 160,000 people — will be decisive in shaping the future of the industry. Taken together, the high exposure of the Italian supply chain to the ongoing transition and its strong territorial differentiation make Italy a valuable case study for understanding broader trends across the EU.

Moreover, the Italian automotive industry is characterised by strong territorial specialisations and geographically embedded supply-chain structures, reflecting the uneven spatial organisation of productive activities across regions (Russo, 2008).

This paper contributes to the study of automotive supply-chains by classifying the Italian suppliers according to their resilience and labor vulnerabilities to the electrification of mobility. A novel indicator, the *technological risk index* is developed in the paper, which is designed to measure the level of technological risk suppliers face during the EV transition based on the types of components they produce.

This indicator serves two key purposes: first, it enables a preliminary analysis of firms in terms of their vulnerability or resilience to the ongoing technological transition in the sector, clearly separating market vs. technological drivers of potential job losses; second, it supports an ex-post analysis of clustering results to identify the types of firms most susceptible to technological or market risks. We argue that a technological risk index is necessary to complement other types of risk-assessment analysis, mainly developed in the financial realm (for a review, see Atwater, Gopalan, Lancioni, and Hunt, 2014), and exploration of supply-chain resilience (for a review, see Hosseini, Ivanov, and Dolgui, 2019), in order to discuss more rigorously the "just transition".

Our contribution is therefore primarily methodological, as it aims to operationalize firm-level exposure within the broader just transition framework. At the same time, by identifying heterogeneous vulnerability and adaptation profiles across suppliers, the study also contributes to ongoing debates in sustainability transitions and economic geography concerning differentiated transition pathways, firm-level resilience, and the uneven distribution of transition risks.

Additionally, the paper offers valuable insights for policy and strategy-making. By exploring and classifying the composition of the Italian automotive ecosystem, it identifies the specific challenges automotive suppliers must address during the transition to electromobility. Furthermore, it highlights the types of policy support that could be most effective in overcoming these obstacles, and thus reducing the risk of job losses in the sector.

The paper is structured as follows. Next section summarizes the main literature investigating the organizational and labor impacts of the EV transition in Europe and depicts the main traditional and emerging features of the Italian automotive ecosystems, providing a background analysis of the sector's industrial context and its response to the ecological transformations. Section 3 offers a preliminary description of the Italian automotive ecosystems by introducing a novel set of data on the suppliers and their productive activities, while the fourth section outlines and discusses the results of a cluster analysis with two levels of granularity, providing a summary of the policy implications. The last section concludes highlighting future avenues of research on the topic.

## 2. Theoretical framework

### *2.1. Toward a just transition: labor implications of the shift to electric vehicles*

The greening of the automotive industry has evolved from incremental improvements to internal combustion engine (ICE) technologies toward broader sustainability strategies aligned with the principles of a "just transition" (Calabrese, 2016; Basu and Ferreira, 2021; Newell and Mulvaney, 2013; Szabó and Newell, 2024). This perspective emphasizes not only decarbonization but also fairness, inclusivity, and the mitigation of adverse social impacts for workers and communities (Healy and Barry, 2017). Achieving sustainable mobility therefore requires deep socio-technical transformations involving firms, governments, and trade unions (Pichler, 2021b; Sovacool et al., 2020; Szabo, 2023).

The current transition toward battery electric vehicles (BEVs), widely regarded as the leading solution for decarbonizing road transport (Del Pero et al., 2018; Alochet and Midler, 2019), represents a significant departure from the incumbent ICE-based system. As a result, it is expected to reshape industrial structures, redistribute value among actors, and generate distributive and procedural justice concerns regarding who benefits and who bears the costs of restructuring (Galgóczi, 2019; Markkanen and Anger-Kraavi, 2019).

Changes in product architecture are likely to alter the automotive division of labor. The reduced complexity of BEV powertrains may weaken the importance of traditional system-integration capabilities while creating opportunities for new entrants and specialized suppliers (Schulze et al., 2015; Murmann and Schuler, 2022). Batteries, electronics, software, and digital infrastructures have become strategic sources of value creation, increasing the influence of new actors and reshaping industrial power relations (Jacobides et al., 2016; Ferloni, 2022; Li Pira and Moretti, 2024).

These transformations have important employment implications. Suppliers specialized in ICE-related components face declining prospects, while firms active in batteries, electronics, and software are expected to benefit (Wilhelm and Dolfsma, 2018; Li Pira and Moretti, 2024). Existing studies provide mixed evidence on the employment effects of electrification. Some anticipate net job creation through the expansion of battery and electronics supply chains (TE, 2017; Garcia et al., 2020; Kupper et al., 2020), while others emphasize uneven impacts across firms, regions, and countries, potentially exacerbating territorial inequalities (CLEPA, 2021; Galgóczi, 2023; Novaresio, 2024). Moreover, the lower labor intensity of EV production may reduce employment unless accompanied by large-scale reskilling and upskilling initiatives (Bauer et al., 2018; Cotterman, 2022).

Despite growing attention to just transition challenges, existing quantitative approaches largely rely on sector-level projections and rarely operationalize firm-level exposure to technological disruption. Moreover, they often overlook technological compatibility between firms' product portfolios and emerging EV architectures. Our study addresses this gap by introducing a product-based technological exposure indicator that complements market- and performance-based measures, enabling a more granular assessment of labor vulnerability during electrification.

### *2.2. Reshaping the italian automotive ecosystem: old criticalities and new frontiers*

Our focus is on the Italian automotive industry, which is considered a "core" country in automotive geography, although it is moving toward the "semi-periphery" in terms of competitiveness and productivity (Calabrese and Falavigna, 2022) due to a long-term industrial crisis exacerbated by persistent industrial and institutional inefficiencies, as well as current trade and technological challenges (Gaddi and Garbellini, 2023; Bubbico, 2023).

Moreover, the Italian automotive supply chain displays several structural "anomalies" that increase its vulnerability to the electromobility transition (Moretti and Zirpoli, 2022). It is highly dependent on a single producer—Stellantis—which accounts for about 50% of suppliers' turnover; highly fragmented, with around half of suppliers employing fewer than 50 workers; characterized by comparatively low R&D investment; and strongly reliant on German exports, despite some signs of diversification (Calabrese, 2022). These features shape firms' innovation capacity, competitiveness, and long-term strategies (Calabrese, 2020).

As supply chains increasingly adopt more sustainable and eco-friendly practices (Karaosman, Marshall, and Ward, 2025; Tribaldos and Kortetmäki, 2022), it is essential to identify which types of suppliers—distinguished by their product specialization, technological orientation, and economic characteristics—are most likely to benefit from, or be adversely affected by, the EV transition, offering precise insights for policy design.

Traditional industrial classifications such as ISIC[10], NACE[11], and ATECO[12] provide a standardized framework that enables access to large-scale data on production, employment, and trade. However, they typically classify automotive component manufacturers under code 29, while many critical and emerging suppliers are assigned to different sectors. As a result, analyses based solely on these classifications tend to focus narrowly on traditional automotive components, failing to capture the broader automotive ecosystem and its ongoing transformation. This limitation is particularly relevant as electrification and digitalization introduce new actors operating across multiple industries, including batteries, electronic modules, and EV charging infrastructure (Wittmann, 2017). Consequently, traditional classification systems are increasingly inadequate for capturing the full structure of the automotive industry and the technological risks associated with its transformation, highlighting the need for more granular and dynamic approaches.

Early contributions mapped automotive global value chains and the participation of small and medium-sized enterprises within them (Sturgeon et al., 2009; Memedovic, 2007). Building on this literature, Rossini et al. (2016) and Pavone and Russo (2017) developed more granular taxonomies of the Italian automotive supply chain based on firms' characteristics, strategic responses, business specialization, and geographic localization. Despite their valuable insights, these approaches rely on standard industrial classifications and survey-based evidence, limiting their ability to provide a comprehensive picture of the supply chain. Moreover, they do not explicitly link firms' technological and business characteristics to transition-related vulnerabilities and labor market implications.

Our study advances this literature by combining a comprehensive mapping of the Italian automotive ecosystem—based on a novel dataset that includes both traditional and emerging automotive firms—with a cluster analysis linking product portfolios, economic characteristics, and labor impacts. Specifically, it contributes by: (1) analysing the composition and geography of the supply chain, including emerging suppliers; (2) developing a novel classification based on products, financials, and employment characteristics; and (3) assessing labor profiles of electrification through an indicator that contrasts technological risks and market vulnerabilities across clusters.

In response to the challenges posed by the socio-technical transition toward electromobility (Chizaryfard and Karakaya, 2022), our research provides an updated picture of the Italian automotive ecosystem and identifies the types of firms most likely to face technological and market-related difficulties, offering policymakers evidence-based and firm-specific guidance.

Conceptually, this study does not aim to develop a new theory of socio-technical transitions or industrial restructuring. Rather, it contributes primarily at the methodological level by operationalizing the firm as the unit of analysis within the broader just transition debate. Specifically, we focus on how technological change interacts with firms' product portfolios and economic characteristics to generate differentiated exposure to labor risks. By integrating insights from sustainability transitions, industrial organization, and risk assessment literature, we develop a measurable framework capable of identifying heterogeneous vulnerability profiles among suppliers. This methodological focus allows us to connect macro-level transition narratives with micro-level industrial dynamics, while also contributing to ongoing discussions on differentiated firm trajectories and uneven transition outcomes within sustainability transitions.

## 3. Data and preliminary descriptive statistics

This study is based on an original dataset built within the Observatory TEA.[1] This database has been constructed and continuously refined over >30 years of research on the national automotive supply chain, and benefits from a long-standing collaboration with industry associations, trade unions, the chamber of commerce system, and regional and local administrations. The updating of the database relies not only on this institutional and industry network, but also on continuous monitoring activities, including participation in sectoral events and trade fairs, as well as the systematic consultation of relevant company websites and industry sources. This process allows for the identification of both traditional automotive suppliers and emerging actors involved in related activities along the extended supply chain.

For the purposes of this study, the Observatory database has been further integrated with firm-level economic and financial data retrieved from the AIDA database (Bureau van Dijk). In particular, variables such as revenues, employment, and value added have been matched at the firm level and combined with the product-based information collected within the Observatory.

This integration enables the construction of a unique dataset that combines detailed information on firms' product portfolios with standardized economic indicators, thus capturing both technological positioning and market characteristics.

The resulting dataset encompasses traditional and emergent Italian suppliers along the extended automotive supply-chain, which includes not only the activities strictly related to the manufacturing of the car's components, but also those associated to the production and refinery of raw materials involved in car production or the development and commercialization of goods and services in support of the new energy infrastructures and systems, especially those devoted to the EV charging.

This is the first feature that distinguishes our study from the others, as it does not rely on data solely related to firms classified as operative in the automotive industry by the national statistical institutes, namely those labeled with the ATECO code "29″, which represent just the 26% of our firms' population, but it accounts also for an additional 74% of firms traditionally classified under other economic categories, as Table 1 shows.

Our focus is thus on suppliers engaged in the production of components involved along the automotive supply-chain, from Tier 1 to Tier 3+, those specialized in the production and development of goods and services related to EV charging infrastructures and those affiliated to the aftermarket.

Suppliers are characterized according to the four main products they produce or sell, which are classified using a novel taxonomy based on their modular application within the vehicle and their compatibility with the electric powertrain. Summarized in Table 2, this taxonomy covers >100 automotive components and parts,[2] organized into 15 modules and assigned an EV fitness level (yes, no, or maybe) according to their compatibility with electric powertrains, based on the researchers' expert judgment.[3] This novel classification[4] constitutes the second major contribution of the study, as it enables a more granular analysis of the Italian automotive supply chain than existing standard classifications, which do not adequately capture the structure of firms' product portfolios.

The suppliers are also described in terms of geographical location, financial performance, employment, and productivity, using data retrieved from the Italian division of the European Van Dijck Bureau[5] on their regional location,[6] annual revenues recorded in 2022, number of employees recorded in 2022, level of productivity, captured by three distinct indicators related to the value added produced.[7]

[1] Osservatorio sulle Trasformazioni dell'Ecosistema Automotive, for further details, see: https://www.osservatoriotea.it

[2] Each component has been identified through online research on firms' websites and given a number uniquely assigning the component to a specific category (e.g. a firm producing filters features among its four components the component assigned to the category "air and liquid filters", which has been given the number "9" as a unique identifier).

[3] The evaluation of the components' compatibility with the EV involved the revision of an engineer with expertise in the automotive mechanics.

[4] The complete components' classification with all qualitative details is available upon request.

[5] The online archive used is AIDA, which provides granular information on the economic and financial features of all the Italian firms.

[6] The regional location of their headquarters.

[7] The three indicators of labor productivity are the following: 1) the valued added per worker, 2) the value added per total personnel cost (TCP) and 3) the value added per salaries and stipend (SS).

**Table 1**
The composition of the Italian automotive ecosystem based on the ATECO classification.

| ATECO CODE | Freq. Percent. |
|---|---|
| 29 "*Manufacture of motor vehicles, trailers and semi-trailers*" | 546 25,6% |
| Other ATECO categories | 1583 74,4% |
| Total | 2129 100.00 |

**Table 2**
The list of components included and their EV fitness.

| Category | Number of components | EV fitness |
|---|---|---|
| Auxiliary systems | 8 components | 5 EV-compatible, 1 EV-uncertain, 1 EV non-compatible |
| Electric traction motor | 7 components | 6 EV-compatible, 1 non-compatible |
| Electric components | 8 components | 8 EV-compatible |
| Energy Management System | 4 components | 3 EV-compatible, 1 EV non-compatible |
| Energy Storage System and fuel/energy delivery system | 8 components | 3 EV-compatible, 5 EV-non compatible |
| Internal combustion engine | 17 components | 15 EV-non compatible, 1 EV-uncertain, 1 EV-compatible |
| Power electronics | 4 components | 4 EV-compatible |
| Suspension Steering and Braking systems, wheels | 13 components | 13 EV-compatible |
| Transmission | 5 components | 3 EV-compatible, 2 EV-non compatible |
| Mechanics and Raw Materials | 5 components | 5 EV-compatible |
| Internal components and Coachwork | 5 components | 5 EV-compatible |
| IT and automation | 2 components | 2 EV-compatible |
| Engineering and Design | 2 components | 1 EV-compatible, 1 EV-uncertain |
| EV infrastructures and services | 4 components | 4 EV-compatible |
| Battery components | 9 components | 9 EV-compatible |

A preliminary analysis of the data highlights that nearly 70% of the suppliers are mapped in Piedmont (29%), Lombardy (28%) and Emilia-Romagna (Fig. 1) (12%), where the main Italian OEMs were born, and the most vibrant economic activities are located. We acknowledge that the sample is geographically concentrated and reflects the structural characteristics of the Italian automotive supply chain, including the prevalence of small and medium-sized firms and the significant share of suppliers not classified under ATECO code 29. These features may influence the clustering results, as regional and size-related characteristics are embedded in the data.

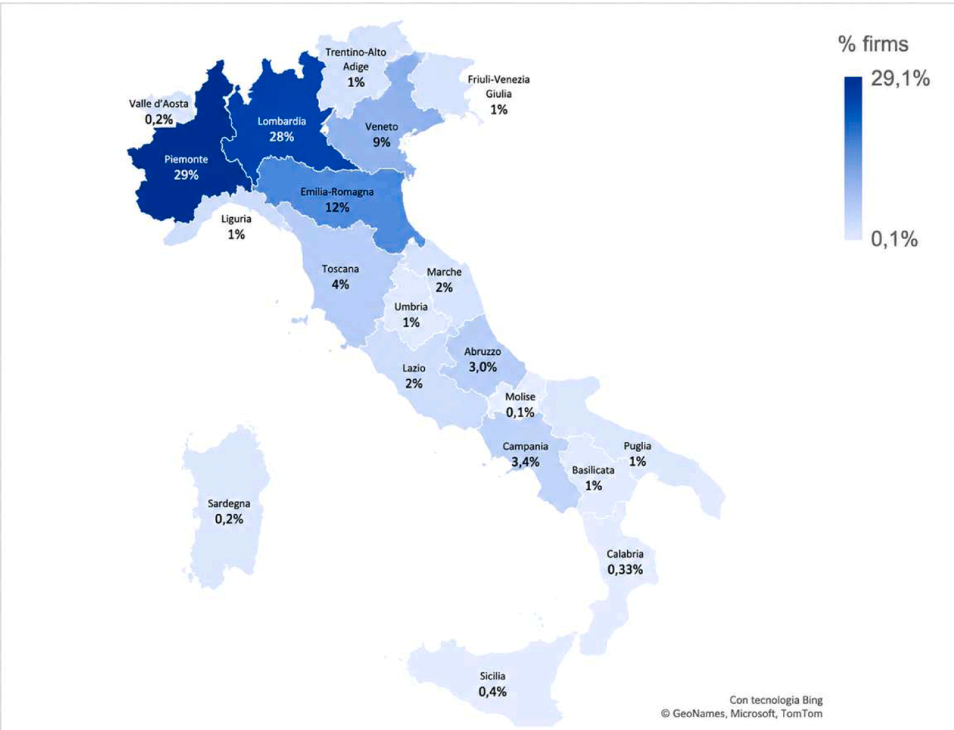


**Fig. 1.** The regional distribution of the Italian auto suppliers (source: author's elaboration).

**Table 3**
The features of the Italian automotive ecosystem by region (source: author's elaboration).

| Regions | Geo area | N° firms | % firms | Revenues (average value) | Employees (average value) | Added Value per Worker (A.V.PW) (average value) | Added Value per Salary and Stipend (A.V. SS) (average value) | Added Value per total personnel cost (A.V. TCP) (average value) |
|---|---|---|---|---|---|---|---|---|
| Abruzzo | South | 63 | 3% | 44,316,38 | 154 | 63,723 | −0,08 | −0,20 |
| Basilicata | South | 16 | 1% | 37,347,31 | 44 | 60,113 | 2,03 | 1,43 |
| Calabria | South | 7 | 0.33% | 2534,10 | 11 | 46,917 | 2,25 | 1,77 |
| Campania | South | 73 | 3.4% | 23,904,96 | 82 | 60,795 | 3,35 | 2,46 |
| Emilia-Romagna | Center | 256 | 12% | 30,830,59 | 90 | 83,902 | 2,43 | 1,70 |
| Friuli Venezia e Giulia | Northeast | 27 | 1% | 76,350,70 | 151 | 69,109 | 2,03 | 1,44 |
| Lazio | Center | 50 | 2% | 31,372,75 | 71 | 77,688 | 1,93 | - 26,92 |
| Liguria | Northwest | 19 | 1% | 53,105,85 | 122 | 107,127 | 2,47 | 1,82 |
| Lombardia | Northwest | 605 | 28% | 80,975,94 | 180 | 92,106 | 2,42 | 2,23 |
| Marche | | 33 | 2% | 21,494,65 | 89 | 61,281 | 1,89 | 1,33 |
| Molise | | 3 | 0.1% | 18,578,99 | 69 | 90,433 | 2,13 | 1,52 |
| Piemonte | Northwest | 619 | 29% | 43,073,52 | 128 | 73,889 | 2,16 | 1,73 |
| Puglia | South | 28 | 1% | 54,708,73 | 183 | 71,805 | 1,35 | 1,05 |
| Sardegna | South | 5 | 0.2% | 6519,60 | 44 | 18,294 | 67,87 | −736,41 |
| Sicilia | South | 9 | 0.4% | 17,893,10 | 58 | 47,807 | 2,32 | 1,73 |
| Toscana | Center | 74 | 4% | 25,956,73 | 78 | 71,253 | 22,63 | 22,02 |
| Trentino-Alto Adige | Northeast | 27 | 1% | 83,467,89 | 258 | 91,100 | 1,94 | 5,13 |
| Umbria | Center | 26 | 1% | 78,368,81 | 232 | 66,892 | 2,06 | 1,52 |
| Valle d'Aosta | Northwest | 4 | 0.2% | 27,125,91 | 98 | 93,153 | 2,36 | 1,70 |
| Veneto | Northeast | 184 | 9% | 35,791,42 | 100 | 75,423 | 2,20 | 2,57 |
| **Total/ National Average** | **Italy** | **2128** | **100%** | **51,094** | **129,39** | **79,419,22** | **3,1** | **0,24** |

Therefore, the findings should be interpreted as representative of the observed population and should be generalized with caution beyond the Italian case. At the same time, this composition reflects the actual structure of the Italian automotive ecosystem, which is characterized by strong regional concentration and fragmentation, and is therefore analytically relevant rather than a sampling bias in the strict sense.

The wealthiest suppliers in terms of revenues are in the Northeast, Umbria and Abruzzo, which are regions that host the biggest suppliers also in terms of employees. The most productive firms in term of labor and value added produced are concentrated in the

**Table 4**
The firms' distribution by revenues' category (source: author's elaboration).

| Revenues | Freq. Percent. Cum. |
|---|---|
| *< 1 mln* | 279 13,10% 13,10% |
| 1–5 mln | 480 22,55% 35,65% |
| 5–10 mln | 284 13,34% 48,99% |
| 10–25 mln | 428 20,10% 69,09% |
| 25–50 mln | 241 11,32% 80,41% |
| 50–100 mln | 167 7,84% 88,26% |
| 100–250 mln | 140 6,58% 94.83% |
| >250 mln | 80 3,76% 98,59% |
| not available | 30 1,41%. 100,00% |
| Total | 2128 100.00 |

**Table 5**
The firms' distribution by employees' category (source: author's elaboration).

| Employees | Freq. Percent. Cum. |
|---|---|
| 0 - 9 empl | 318 14,94% 14,94% |
| 10 – 49 empl | 821 38,56% 53,5% |
| 50–249 emp | 661 31,05% 84,55% |
| >250 empl | 322 15,12% 99,67% |
| Not available | 7 0,33% 100% |
| Total | 2128 100.00 |

Northern and Center regions, as Table 3 shows.

In more absolute terms, our data confirm that the Italian automotive supply-chain is characterized by a majority of small and medium-size firms, with 49% of the suppliers recording up to 10€ millions of revenues in 2022, 20% displaying revenues between 10 and 25€ millions and only one-third-of the suppliers declaring revenues higher than 25€ millions, as Table 4 shows.

On the other hand, Table 5 shows that 70% of the suppliers rely on a workforce between 10 and 249 employees, while 15% of them employ <10 or >250 employees.

## 4. Methodologies

### 4.1. The clustering approach

This study aims to develop a novel classification of Italian automotive suppliers based on their resilience to the EV transition. To this end, we employ an unsupervised clustering approach that integrates information on firms' production portfolios, labor productivity, and overall economic performance. The resulting clusters are subsequently analyzed through the lens of technological and market risk indices, allowing us to assess suppliers' occupational resilience to the ongoing transition. On this basis, firms are assigned a "labor impact profile" that reflects their potential vulnerability to EV-driven technological and market transformations.

To identify groups of similar firms, we implement a hierarchical clustering procedure based on the standard Gower distance (Gower, 1971). This metric is particularly well suited to our setting, as it accommodates the heterogeneous nature of the variables included in the analysis—combining categorical information (e.g., types of components produced or commercialized) with numerical indicators of firms' economic performance and productivity (i.e., revenues, employment, labor productivity, and value added). Importantly, Gower distance standardizes each numerical variable by its observed range, ensuring comparability across variables with markedly different units and dispersion (for further discussion of this methodological choice, refer to Section 1 in the Appendix).

Given the absence of strong theoretical or empirical grounds to assign differential importance to specific variables, an unweighted specification is adopted, thereby treating all dimensions of firm characteristics symmetrically and avoiding the introduction of arbitrary weighting schemes. Although some variables exhibit substantial skewness and dispersion, no logarithmic transformation is applied, as this would compress economically meaningful differences—particularly those related to firm size—and was found to reduce the interpretability and stability of the resulting clusters. Instead, the analysis relies on the intrinsic normalization properties of the Gower metric, complemented by data inspection to mitigate the influence of extreme values where necessary. We nevertheless acknowledge that, in mixed-data clustering, an unweighted specification may still reflect the composition of the dataset, including the relative presence of product-related versus economic variables. For this reason, the resulting partition should be interpreted as an exploratory classification of firms' profiles rather than as a mechanically weight-neutral representation of all dimensions.

Clusters are formed using Ward's linkage method, which minimizes the increase in within-cluster variance at each step of the aggregation process. The optimal number of clusters is primarily determined using the Calinski–Harabasz (CH) criterion, which indicates a four-cluster solution as the first best solution, which is further validated through the Duda–Hart (DH) stopping rule. The robustness of the clustering results is confirmed by the Adjusted Rand Index (ARI), which shows high to perfect agreement between Ward and average and complete linkage methods. This choice is further supported by silhouette analysis, which provides an additional validation of cluster cohesion and separation, confirming the adequacy of the four-cluster solution. We do not rely on alternative criteria such as the gap statistic, as these are typically designed for centroid-based methods (e.g., k-means) and Euclidean distances, and are therefore not directly comparable with the hierarchical clustering approach based on Gower distance adopted in this study. Taken together, these criteria consistently indicate that the four-cluster solution provides the most parsimonious and interpretable representation of the data. Full details of the tests conducted to determine the optimal number of clusters and to evaluate the robustness of the clustering model are provided in the Appendix.

### 4.2. The classification: technological risk, market risk and occupational outlook

Besides the clustering approach, this study provides three additional methodological contributions to classify Italian automotive suppliers within the broader context of the ongoing socio-technical transition toward electric mobility. First, it introduces a novel technological risk index that captures firms' exposure to technological disruption associated with the transition from internal combustion engine (ICE) technologies to battery electric vehicles (BEVs). The index assigns each firm a technological risk level—null, low, medium, or high—according to the EV compatibility of its product portfolio, thereby reflecting its positioning within the technological transition. Specifically, firms are classified based on the composition of their portfolios in terms of BEV-compatible (Xc), BEV-neutral (Xn), and BEV-non-compatible (Xnc) components (Table 6). The technological classification is based on expert judgment informed by engineering knowledge and validated through consultation with automotive specialists and should therefore be interpreted as an exploratory rather than fully data-driven measure. Formally, the technological risk index is defined as follows:

$$\text{Tech\_risk\_index\_i} = \begin{cases} \text{NULL} & \text{if } Xc > 0 \text{ and } Xn = 0 \text{ and } Xnc = 0 \\ \text{LOW} & \text{if } (Xc + Xn) > Xnc \\ \text{MEDIUM} & \text{if } Xnc > (Xc + Xn) \\ \text{HIGH} & \text{if } Xnc > 0 \text{ and } (Xc + Xn) = 0 \end{cases}$$

**Table 6**
Technological risk index based the product portfolio composition.

| Technological risk | Null | Low | Medium | High |
|---|---|---|---|---|
| **BEV compatible** | > 0 | > BEV-nc | < BEV-nc | = 0 |
| **Neutral** | = 0 | > BEV-nc | < BEV-nc | = 0 |
| **BEV non compatible** | = 0 | < BEV-c + BEV-n | > BEV-c + BEV-n | > 0 |

The underlying assumption is that firms specializing in components specific to incumbent ICE technologies are more exposed to technological disruption and the associated employment risks arising from the EV transition, whereas firms with more diversified product portfolios, particularly those including BEV-compatible components, are expected to display greater resilience, thereby highlighting heterogeneous adjustment pathways within the transition process.

Second, we construct a market risk index based on firms' economic characteristics, namely revenues, employment, value added, and labor productivity. This index captures firms' exposure to market-related risks associated with the transition to battery electric vehicles (BEVs). Firms are assigned to four market risk categories—null, low, medium, and high—by comparing their performance on each economic indicator with the corresponding national average, reported at the end of Table 3, which serves as the benchmark for the classification. Specifically, the thresholds used to define each risk category are summarized in Table 7. Similarly to the technological risk index, the market risk index should be interpreted as an exploratory proxy for firms' occupational vulnerability, reflecting their market capabilities and capacity to adapt to the structural changes induced by the EV transition. Formally, the market risk index is defined as follows:

$$\text{Market\_risk\_index}_i \begin{cases} \text{NULL} & \text{if economic indicators are more than 15\% above the national average} \\ \text{LOW} & \text{if economic indicators are aligned with the national average } (\pm 15\%) \\ \text{MEDIUM} & \text{if economic indicators are more than 15\% below the national average} \\ \text{HIGH} & \text{if these indicators are more than 40\% below the national average} \end{cases}$$

Similarly to the technological risk index, the market risk index serves as a proxy for firms' occupational vulnerability. In this case, vulnerability is linked to economic performance, which reflects firms' market capabilities and their capacity to adapt to structural changes induced by the EV transition. This dimension captures firms' adaptive capacity, a key determinant of their ability to respond to the structural pressures generated by sustainability transitions.

Third, we construct a composite indicator capturing firms' occupational outlook in the context of the EV transition. The indicator combines the technological and market risk indices to jointly reflect firms' technological positioning and economic resilience. Specifically, the occupational outlook indicator is derived through a rule-based classification that maps combinations of technological and market risk into different occupational outlook categories, as summarized in Table 8.

Table 8 helps clarify how the categorical combination of technological and market risks captures heterogeneous transition pathways beyond a simple "brown vs green" dichotomy. For instance, a supplier characterized by strong market positioning (low or null market risk) but limited technological diversification (high technological risk) may still face moderately negative or negative occupational outlooks, since solid current economic performance may not fully compensate for long-term exposure to technological

**Table 7**
Market risk index based on firm's features.

| Market risk | Null | Low | Medium | High |
|---|---|---|---|---|
| **Thresholds (relative to national average)** | **> +15% vs. national average** | **−15% to +15% vs. national average** | **−15% to −40%vs. national average** | **< −40% vs. national average** |
| **Revenues** | Large (>250€ mln) | Medium-Large (50–250 mln) | Small-Medium (<50 mln) | Small (<25 mln) |
| **Size (Employees)** | Large (>250 empl) | Medium (50–249 empl) | Small-Medium (< 50 empl) | Small (<10empl) |
| **Added Value per Worker** | High (>91.000) | Medium (≥67,000; ≤91,000) | Medium-Low (≥48,000; <67,000) | Low (< 48,000) |
| **Added Value per salaries and stipend (SS)** | High (≥4) | Medium (≥2.63; <4) | Medium-Low (≥1.86; <2.63) | Low (<1.86) |
| **Added Value per total personnel cost (TCP)** | High (≥0.27) | Medium (≥0.24; <0.27) | Medium-Low (≥0.144; <0.24) | Low (< 0.144) |

**Table 8**
Occupational outlook: categorical combination of technological and market risks.

| Technological risk/ Market risk | Null | Low | Medium | High |
|---|---|---|---|---|
| **Null** | Positive | Positive | Moderately positive | Moderately negative |
| **Low** | Positive | Moderately positive | Moderately negative | Negative |
| **Medium** | Moderately positive | Moderately negative | Moderately negative | Negative |
| **High** | Moderately negative | Negative | Negative | Negative |

obsolescence linked to ICE-related production. Conversely, firms with highly EV-compatible product portfolios (null or low technological risk) but weaker economic performance (high market risk) may display only moderately negative or negative occupational outlooks, reflecting the fact that technological alignment alone does not guarantee competitiveness, adaptive capacity, or long-term resilience. These examples illustrate how the proposed framework combines technological exposure and market vulnerability to identify differentiated transition trajectories across suppliers. These rules provide a transparent and replicable mapping from the two underlying indices to the final occupational outlook categories, ensuring that the classification is not based on qualitative interpretation but on explicit and consistent criteria. Importantly, the composite indicator is not constructed as a linear or weighted sum, but as a categorical combination of the two indices, reflecting different configurations of technological exposure and market vulnerability.

Finally, these indicators are not directly used in the clustering procedure; rather, they serve as an interpretative framework to understand how different groups of firms are positioned within the EV transition. We nevertheless acknowledge that technological risk is derived from product characteristics that are also included among the clustering variables. As a result, this shared informational basis is reflected in part of the observed alignment between cluster composition and technological risk. For this reason, the technological risk index should be interpreted as an ex-post analytical lens that helps to characterize and compare clusters, rather than as an independent explanatory driver of the clustering results. Importantly, the clustering also incorporates economic and productivity variables, which contribute to differentiating firms beyond their product portfolios, ensuring that cluster membership is not determined by technological characteristics alone. While the clustering—based on the original variables—identifies groups of structurally similar firms, the technological and market risk indices enable us to assess their relative exposure, adaptive capacity, and potential employment trajectories. In this sense, the proposed framework contributes not only methodologically, but also conceptually to the literature on sustainability transitions by highlighting how firms may experience the green transition through differentiated technological and market trajectories, rather than through uniform patterns of industrial change.

## 5. Empirical analysis

### *5.1. Clustering results*

The cluster analysis based on the 4-cluster rule reveals four clusters (see Fig. 2) with distinctive features, summarized in Table 9.

As Table 9 shows, firms in the first and second clusters belong to the same branch and share several characteristics: they produce components more closely related to the conventional powertrain and traditional automotive industry, employ a relatively large workforce, generate small-to-medium revenues, and display relatively low labor productivity. By contrast, the third and fourth clusters belong to a different industrial domain, characterized by firms specialized in cross-cutting products, Engineering & Design (E&D), IT and automation solutions, and EV-related components and services. These firms exhibit higher labor productivity and greater

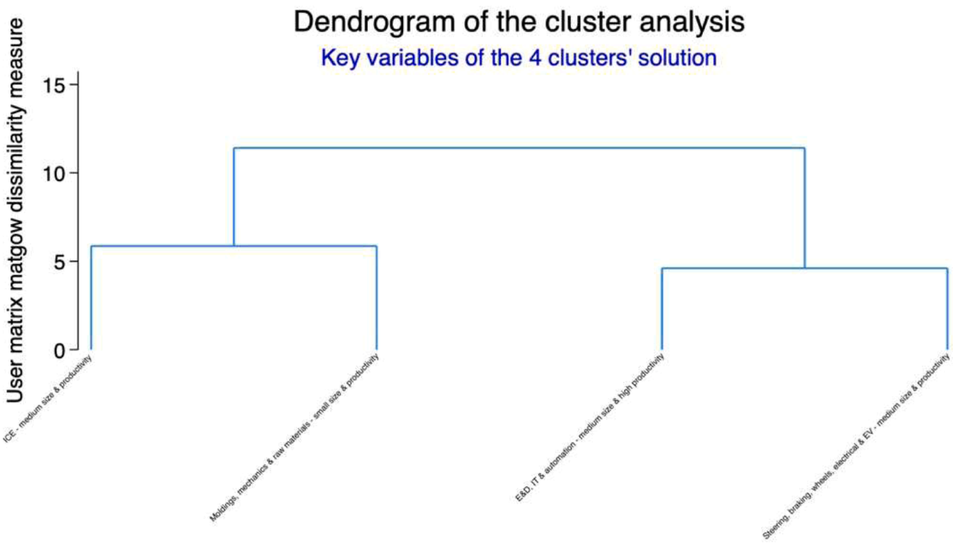


**Fig. 2.** The dendrogram for the 4 clusters' solution (source: author's elaboration).

**Table 9**
The features of clusters in the 4-cluster solution (source: author's elaboration).

| Cluster | Freq. % | Components | Industrial size (%) | Labor Productivity (av.) | Regional Specialization |
|---|---|---|---|---|---|
| 1 | **304**<br>**14%** | **ICE components Fuel cell parts** | **Revenues: Small**<br>< 25€ mln = 63%<br>< 50€ mln = 77%<br>**Size: Medium**<br>10–49 empl. = 34%<br>50–249 empl. = 33% | **Per-Worker** = 77,000 **Medium**<br>**SS** = 2.2 **Medium-Low**<br>**TCP** = 1.6 **High** | **North-East, Center** |
| 2 | **1230**<br>**58%** | **Mechanics & raw materials**<br>**Interior / exterior accessories** | **Revenues: Small**<br>< 25€ mln = 68%<br>< 50€ mln = 78%<br>**Size: Medium-Small**<br><50 empl. = 60% | **Per-worker** = 51,000 **Low**<br>**SS** = 3.1 **Medium**<br>**TCP** = −1.16 **Low** | **Center, South** |
| 3 | **95**<br>**4.5%** | **Auxiliary systems**<br>**Engineering & Design**<br>**IT and industrial automation** | **Revenues: Medium-Large**<br>< 50€ mln = 55%<br>>250€ mln = 16%<br>**Size: Medium-Small**<br><50 empl. = 58% | **Per-worker** = 260,000 **High**<br>**SS** = 6.4 **High**<br>**TCP** = 4.7 **High** | **North-West** |
| 4 | **499**<br>**23%** | **Suspension Steering and Braking systems, wheels, transmission**<br>**Electrical components**<br>**EV charging infrastructure & services**<br>**Battery components** | **Revenues: Medium**<br>< 25€ mln = 31%<br>< 50€ mln = 58%<br>**Size: Large**<br>50–249 empl. = 38%<br>>250€ empl. = 24% | **Per-worker**= 117,000 **High**<br>**SS** = 3 **High**<br>**TCP** = 2 **High** | **North-West, North-East** |

heterogeneity in size and revenues.

The regional distribution of suppliers broadly mirrors the geography of the Italian automotive ecosystem, with the highest concentration of firms in Northwestern regions, followed by Emilia-Romagna and the Northeast, while the South accounts for the smallest share. However, the Relative Specialization Index (RSI) ,[8] derived from the revealed comparative advantage approach proposed by Balassa (1965), highlights distinct regional patterns (Fig. 3).

Northwestern regions exhibit specialization in E&D and IT activities (RSI = 1.17 in Cluster 3) and in BEV-related and suspension/braking technologies (RSI = 1.09 in Cluster 4), providing greater technological resilience and readiness for electrification. By contrast, Northeastern and Central regions show higher concentrations of suppliers in Cluster 1 (RSI = 1.26 and 1.04), which is more exposed to technological obsolescence. Nevertheless, they also display specialization in Clusters 4 and 2, respectively, suggesting the presence of BEV-specific and cross-cutting technological capabilities. Southern regions are most specialized in Cluster 2 (RSI = 1.19), whose product portfolio is comparatively resilient to technological change but whose firms remain vulnerable because of smaller size and lower labor productivity.

Overall, these findings highlight substantial spatial heterogeneity in the technological opportunities and challenges associated with electrification, reflecting the persistent role of territorially embedded productive specialisations in shaping regional industrial structures (Russo, 2008) and the spatial organisation and locational adjustment of automotive supply chains (Kim and McCann, 2008).

To further explore the labor implications of electrification, we analyse the clusters through the technological risk index developed in the first part of the study. Firms most exposed to technological obsolescence are concentrated in Cluster 1, which consists mainly of suppliers specialized in ICE components; nevertheless, 39% of firms in this cluster face null or low technological risk thanks to more diversified product portfolios. By contrast, Cluster 2, the largest group, is the least exposed to technological disruption, with 96% of firms facing null or low technological risk owing to the cross-cutting nature of their products, although they may still be affected by the

[8] The Relative Specialization Index (RSI) is computed as the ratio between the regional concentration of firms in a given cluster and the corresponding national concentration in the same cluster. An RSI greater than 1 denotes that the region is relatively more specialized in that cluster than the national average, while values below 1 indicate relative under-specialization. The indicator is conceptually derived from Balassa's (1965) revealed comparative advantage measure.

[9] Notes: Values are row percentages. The table reports the distribution of firms assigned to each Ward cluster across PAM clusters. High concentrations along a single column indicate strong correspondence between the two clustering methods.

[10] The ISIC is the international standard classification of all economic activities, developed and periodically revised by the United Nations Statistics Division. For further details, see United Nations Statistics Division (UNSD) (2023), *International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 5*. Available at: https://unstats.un.org/unsd/classifications/Econ/.

[11] NACE is the European statistical classification of economic activities, developed and maintained by Eurostat and aligned with the United Nations' International Standard Industrial Classification of All Economic Activities (ISIC). For further details, see Eurostat, *Statistical Classification of Economic Activities in the European Community (NACE Rev. 2.1)*. Available at: https://ec.europa.eu/eurostat/web/nace.

[12] ATECO is the Italian statistical classification of economic activities, developed and maintained by the Italian National Institute of Statistics (ISTAT) and derived from the European NACE classification. For further details, see ISTAT, *Classificazione delle attività economiche – ATECO*. Available at: https://www.istat.it/classificazione/classificazione-delle-attivita-economiche-ateco/.

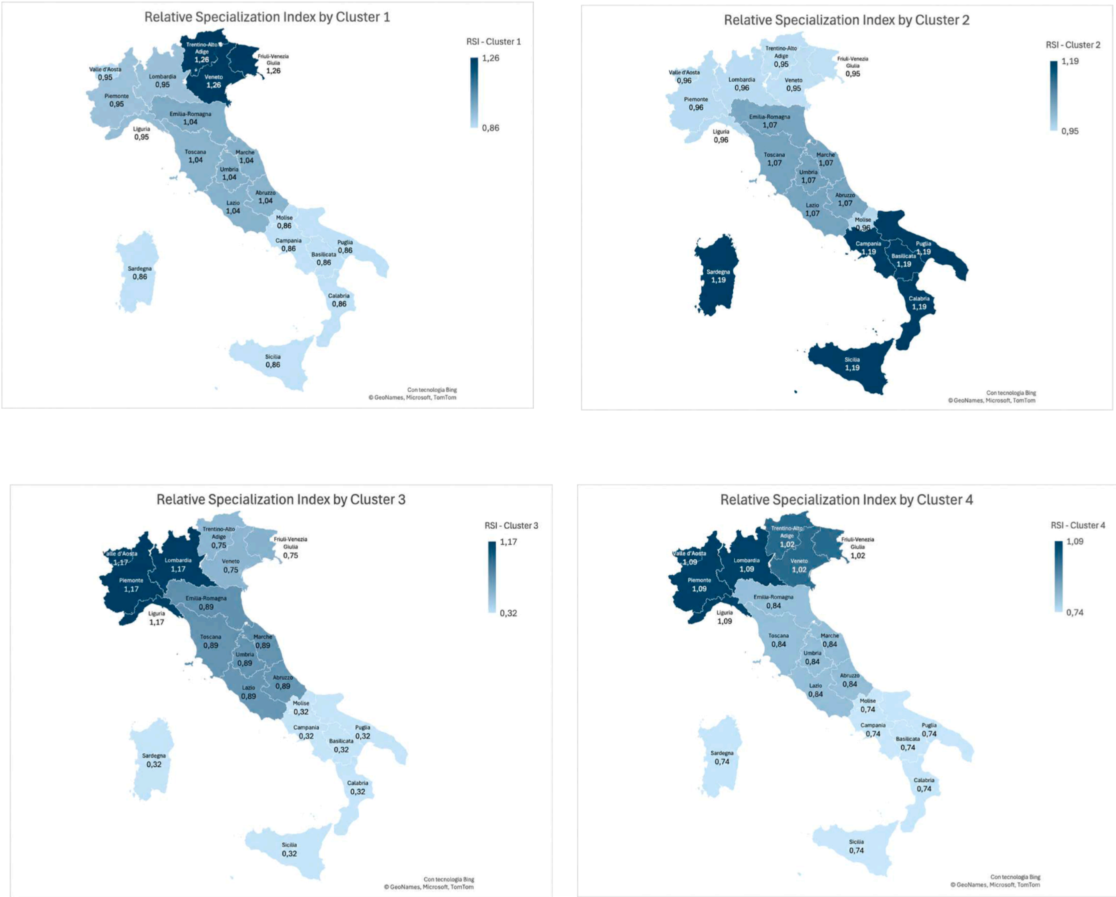


**Fig. 3.** The regional specialization of the Italian auto suppliers by cluster (source: author's elaboration).

reduced number of mechanical parts required in EVs. Cluster 3 comprises firms specialized in engineering and design (E&D), information technology (IT), and industrial automation—activities expected to benefit from the transition—and accordingly 90% of these firms face no technological risk. Finally, Cluster 4 is expected to benefit the most, as it includes suppliers specialized in batteries, electronics, electrical components, and charging systems; the small share of firms classified as at risk consists primarily of producers of suspension and braking systems that have not aligned their product portfolios with recent technological developments (Table 10).

While product portfolios provide important insights into firms' exposure to electrification, they offer only a partial picture of labor vulnerability. We therefore complement the technological assessment with firm-level characteristics, including size, revenues, and labor productivity, to capture exposure to market-related risks. As shown in Table 11, firms in Clusters 1 and 2 face higher market risk because of their relatively small-to-medium size and lower productivity levels, whereas firms in Clusters 3 and 4 combine more resilient product portfolios with higher revenues and labor productivity, making them better positioned to withstand market competition.

The composite indicator combining technological and market risks is summarized in Table 12. Firms in Clusters 1 and 2 are expected to experience negative or moderately negative labor impacts, whereas firms in Clusters 3 and 4 are likely to benefit from the EV transition.

**Table 10**
The number and frequency of firms in the 4 clusters by level of "*technological risk*" (source: author's elaboration).

| Cluster | Null | | Low | | Medium | | High | | Tot | | Technological Risk |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 118 | 39% | 27 | 9% | 59 | 19% | 100 | 33% | 304 | 14% | **High** |
| 2 | 1182 | 96% | 15 | 1.22% | 25 | 2% | 8 | 0.64% | 1230 | 58% | **Low** |
| 3 | 85 | 90% | 4 | 4.2% | 1 | 1.1% | 5 | 5.3% | 95 | 4.5% | **Null** |
| 4 | 467 | 94% | 18 | 3.6% | 12 | 2.4% | 2 | 0.4% | 499 | 23% | **Null** |
| Tot | 1852 | **87%** | 64 | 3% | 97 | 4.55% | 115 | 5.4% | 2128 | 100% | **Low** |

**Table 11**
The number and frequency of firms in the 4 clusters by level of "*market risk*" (source: author's elaboration).

| | Revenues | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cluster | Null | | Low | | Medium | | High | | Tot | | Market Risk |
| 1 | 4 | 1.32% | 66 | 0.22% | 40 | 0.24% | 192 | 63% | 304 | 14% | **High** |
| 2 | 1 | 0.08% | 69 | 5.6% | 109 | 8.86% | 1024 | 83% | 1230 | 58% | **High** |
| 3 | 15 | 15.8% | 24 | 25.2% | 15 | 15.8% | 41 | 43.1% | 95 | 4.5% | **Medium** |
| 4 | 60 | 12% | 148 | 29.6% | 77 | 15.43% | 214 | 42.9% | 499 | 23% | **Medium** |
| Tot | 80 | 3.8% | 307 | 14.42% | 241 | 12.88% | 1471 | **69.1**% | 2128 | 100% | **High** |
| **Cluster** | **Employees** | | | | | | | | | | |
| 1 | 51 | 16.8% | 101 | 33.2% | 104 | 34.2% | 48 | 15.8% | 304 | 14% | **Medium-Low** |
| 2 | 143 | 6.7% | 335 | 15.74% | 539 | 25.32% | 207 | 9.7% | 1230 | 58% | **Medium-Low** |
| 3 | 7 | 7.3% | 35 | 36.8% | 33 | 34.73% | 20 | 21% | 95 | 4.5% | **Medium-Low** |
| 4 | 121 | 24.2% | 190 | 38.1% | 145 | 29% | 43 | 8.6% | 499 | 23% | **Low** |
| Tot | 322 | 15% | 661 | 31% | 821 | **39**% | 318 | 15% | 2128 | 100% | **Medium-Low** |
| **Cluster** | **Added Value per capita** | | | | | | | | | | |
| 1 | 91 | 30% | 66 | 22% | 95 | 31% | 52 | 17% | 304 | 14% | **Medium** |
| 2 | 21 | 1.7% | 325 | 26.4% | 438 | 35.6% | 446 | 36.3% | 1230 | 58% | **High** |
| 3 | 95 | 100% | 0 | 0% | 0 | 0% | 0 | 0% | 95 | 4.5% | **Null** |
| 4 | 407 | 81.5% | 78 | 15.6% | 13 | 2.6% | 1 | 0.2% | 499 | 23% | **Null** |
| Tot | 614 | **28.9**% | 469 | 22% | 546 | 25.7% | 499 | 23.4% | 2128 | 100% | **Medium-Low** |
| **Cluster** | **Added Value per Salaries and Stipends** | | | | | | | | | | |
| 1 | 15 | 4.9% | 51 | 16.77% | 112 | 36.84% | 124 | 40.8% | 304 | 14% | **High** |
| 2 | 17 | 1.4% | 102 | 8.2% | 451 | 36.7% | 660 | 53.6% | 1230 | 58% | **High** |
| 3 | 67 | 70.5% | 16 | 16.8% | 10 | 10.5% | 2 | 2.1% | 95 | 4.5% | **Null-Low** |
| 4 | 53 | 10.6% | 227 | 45.5% | 173 | 34.6% | 46 | 9.2% | 499 | 23% | **Low-Medium** |
| Tot | 152 | 7.1% | 396 | 18.6% | 746 | 35% | 832 | **39**% | 2128 | 100% | **Medium-High** |
| **Cluster** | **Added Value per Total Personnel Cost** | | | | | | | | | | |
| 1 | 304 | 100% | 0 | 0% | 0 | 0% | 0 | 0% | 304 | 14% | **Null** |
| 2 | 1208 | 98.2% | 0 | 0% | 0 | 0% | 22 | 1.7% | 1230 | 58% | **Null** |
| 3 | 95 | 100% | 0 | 0% | 0 | 0% | 0 | 0% | 95 | 4.5% | **Low** |
| 4 | 499 | 100% | 0 | 0% | 0 | 0% | 0 | 0% | 499 | 23% | **Null** |
| Tot | 2106 | **99%** | 0 | 0% | 0 | 0% | 22 | 1% | 2128 | 100% | **Null** |

**Table 12**
The firm's "labor impact profile" of the 4-cluster solution based on their tech and market risk (source: author's elaboration).

| Electromobility risks | | | | |
|---|---|---|---|---|
| Cluster | *Technological* | *Market* | *Occupational outlook* | *Suppliers Profile* |
| 1 | High | High | **Negative** | **Brown** |
| 2 | Low | Medium | **Moderately negative** | **Greenish** |
| 3 | Null | Low | **Positive** | **Green I** |
| 4 | Null | Medium | **Moderately positive** | **Green II** |

Cluster 1 firms ("brown" suppliers) are the most vulnerable because they combine ICE-oriented product portfolios with relatively low revenues and productivity, making them more likely to experience significant job losses. Cluster 2 firms ("greenish" suppliers) benefit from cross-cutting products but remain exposed to market pressures due to their small size and low productivity, particularly when disconnected from international value chains.

By contrast, Cluster 3 firms ("green suppliers – type 1″), specialized in E&D, IT, and automation, are expected to benefit from rising demand associated with electrification. Their high labor productivity and revenues further strengthen their resilience. Finally, Cluster 4 firms ("green suppliers – type 2") possess highly resilient product portfolios and advanced competences, positioning them to gain the most from the transition. Although their relatively small revenues may increase exposure to competitive pressures, their high productivity supports a positive occupational outlook. The results are robust to the cluster stability analyses reported in the Appendix.

## 6. Discussion and policy implications

The findings of the cluster analysis highlight significant differences in the resilience of Italian automotive suppliers to the labor impacts of the EV transition, and these insights translate into important policy implications.

In this sense, the EV transition represents not only a disruptive challenge but also an opportunity for industrial renewal and strategic repositioning.

Our study reveals substantial intra-industry heterogeneity, showing that suppliers differ markedly in their exposure to market and technological risks, as well as in their capacity to adapt to the transition. This finding points to the need for a balanced policy mix that is explicitly informed by the composition of the supply chain and by the specific vulnerabilities of its constituent firms, as captured by our composite indicator of firms' "occupational outlook". In the absence of a careful characterization of suppliers' market and technological risk profiles, policymakers may struggle to identify the most appropriate interventions, risking either overly generic measures or support schemes that fail to address firms' actual constraints and transformation potential. Our approach enables policymakers to differentiate policy responses according to suppliers' specific vulnerabilities and adaptive capacities, thereby supporting both industrial resilience and transition-oriented innovation. By aligning interventions with the heterogeneous profiles of suppliers, the transition can help protect employment, strengthen long-term competitiveness, and foster industrial resilience (Fredriksson et al., 2018), while reducing the risk of lock-in to obsolete technologies and avoiding the so-called "sailing ship effects" (Corrocher et al., 2025).

The proposed framework contributes to policy debates precisely because it highlights heterogeneous supplier pathways, suggesting that policy interventions should be calibrated according to firms' specific combinations of technological exposure and market vulnerability rather than applied uniformly across the sector.

Importantly, the transition toward electromobility should not be interpreted as a simple replacement of "brown" firms with "green" firms. Sustainability transitions are characterized by complex interactions between incumbent and emerging technologies, actors, organizational configurations, and production systems, and firms' trajectories are likely to remain highly heterogeneous. In this context, suppliers' long-term resilience will depend not only on their current technological positioning, but also on their ability to innovate, diversify, develop new competences, and leverage supportive local and international networks. This implies that some traditionally exposed suppliers may successfully adapt to the transition, while some technologically advanced firms may still face market-related vulnerabilities and competitive pressures. For this reason, it is crucial to identify proper policy support for different types of firms also leveraging on local capabilities and regional specializations.

For "brown" firms, which are highly vulnerable because of their technological exposure, low labour productivity, small revenues, and limited capacity to absorb market shocks, policy interventions should prioritise cushioning the immediate social and economic costs of the transition while enabling technological upgrading and diversification. This requires public incentives and tailored industrial conversion programmes aimed at supporting the acquisition, development, and deployment of new technologies. It also calls for stronger collaboration with research institutions, technology providers, and innovative firms, as well as support for internationalisation strategies that can help vulnerable suppliers access broader and more diversified markets. Such measures would mitigate the risks of job losses and local economic decline, while ensuring that traditional suppliers are not excluded from the green transition. In this sense, policy should not simply compensate vulnerable firms for transition-related losses, but actively support their repositioning within emerging automotive value chains.

For "greenish" and "green" suppliers, which are characterised by stronger technological portfolios, higher labour productivity, and greater adaptability to market change, policy attention should shift from cushioning risks to enabling innovation, investment, and expansion. For "greenish" firms, support should focus on strengthening productivity and resilience by encouraging process and product upgrading, promoting integration into international value chains, and improving access to finance so that they can withstand increasing competitive pressures. For "green" firms, which are high-potential suppliers directly connected to BEV-related technologies, the priority should be to sustain growth and scale-up. This requires the development of a favourable innovation ecosystem, including targeted R&D funding, innovation incentives, and financial instruments capable of lowering investment barriers. At the same time, partnerships across the EV supply chain, advanced skills development, and support for global market integration will be essential to consolidate their expansion.

However, firm-level characteristics alone do not fully explain suppliers' capacity to adapt to the ongoing transition. The effectiveness of policy interventions also depends on the territorial contexts in which firms operate. The evidence presented above shows that firms are unevenly distributed across regions and that regional automotive ecosystems differ substantially in terms of technological capabilities, specialisation patterns, and innovation assets. As a result, firm-level interventions should be complemented by place-based innovation policies that leverage local strengths while addressing region-specific vulnerabilities. From this perspective, supporting the transition requires not only tailoring policy instruments to the needs of different categories of firms, whether "brown", "greenish", or "green", but also embedding these instruments within regional development strategies capable of mobilising local knowledge bases, institutional capacities, and innovation networks.

The regional analysis therefore points to the need for differentiated place-based innovation strategies that reflect the heterogeneous technological profiles of regional automotive ecosystems. In the Northwestern regions, where firms exhibit stronger capabilities in BEV-related technologies and engineering-intensive activities, policy interventions could focus on reinforcing existing innovation strengths and supporting the commercialisation and scaling-up of emerging technologies through R&D collaboration, advanced skills development, and technology transfer initiatives. In the Northeast and Central regions, where a relatively large share of suppliers remains specialised in incumbent technologies, but complementary capabilities are already present, policy efforts should facilitate diversification and the redeployment of existing competences toward emerging segments of the automotive value chain. In Southern regions, where suppliers appear comparatively resilient from a technological standpoint but face structural weaknesses related to firm size and productivity, interventions could prioritise business growth, productivity upgrading, and stronger integration into national and European innovation networks. Overall, these findings suggest that place-based innovation policies can play a key role in supporting industrial adaptation to the BEV transition by aligning policy instruments with the specific strengths, capabilities, and vulnerabilities of regional ecosystems.

Finally, policy design should also account for a distinctive feature of the Italian automotive industry. Unlike other major car-producing countries, Italy's supplier base is strongly conditioned by the strategic choices of a single mass vehicle producer, Stellantis. This creates an additional layer of dependency and uncertainty for suppliers, whose opportunities for technological upgrading, diversification, and market expansion are partly shaped by downstream investment decisions. For this reason, policies aimed at supporting the transition of the Italian automotive ecosystem should not focus exclusively on suppliers. They should also facilitate the development of the downstream segment of the value chain by attracting investment in vehicle assembly, both from Stellantis and from other potential vehicle manufacturers. Strengthening and diversifying the domestic assembly base would help create stronger demand-side anchors for suppliers, reduce excessive dependence on a single lead firm, and enhance the resilience and evolutionary potential of the Italian automotive ecosystem as a whole.

## 7. Conclusions

Electromobility represents a critical challenge for the global automotive industry, as incumbent value chains undergo profound reconfiguration in response to the sustainability transition (Chizaryfard and Karakaya, 2022). These challenges are particularly relevant in Italy, where OEMs and suppliers remain strongly tied to internal combustion engine technologies and remain only weakly internationalized (Moretti and Zirpoli, 2022). Against this backdrop, this study contributes to the debate on the occupational implications of the EV transition within the Italian automotive supply chain by leveraging a multidimensional dataset and cluster analysis to identify differentiated profiles of supplier resilience and vulnerability.

Our findings show that a relatively small group of suppliers specialized in internal combustion technologies ("brown" suppliers) is most exposed to production contraction and potential job losses. By contrast, many firms produce components with cross-cutting applications and display lower technological vulnerability. "Greenish" suppliers generally appear more resilient, although smaller firms may remain exposed to market volatility, while "green" suppliers operating in batteries, electronics, and EV infrastructure exhibit stronger competitiveness and higher value creation.

These results are broadly consistent with Rossini et al. (2016), but extend previous research by explicitly linking firms' product portfolios and business characteristics to technological and market risks and their potential labor market impacts. More broadly, the findings reinforce the idea that sustainability transitions unfold through heterogeneous firm-level trajectories shaped by adaptive capacities, productive configurations, and industrial embeddedness.

From a policy perspective, this classification provides a framework for targeted interventions: supporting reconversion and reskilling for "brown" suppliers, enhancing competitiveness and upgrading for "greenish" firms, and fostering innovation and scaling opportunities for "green" firms, while promoting regional smart specialization patterns (Balland et al., 2019). More broadly, the results align with evidence pointing to a structural shift in employment from traditional automotive suppliers toward producers of batteries, electrical, and electronic components (Garcia et al., 2020; Kupper et al., 2020; Novaresio, 2024).

The adaptive capacity of the Italian automotive supply chain may also matter for the country's catch-up in the rapidly evolving EV market. Möring-Martínez et al. (2024) classify Italy among the so-called late-majority European EV markets, highlighting its relatively slower trajectory of electrification. In this context, strengthening supplier adaptability may help support both industrial upgrading and market diffusion.

Importantly, both the methodological approach and the empirical findings have broader applicability beyond the Italian case. The proposed cluster-based framework can be extended to other national and regional supply chains to identify patterns of vulnerability and resilience and to support a just transition in carbon-intensive sectors. Future research could build on this framework by further exploring the role of internationalization in facilitating access to knowledge, technologies, and markets, the importance of local industrial linkages and regional ecosystems in fostering upgrading and resilience, and the labor implications of technological change, particularly its effects on occupational structures and skill requirements. Advancing these research directions would contribute to a deeper understanding of how technological transformation, global integration, and territorial dynamics jointly shape competitiveness and inclusiveness in the green transition.

## Authors' statement

This article investigates the vulnerability and resilience of the Italian automotive ecosystem in the context of the ongoing transition to electromobility, situating the analysis within broader socio-technical transformations affecting the European automotive sector. The motivation for this study stems from the prolonged structural crisis of Italian automotive production, compounded by emerging trade tensions and the rapid evolution of new mobility paradigms, which collectively challenge the sector's prospects for recovery and renewal.

The Italian case offers a particularly insightful perspective, as it combines a unique industrial structure—centred around a single national original equipment manufacturer (OEM), Stellantis—with a highly regionally embedded and internationally interconnected supply chain. This duality makes Italy both a singular and representative case for understanding how legacy automotive systems adapt to disruptive technological change.

By mapping the composition of the Italian automotive supply chain and identifying key supplier typologies, this article aims to assess both the strengths to be leveraged and the critical vulnerabilities that require targeted policy intervention. While the empirical focus is national, the findings are intended to inform broader European debates on industrial transformation, given the centrality of the automotive sector to manufacturing systems and employment across the continent.

Methodologically, the study introduces an original approach that links firms' product portfolios to their exposure to the risks of the green transition, distinguishing between technological and market-related challenges, particularly in terms of labour implications. This perspective contributes to ongoing discussions on ensuring a "just transition" by highlighting how different segments of the supply chain are unevenly affected by electrification.

Overall, the article contributes to a more nuanced understanding of the technological capabilities, labour dynamics, and policy needs associated with the electrification process. It seeks to provide relevant insights for scholars and policymakers engaged in navigating the complex interplay between environmental innovation and societal transformation.

## CRediT authorship contribution statement

**Anna Novaresio:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Anna Moretti:** Validation, Supervision, Formal analysis, Conceptualization. **Francesco Zirpoli:** Validation, Supervision, Formal analysis, Conceptualization.

## Declaration of competing interest

The authors of the manuscript declare no potential competing or non-financial interest related to this research.

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## Appendix

1. **Gower Similarity and Weighted Clustering**

To cluster firms characterized by mixed types of variables, we adopt the Gower similarity coefficient (Gower, 1971), which is specifically designed to handle heterogeneous data. While extensions of the Gower index allow for the introduction of variable-specific weights, we employ its unweighted formulation, where all attributes contribute equally to the overall similarity measure:

$$S(X_a, X_b) = \frac{\sum_{k=1}^{n} w_k \, \omega\left(x_{a,k}, x_{b,k}\right)}{\sum_{k=1}^{n} w_k} \tag{1}$$

where $n$ is the number of attributes, $\omega\left(x_{a,k}, x_{b,k}\right)$ is the similarity between observations $a$ and $b$ on attribute $k$, and $w_k$ is the weight assigned to attribute $k$, reflecting its relative importance in the clustering.

The choice of an unweighted specification is supported by preliminary exploratory analysis, which does not reveal the presence of dominant variables, highly redundant features, or attributes with low informational content. Moreover, no systematic imbalances emerge across variable types (categorical versus continuous), nor are there differences in dispersion or relevance that would justify the introduction of differentiated weights. In this context, assigning uniform weights is consistent with the structure of the dataset and allows us to preserve a fully exploratory approach, avoiding the introduction of empirically unsupported assumptions.

Categorical variables are therefore treated using the standard Gower formulation, without additional weighting. This choice is particularly appropriate given the presence of product variables with a large number of categorical levels, for which alternative weighting schemes—such as dummy-based or frequency-based weights—could introduce distortions by overemphasizing rare categories or underrepresenting structurally important ones.

For continuous variables, we experimented with a log transformation to address skewness and reduce the influence of extreme values. However, this preprocessing step resulted in a deterioration of clustering quality, as indicated by weaker separation and lower interpretability of the resulting clusters. Consequently, we retained the variables in their original scale, as this specification preserved more meaningful variation for the clustering procedure and yielded more coherent group structures.

Clustering validation metrics further support the use of the unweighted Gower index, as discussed in the following section.

2. **Hierarchical Clustering and Optimal Clustering Selection**

To organize firms into meaningful groups based on the unweighted Gower similarity, we employ hierarchical clustering with Ward's linkage method (Ward, 1963). Ward's method minimizes the total within-cluster variance at each step, producing compact, well-separated clusters, which is particularly effective when dealing with mixed-type data and varying attribute importance.

To determine the optimal number of clusters, we first inspect the graphical results of the **Calinski-Harabasz (CH) test**, also referred to as the "elbow method." The CH plot indicates an inflection point at 3–4 clusters, as illustrated in Fig. A1.

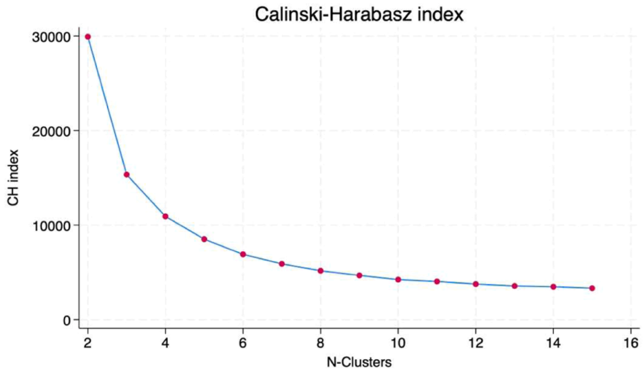


**Fig. A1.** Calinski-Harabasz test - elbow's test (source: author's elaboration).

We further validate this choice using an alternative stopping rule suitable for hierarchical clustering, the **Duda-Hart (DH) test**. The DH results support the CH-based partitioning: we observe high Je(2)/Je(1) values and low T-squared values at 3 clusters, as reported in Table A1.

**Table A1**
The duda-hart test.

| Number of clusters | Duda/Hart on distances | |
|---|---|---|
| | Je(2)/Je(1) | Pseudo T-squared |
| 1 | 0.0664 | 29,926.86 |
| 2 | 0.9762 | 1.34 |
| 3 | 0.9354 | 3.52 |
| **4** | **0.9567** | **2.17** |
| 5 | 0.9106 | 3.43 |
| 6 | 0.6905 | 0.90 |
| 7 | 0.8841 | 1.44 |
| 8 | 0.4447 | 1.25 |
| 9 | 0.9268 | 1.18 |
| 10 | 0.8667 | 2.77 |
| 11 | 0.8332 | 1.40 |
| 12 | 0.8948 | 1.65 |
| 13 | 0.0000 | . |
| 14 | 0.6659 | 1.00 |
| 15 | 0.9337 | 1.14 |

Since the diagnostics proposed by Makles (2012) and Tibishirani, Walther & Hastie (2001) are derived for k-means clustering, whereas our analysis relies on hierarchical clustering based on Gower distance, the final choice of the clustering solution is based on the evidence produced by Silhouette measures, along with the interpretability and consistency of the resulting clusters.

**3. Cluster Validation**

To assess the internal validity, and reliability of the clustering solution, we compute the Silhouette Score, which measures cluster cohesion and separation by comparing the average intra-cluster distance of each observation with its average distance to the nearest neighbouring cluster (Rousseeuw, 1987). The index ranges from −1 to 1, with higher values indicating better-defined clusters. Values close to 1 imply that observations are well matched to their assigned cluster and poorly matched to neighbouring clusters, whereas values near 0 indicate overlapping clusters.

This approach is particularly appropriate in contexts characterized by heterogeneous firm attributes, such as sustainability transitions, where firms differ along both technological and economic dimensions. Table A2 and Fig. A2 report cluster-level Silhouette statistics for the four-cluster solution. The weighted average Silhouette score of 0.29 indicates a moderate and acceptable exploratory partition, supporting the validity of the clustering model. Most clusters exhibit satisfactory levels of cohesion and separation, suggesting that the solution captures meaningful heterogeneity within the automotive supply chain (Table A3, A4).

**Table A2**
Silhouette statistics for the 4-cluster solution (unweighted Gower distance).

| Cluster | N | Min | Mean | Max |
|---|---|---|---|---|
| 1 | 304 | −0.31 | 0.23 | 0.51 |
| 2 | 1231 | −0.16 | 0.49 | 0.65 |
| 3 | 95 | 0.02 | 0.36 | 0.55 |
| 4 | 499 | −0.37 | 0.09 | 0.36 |

**Weighted average Silhouette score: 0.29**

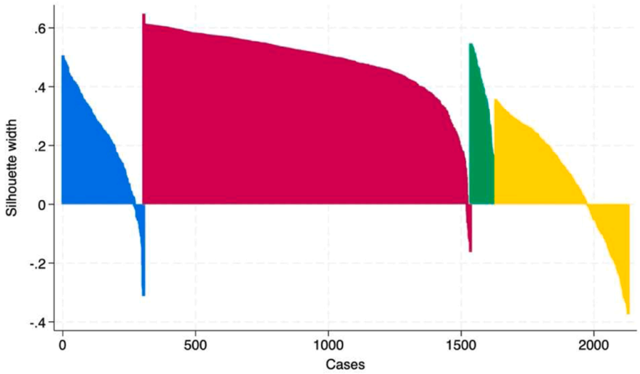


**Fig. A2.** Silhouette test: the results for the 4-clusters' solution (source: author's elaboration).

**Table A3**
Adjust rand index complete vs ward.

| complete | wards<br>1 2 3 4 | Total |
|---|---|---|
| 1 | 50 0 0 0 | 50 |
| 2 | 0 3 0 0 | 3 |
| 3 | 0 0 4 0 | 4 |
| 4 | 0 0 0 1 | 1 |
| Total | 50 3 4 1 | 58 |

**Adjust Rand Index Complete vs Ward = 1.00**

**Table A4**
Adjust rand index: average vs ward.

| Average | Wards<br>1 2 3 4 | Total |
|---|---|---|
| 1 | 50 0 0 0 | 50 |
| 2 | 0 3 0 0 | 3 |
| 3 | 0 0 1 0 | 1 |
| 4 | 0 0 0 1 | 1 |
| Total | 50 3 4 1 | 58 |

**Adjust Rand Index: Average vs Ward = 0.72**

**4. Cluster Stability Analysis**

To assess the robustness of our primary four-cluster taxonomy obtained via Ward's hierarchical linkage, we performed two complementary robustness checks. First, we compared the hierarchical solution with a non-hierarchical Partitioning Around Medoids (PAM) algorithm based on the same Gower dissimilarity matrix. Second, we evaluated cluster stability through repeated subsampling procedures using both the Adjusted Rand Index (ARI) and cluster-specific Jaccard coefficients.

Since Ward's method minimizes global variance and can be sensitive to extreme observations, whereas PAM minimizes absolute dissimilarities around representative observations (medoids), comparing the two approaches helps determine whether the identified groups reflect genuine industrial structures rather than algorithm-specific artifacts. The cross-tabulation between the two methods reveals substantial convergence, confirming the structural robustness of the taxonomy. Specifically, 75.6% of firms within the ICE and

Fuel Cell Components cluster (230 out of 304 firms) are jointly assigned to PAM Cluster 4. Similarly, the broad manufacturing base represented by the Moldings, Mechanical and Metalworking cluster (1231 firms under Ward's solution) exhibits remarkable stability, with 99.3% of firms assigned either to PAM Cluster 2 (33.5%) or PAM Cluster 3 (65.8%), indicating remarkable stability of this manufacturing segment across clustering methods. The overall correspondence between the Ward and PAM solutions is illustrated in Table A5.

**Table A5**
Correspondence between Ward and PAM clustering solutions (row percentages)[9].

| Ward Cluster | PAM Cluster 1 | PAM Cluster 2 | PAM Cluster 3 | PAM Cluster 4 | Total |
|---|---|---|---|---|---|
| ICE and Fuel Cell Components | 5.3% | 4.6% | 14.5% | **75.6%** | 100% |
| Moldings, Mechanical and Metalworking | 0.0% | 33.5% | **65.8%** | 0.7% | 100% |
| Auxiliary Systems | **100.0%** | 0.0% | 0.0% | 0.0% | 100% |
| Suspension, Steering and Braking | 35.3% | **61.1%** | 1.8% | 1.8% | 100% |

N = 2129 firms.

Nevertheless, two systematic deviations emerge. First, while Ward's linkage maintains the distinction between Auxiliary Systems and Suspension, Steering and Braking firms because of their different technological capabilities, PAM merges them into a single cluster driven by their similar financial profile, characterized by higher revenues and added value. For the purposes of this study, Ward's specification is preferred because transition pathways, labor reskilling opportunities, and diversification prospects depend primarily on technological capabilities and accumulated engineering knowledge rather than on financial scale alone. Second, within the Moldings and Mechanical macro-category, Ward captures technological commonality but masks substantial heterogeneity in economic performance. The PAM solution reveals an internal polarization by separating a productive segment of medium-sized suppliers from a larger group of micro-firms operating at substantially lower productivity levels.

Cluster stability was further assessed through 100 subsampling replications. The mean Adjusted Rand Index (ARI) was approximately 0.60 (SD = 0.14), indicating a reasonably stable and reproducible clustering solution. Fig. A3 reports the distribution of ARI values across the resampling iterations, showing a concentration around the mean and confirming the moderate-to-high stability of the overall partition. Cluster-specific Jaccard coefficients revealed heterogeneous stability across groups: Cluster 1 exhibited very high stability (mean Jaccard = 0.86), Cluster 2 showed moderate-to-high stability (0.70), whereas Clusters 3 and 4 displayed lower stability levels (0.38 and 0.43, respectively). Fig. A4 presents the cluster-level stability profile and highlights the markedly higher robustness of Clusters 1 and 2 relative to Clusters 3 and 4.

Importantly, these results provide additional support for the Ward hierarchical solution. The first cluster and the second largest cluster were consistently recovered across subsamples, demonstrating robustness to sampling variation. Conversely, the lower stability of Clusters 3 and 4 mirrors the PAM results, which tend to combine these groups into broader categories. This suggests that the boundaries separating the latter clusters are less pronounced, although they remain meaningful from a technological and industrial perspective.

Overall, the robustness checks support the validity of the proposed taxonomy. While Clusters 1 and 2 emerge as highly stable and consistently identifiable across alternative specifications and subsamples, Clusters 3 and 4 appear more heterogeneous and less sharply separated. This pattern is consistent across the PAM comparison, the subsampling analysis, and the sensitivity tests, suggesting that firms in the latter groups occupy more transitional positions within the supply chain. From a policy perspective, these findings reinforce the need for transition strategies that combine technology-specific interventions with measures tailored to firm-level financial resilience, productivity, and adaptive capacity.

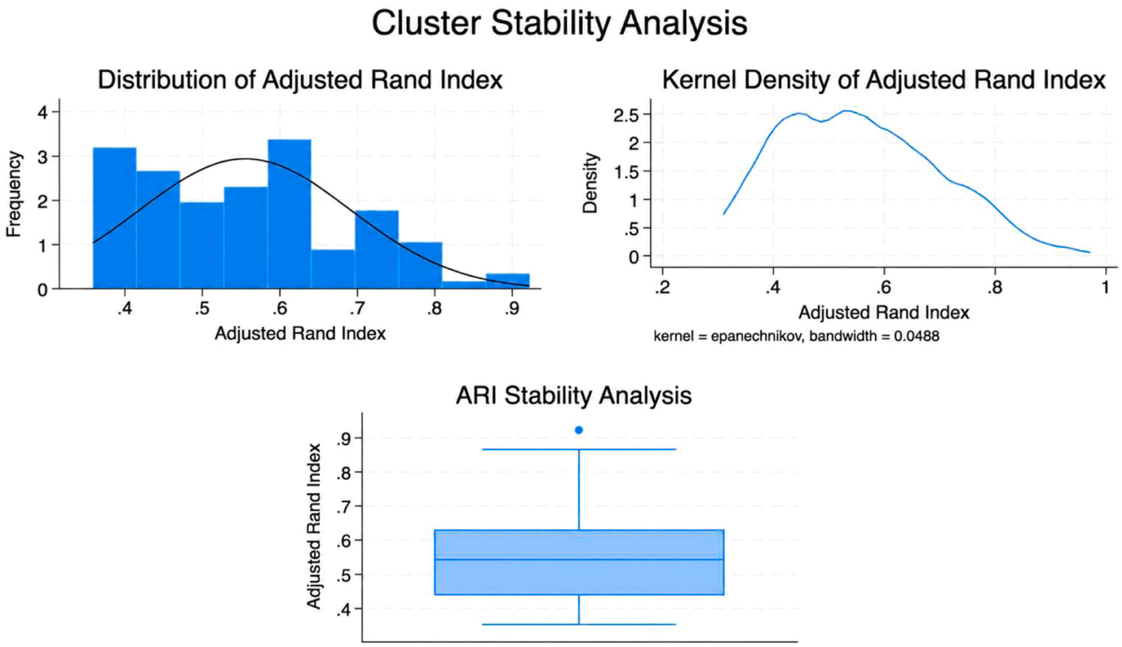


**Fig. A3.** Cluster stability analysis based on the adjusted rand index.

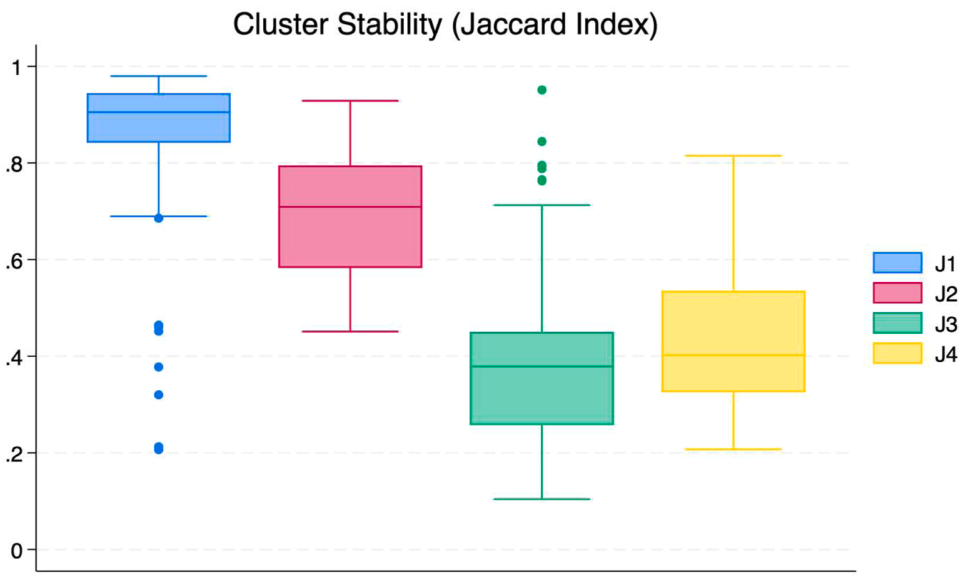


**Fig. A4.** Cluster stability analysis based on the jaccard index.

As an additional sensitivity analysis, we assessed the extent to which the clustering results depend on the specific groups of variables included in the taxonomy. Using the same Gower dissimilarity measure and Ward hierarchical clustering procedure, we re-estimated the clustering separately using only the product-specialization variables (Product1–Product4) and only the economic variables (revenues, employment, value added per employee, and productivity indicators). The resulting partitions were compared with the baseline four-cluster solution using the Adjusted Rand Index (ARI). The product-only specification exhibited limited agreement with the baseline taxonomy (ARI = 0.193), whereas the economic-only specification showed a higher but still incomplete correspondence (ARI = 0.417). These findings indicate that neither technological specialization nor economic characteristics alone are sufficient to reproduce the observed clustering structure. Rather, the proposed taxonomy emerges from the combined contribution of both dimensions, supporting the multidimensional nature of the classification and alleviating concerns that the results are driven primarily by a single group of variables.

5. Dataset overview with the clustering results (Fig. A5).

| id | Regione | ATECO | Overview | Product1 | Product2 | Product3 | Product4 | LaborProductivity1 | LaborProductivity2 | Added_Value_pc | Employees_cat | g4_hierachical ICE and fuel cell components | g4_pam |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Piemonte | 293209 | Automotive Plastic Components | 20 | 16 | 18 | | 1,70 | 1 | 65280 | 50-100 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 4 |
| 2 | Piemonte | 222909 | Plastic molding, mold production | 110 | | | | 2,16 | 2 | 56640 | 1-5 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 3 |
| 3 | Piemonte | 255000 | Electrical Components for Internal Combustion Engines | 110 | | | | 4,25 | 3 | 186500 | 50-100 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 1 |
| 4 | Friuli-Venezia Giulia | 293209 | Fluid jet system to counteract aquaplaning (STARTUP) | 116 | | | | 0,99 | 1 | 41830 | 0-1 mln | Auxiliary systems, E&D, IT & automation | 4 |
| 5 | Emilia-Romagna | 293100 | Hydraulic and Pneumatic Systems | 27 | | | | 2,43 | 2 | 100250 | 25-50 mln | ICE and fuel cell components | 4 |
| 6 | Lombardia | 281510 | Power Transmission Components | 20 | 16 | | | 1,68 | 1 | 65110 | 10-25 mln | ICE and fuel cell components | 4 |
| 7 | Piemonte | 279009 | Electrical and Electronic Equipment | 116 | | | | 2,68 | 2 | 94940 | 25-30 mln | Suspension Steering & Braking systems, Electrical components, EV batteries & charging systems | 2 |
| 8 | Lombardia | 256100 | Electrolytic galvanizing, galvanic treatments | 101 | | | | 1,73 | 1 | 79240 | 1-5 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 2 |
| 9 | Piemonte | 256200 | High-Precision Hydraulic & Pneumatic Components | 99 | | | | 2,08 | 1 | 78570 | 10-25 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 2 |
| 10 | Piemonte | 222200 | Plastic Products Manufacturing | 101 | | | | 1,39 | 1 | 46660 | 10-25 mln | ICE and fuel cell components | 3 |
| 11 | Piemonte | 270000 | Electromechanical Automotive Components | 48 | 50 | 51 | | 2,62 | 1 | 80590 | 100-250 mln | ICE and fuel cell components | 4 |
| 12 | Piemonte | 310920 | Artisan saddlery | 100 | | | | 2,04 | 1 | 39280 | 0-1 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 3 |
| 13 | Piemonte | 222100 | Steel Tubing | 62 | 109 | | | 1,86 | 1 | 66240 | 50-100 mln | ICE and fuel cell components | 2 |
| 14 | Piemonte | 243300 | Steel Foundry Products | 6 | 99 | | | 1,84 | 1 | 63170 | 1-5 mln | Suspension Steering & Braking systems, Electrical components, EV batteries & charging systems | 4 |
| 15 | Piemonte | 243300 | Industrial Gears and Drivetrain Components | 99 | 102 | | | 4,15 | 3 | 172680 | 5-10 mln | Suspension Steering & Braking systems, Electrical components, EV batteries & charging systems | 1 |
| 16 | Piemonte | 293209 | Sheet Metal and Tubular Components | 110 | | | | 1,50 | 1 | 52420 | 5-10 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 3 |
| 17 | Piemonte | 281520 | Precision Steel Balls and Bearing Components Automotive Prototype and OEM Components | 22 | 162 | 101 | 99 | 2,08 | 1 | 91410 | 50-100 mln | ICE and fuel cell components | 4 |
| 18 | Piemonte | 255000 | Transmission and Differential Spare Parts | 110 | | | | 1,75 | 1 | 64230 | 10-25 mln | Suspension Steering & Braking systems, Electrical components, EV batteries & charging systems | 2 |
| 19 | Emilia-Romagna | 293209 | Internal carpets and moquette | 99 | 18 | 105 | | 3,37 | 2 | 147600 | 100-250 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 1 |
| 20 | Basilicata | 139300 | Moldings, mechanical & metalworking, interior & exterior accessories | 100 | | | | 3,44 | 2 | 25830 | 0-1 mln | Moldings, mechanical & metalworking, interior & exterior accessories | 3 |

**Fig. A5.** Head of the database used in the analysis, with the main firm-level variables and the cluster assignments.

## Data availability

Data can be made available in anonymized form (firms) and with non disclosure agreement (car components' classification) upon reasonable request

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