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Automation, digitalization and decarbonization in the European automotive industry: a roadmap towards a just transition

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2023/36 October 2023
ISSN(ONLINE) 2284-0400

Automation, digitalization and decarbonization in the European automotive industry: a roadmap towards a just transition*

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Abstract

This position paper outlines the characteristics of the trends at stake in affecting the twin transition in the European automotive industry, and the political economy of the actors behind such transition. We first describe the automation and digitalization processes in the automotive sector and their effects on employment. Possible scenarios are analysed, illustrating actual cases of electrification conversion of some European plants of the key OEMs companies as practical examples to understand the employment effects. We then consider the role of the regulatory push in fostering the transition of the automotive sector towards electrification, highlighting the non-neutrality of the process and the risk of a quite limited space for decarbonization. Finally, we discuss the space and capacity of trade unions' actions to orient the twin transition toward social and climate justice.

Keywords: Social dialogue, trade unions, employment, political economy

JEL classification: J5, L6, O2, O3

*The authors wish to acknowledge the funding received from the European Union's Social Prerogative and Specific Competencies Lines (SOCPL) programme under grant agreement N. 101052331 - BARMETAL. The authors wish to acknowledge the comments received by the member of the BARMETAL consortium, participants to the "Industry 4.0 – ten years later" conference (Modena, May 17-19 2023) and to the 31st International Colloquium of GERPISA (Brussels, June 27-30 2023).

1 Introduction

Technological innovation and decarbonization processes are changing value chains' composition and companies' organization, having deep consequences on the labour market. The duality of employment effects of technical change exerting both job creation and job destruction has been at the centre of the debate for decades, especially as a consequence of accelerated automation and introduction of "Industry 4.0" technologies (among others Autor et al., 2003; Acemoglu and Restrepo, 2019; Dosi et al., 2021; Staccioli and Virgillito, 2021).

Digitalised productive processes have also allowed an increase in the speed of globalization and relocation abroad of productive activities and labour-intensive processes towards low-cost countries, with specific concentration into low- and medium-value added phases. Relatively less skilled labour, paid at low-wages and employed in standardised production processes with low technological upgrading has been required in peripheral countries of destination. At the opposite, innovative productions have remained in leading plants located in core countries where high-skilled labour is available to meet the digitalization and automation challenges. This asymmetry is indeed reflected in the heterogeneous levels of R&D investment and innovative efforts across plants and countries, that then translate in different patterns of production upgrading and workforce upskilling.

Decarbonization effects on the reorganization of industries and employment are less straightforward, since the unfolding of the process is still at an infant stage and approached by corporate organizations with quite gradual attitudes, possibly turning the decarbonization transition into a "passive revolution" (Haas and Sander, 2020). The gradual strategy toward a path of complete decarbonization is also engendered by the lack of clear public policy targets, often subject to modifications on the basis of multinational corporate interests (Haas and Sander, 2020) which so far are very rarely shifting toward complete non-fossil fuels strategies (Green et al., 2022). As for automation and digitalization, decarbonization is expected to have heterogeneous impacts with respect to sectors and countries, depending on regulations, corporate strategies in innovation regimes and positioning along global value chains, trade unions and societal movements. All together, they represent the political economy shaping the decarbonization path.

In what follows, we will focus on digitalization, automation and decarbonization trends in the automotive industry, a benchmark case to study the, also equivalently defined, “twin” (digital and “green”) transition. The industry is in fact crossed by the interaction of both transformations. Historically, it has been an exemplary case to assess the effects of the adoption of new advanced technologies on both corporate performance and work-process reorganization, since the first studies on assembly lines and scientific management of the organization of production (Meyer III, 1981). With reference to the technological trends affecting the industry, automation of mechanical processing of metal parts and the deployment of Computer Aided Design (CAD) for prototyping are just two examples of long-lasting automation and digitalization processes occurring in auto factories since the eighties. At the same time, the automotive sector is an archetypal example of the shortcomings of the decarbonization process, mainly due to the uncertainty of its impact on employment, but also one of the most targeted by European regulations in terms of emissions, with the announced ban on the production of internal combustion engine (hereafter ICE) vehicles from 2035, although recently relaxed. To analyse the industry with a European lens, globalization and global value chains should be considered as well, being the sector strongly stratified into a core-periphery structure characterised by a central-continental lead area with decreasing number of employees and able to strategically maintain only some production segments vis-à-vis the peripheral Visegrad area. In particular, the decarbonization of the ICE and the shift toward electric vehicles will fast reconfigure the geography of European production, putting under stress second and third tier suppliers characterised by SMEs located in the East and South of the EU.

To understand on-going trends of digitalization, automation and decarbonization in the European automotive industry, we outline the relevance of the following processes and actors:

- The role of the European geography of production and distribution chains: differentiated impacts for the North vs. the South; for the East vs. the West, for focal/lead/core plants vs. peripheral ones.
- The role of corporate managerial strategies, in relation to globalization processes as well.
- The role of trade unions and space of actions mediated by institutional settings, from

national, to sectoral, to plant level bargaining.

- The role of national, European and international regulations in speeding up or hampering the transition.

This position paper outlines the characteristics of the trends at stake in affecting the twin transition in the European automotive industry, and the political economy of the actors behind such transition. We first describe the automation and digitalization processes in the automotive sector and their effects on employment (Section 2). Possible scenarios are analysed, illustrating actual cases of electrification conversion of some European plants of the key Original Equipment Manufacturers (hereafter OEMs) companies as practical examples to understand the employment effects (Section 3). We then consider the role of the regulatory push in fostering the transition of the automotive sector towards electrification, highlighting the non-neutrality of the process and the risk of a quite limited space for decarbonization (Section 4). Finally, we discuss the space and capacity of trade unions' actions to orient the twin transition toward a path of just transition (Section 5). Our conclusions are laid out in Section 6.

2 Digitalization and automation in the automotive industry: trends and employment effects

Already at the beginning of the XX century, Ford introduced the automation of mechanical processing of metal parts to obtain mass production, numerical control (NC) machines were introduced in the 1940s, while computer numerical control (CNC) machines in 1970s (Meyer III, 1981; Krzywdzinski, 2021). Digitalization and automation processes in the automotive sector started in the late eighties. With digitalization we define process monitoring, control and optimization of work activities by means of software systems, connecting machines with databases able to collect analytical information converted into a digital format; with automation technologies we define the machine ability of replicating specific human tasks in a (semi) autonomous manner. In the 1970s and 1980s, welding robots and presses were introduced in car body manufacturing in such a way that in the 1990s, automation levels were at 90%-100%, particularly in countries like Germany. Most recent developments in automation concern "cyber-physical systems" and lightweight robots working on assembly lines, where automation has been slower and more difficult to apply (Krzywdzinski, 2017; Krzywdzinski, 2021).

The digitalization of the automotive industry relates to design, development, prototyping, quality control and product safety.[1] Digitalization improved already in the 2000s with the birth of the "Digital Factory", thanks to the development of virtual reality devices and the Ethernet (Krzywdzinski, 2021). Therefore, strategies to foster total digitalization and automation of the auto industry, as the so-called Industry 4.0 paradigm, essentially turned out to be more national plans to push country-level production capacity, as in the German case, rather than leading to an effective convergence towards the humanless factory (Pardi, 2019). If technological adoption does not necessarily shed labour force, a direct consequence of automation and digitalization is the impact on the employment structure and composition at the plant-level, and of the sector therein, together with the demand of specific skills required by the two processes, in relation to the degree of substitutability/complementarity of manual work (Cirillo et al., 2021). Indeed, so far evidence of massive technological unemployment due to digital and automation adoption is still lacking, while the industry is affected by a deep internal restructuring because of delocalisation and more recently decarbonisation processes.

The automotive industry employs around ten million workers throughout Europe, including direct (2 million) and indirect (8 million) (Gaddi and Garbellini, 2021). Figure 1 presents the absolute numbers and the shares of employees in the manufacturing sector (NACE C) (top panel), the absolute numbers of direct jobs in the automotive industry, namely manufacture of vehicles, trailers and semi-trailers (NACE C-29) and the percentage share over employment in the manufacturing sector (bottom panel) across Germany, Slovakia, Sweden, Italy and Spain.[2] In 2019, in the European Union the manufacturing sector employed 30 million people, on average accounting for 30% of total employment, with more than 3 million people in the automotive industry, accounting for 7.5% of manufacturing employment.

[1] e.g. the Computer Aided Design and the Computer Aided Quality.

[2] The identification strategy of these countries is not representative but rather informative of the overall EU dynamics.

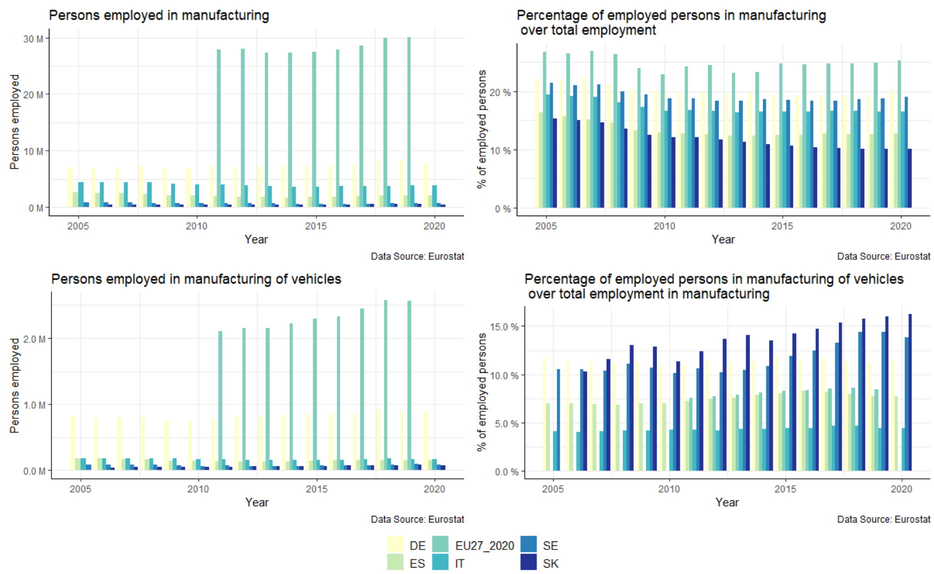


Figure 1: Employment in manufacturing and percentage of employment in the automotive sector. Source: Authors' elaboration of European Labour Force Survey, EUROSTAT data.

Slovakia records the highest share – equal to 15% in 2020 – of direct jobs in the automotive sector with respect to total employment in the manufacturing sector. Sweden and Germany respectively exhibit a share of 14% and 12% in 2020, Spain keeps a share of 7,5%, close to the Eu average while Italy follows behind with less than 5% of manufacturing workers employed in the automotive sector. According to Krzywdzinski (2021), the employment composition in the German automotive industry has undergone a huge restructuring from 1997 to 2018. Overall, employment has increased in the sector (+93,300 units) but the employment structure has changed: the percentage of metal working, metal construction and welding occupations has decreased because of process innovation, while plants and machines operators together with automation related jobs have increased. Complementary evidence is reported in Montobbio et al. (2023) according to which machinery and maintenance jobs represent the second occupation, out of the top twenty 8-digit occupations, to be most exposed to robotic automation and potential substitution.

Overall, in the auto industry, digitalization and automation have acted in a dual direction according to the department/function of interest: automation has tended to replace manual work in the upfront production stages, with welding and mechanical machining requiring less labour and lower production costs; product innovation, creating new products, markets, reskilling of the workforce, new job profiles, as ICT specialists and chief data officers, has implied both process and product innovation, with the latter prevailing and acting instead as a countervailing force. The digital and automation transformations, whenever occurred, have been more a mutation rather than a completely new reconfiguration of the industry, with strong heterogeneity among companies and countries.

One of the sources of such heterogeneity relies in firm organizational capabilities (Costa et al., 2023). Organizational capabilities result to be crucial elements to achieve competitive advantages in the market, being strictly linked with technological innovation and production efficiency (Dosi and Nelson, 2010; Cirillo et al., 2021; Krzywdzinski, 2021). The lean organization has resulted to be the key factor and, in the end, a prerequisite for the success of automation and digitalization (Mokudai et al., 2021; Moro and Virgillito, 2022; Caria et al., 2023). Disembodied knowledge incorporated in organizational capabilities is crucial, since the effect of automation, and technical change in general, unfolds upon the internal organizational structure. Of course, heterogeneous organizational structures are adopted across OEMs, belonging to countries and plants in different countries, according to corporate strategies, institutions at stake, regulations and bargaining power of trade unions, particularly relevant factors in shaping the degree of automation with respect to investment choices and employment skills composition.

In a core-periphery perspective, exploring the sources of the asymmetries across Germany and the CEE is helpful to understand the main challenges that Southern and Eastern European countries are facing. Many of these challenges not only characterize the digitalization and automation process but also decarbonization, being the latter a new trend displaying upon pre-existing asymmetric structures and countries positioning.

2.1 Asymmetries in addressing automation and digitalization: core vs. peripheral plants and countries

While heterogeneity across final OEMs located in different countries is more predictable, plant-level heterogeneity within the same OEM located in the same country is also at stage.

Indeed, in defining the degree of technological innovation to compete in the market, firm's history and corporate strategies, particularly in R&D investments innovation regimes, workforce training and more generally local labour markets, turn out to be crucial factors that, give rise to forms of workplace production regimes. Workplace production regimes represent the interaction among managerial attitudes and strategies, labour processes and techno-organizational systems, at the factory level (Moro and Virgillito, 2022 for Italian automotive sector). Workers' techno-culture and collective attitudes towards technologies (Schaupp, 2021) add on degrees of workplace heterogeneity.

With reference to innovation regimes, Krzywdzinski (2019) reports that only 20% of companies in the CEE declare to be highly automated, while German ones are more than 50%. The CEE automotive industry has developed through processes of relocation of the German automotive low-end manufacturing plants in low labour costs countries. The process has largely invested tier 1 and tier 2 suppliers up to the point that those in CEE have become the main automotive suppliers of parts and components for Germany. In particular, automotive suppliers have relocated activities in the CEE, accounting for 44% of their employment vis-à-vis 11% of final car assemblers (Krzywdzinski, 2019).
On the one hand, thanks to learning by doing, cumulated knowledge, experience, and knowledge exchange with German actors, such as universities and R&D units of the parent companies, CEE players have tried to fill the gap for what concerns product innovation, quality and productivity. Thus, they started competing even with German automotive suppliers, having an advantage on the market because of low-cost production. On the other hand, the innovation upgrading does not hold for all plants in CEE, the advantage in innovation activity is not the same for all suppliers, and Germany could in principle relocate to other low-cost countries breaking the existent knowledge exchange networks.

In particular, the highest innovative advantage is given by the proximity to R&D centres and cumulated investments which have accompanied the evolution of the automotive industry over time (Pardi, 2022; Krzywdzinski, 2019). The strategic choice of where conducting high-level innovative activities by parent companies is non-neutral. The first adoption and testing phases of new technologies is more frequent in German plants with respect to CEE ones. At the same time, plants in high wage countries, as Germany, which are not leading and would need to invest in R&D and in technological innovation, have adopted relocation strategies to low-cost countries to compete in the market, with possible implications for income distribution. Cost-compression strategies behind relocation motives have been recorded by Dachs et al. (2012) employing data from the European Manufacturing Survey. Italy and France are countries apt to the example, largely populated by declining lead OEMs embracing cost-reduction relocation. In fact, between 2012 and 2020, we observe a change in the internal production of parts and components (Figure 2) shifting from core countries (negative rate) to CEE countries (positive rate).

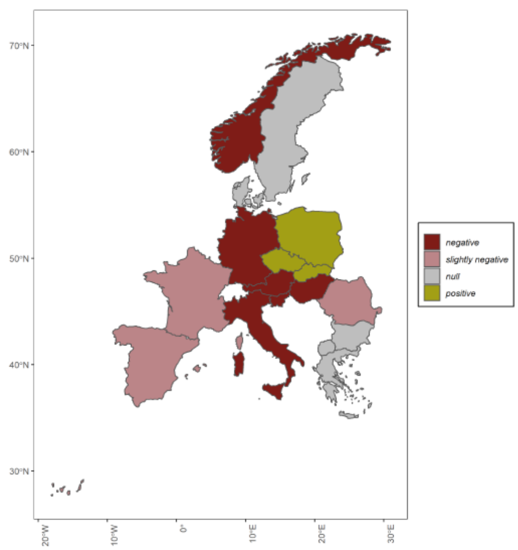


Figure 2: Component-producers differential between 2012 and 2020 in Europe. Source: Collodoro and Virgillito (2023) elaboration on Orbis database.

Heterogeneity in innovation activity across periphery and core countries reflects on the skills distribution of the workforce in the sector, difference also due to asymmetries in the institutional skill formation regimes (Krzywdzinski, 2017). Plants with a higher share of workers with vocational training are more likely to be able to face new challenges of the automation and digitalization process and in particular, the possibility to upskill/reskill workers can offset the risk of technological unemployment for those occupations most likely to be automated.

Trade unions have proven to be effective in shaping the directions of investments and product upgrading in the automotive sector (see Cirillo et al., 2023 and the references therein).

Asymmetries are present with respect to unionisation across Northern, Southern and Eastern Europe, where bargaining coverage oscillates between 25%-30% and 40% (Figure 3). Stronger unions have pushed bargaining towards high vocational training to avoid technological unemployment and labour expulsion, investments in new products and organizational capabilities, asking for corporate investment strategies divergent from low-cost relocation and leading to new and successful organizational structures (Krzywdzinski, 2017).

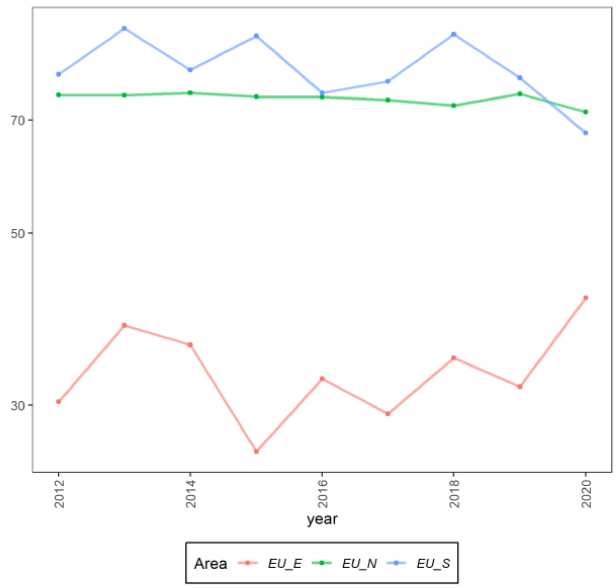
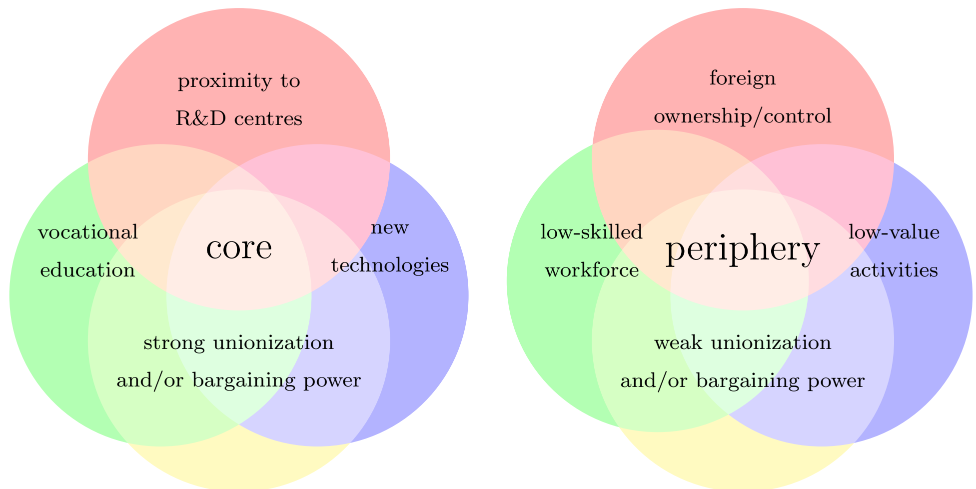


Figure 3: Bargaining coverage in core vs. peripheral European areas. Source: Collodoro and Virgillito (2023) elaboration on ICTWSS database.

Last but not least, institutional factors (acting at different levels) are the common thread behind corporate strategies, organizational structures, level of wages and labour costs, vocational education systems, possibility of relocation and bargaining power, shaping the differences between core and periphery.

In the following diagram, we summarise the relation between the factors shaping core vs. periphery positioning and effects in the automation and digitalization process. A second map is provided at the end of the next section adding the decarbonization process, highlighting the common aspects of the trends under analysis.



(a) Factors shaping core plants and countries **(b)** Factors shaping periphery plants and countries

Figure 4: Factors behind core-periphery dualism, Venn Diagram representation.

3 Decarbonization trends and scenarios for the automotive industry

The transport sector alone is responsible for a level of emissions ranging from 10 to beyond 20 percent of overall annual CO2 emissions. The urgency to tackle climate change has pushed the European Commission to propose a 100% cut in CO2 emissions by 2035. Other countries have declared strategies of phasing-out fossil fuel vehicles by 2040 during the COP 26 in Glasgow. In particular, the resulting Climate Path includes a Declaration on Accelerating the Transition to 100% Zero Emission Cars and Vans ratified by 35 countries and 6 major carmakers, with the notable absence of some big players as Toyota not signing the agreement. As a consequence, the production of vehicles with ICEs must stop and shift to manufacturing electric vehicles, as the main technological paradigm indicated by the institutions.

As automation and technological change, the decarbonization process is characterized by the duality of creation and destruction of jobs. Job losses are expected in the automotive industry, given value chain disruptions due to the shift to electric vehicles, particularly targeted towards blue collars on the assembly lines, given the lower number of components of electric engines vis-à-vis ICEs (Brown et al., 2021), and on second and third tier suppliers of parts and components related to the ICE.

Nevertheless, in a best-case scenario, losses in the automotive industry are expected to be offset by the production of batteries for electric vehicles (hereafter BEVs), together with the improvement in the demand for ICT and engineering occupations, and increase in indirect jobs (eg., related services). However, the reallocation of dismissed workers into BEVs manufacturing depends on (Pirie et al., 2022):

- The decision taken at the OEMs headquarters about producing vis-à-vis importing batteries. In the case of import of BEVs (mostly from Asian countries), the possibility to reallocate blue collars into the battery manufacturing industry fails.
- In the case of internal production of batteries, the decision of the OEMs in which plants to produce and the investments in training the workforce.
- Eventual regulations and policy interventions promoting investments and re-skilling and up-skilling of the workforce.

Such uncertainty largely characterises the automotive industry in central and eastern European countries, where several plants of foreign OEMs are not independent in the decision-making process: the foreign ownership and control via FDI in CEE exceeds 90% in the most relevant countries in the automotive supply chain (Pavlínek, 2023). In addition, foreign companies could decide to import or to produce batteries in high-wage countries, where the required skills are available.[3] At the same time, a high degree of firm-specific innovation activity cumulated over time gives an absolute advantage on the market, and alternative company-level innovation strategies in addressing the shift to electrification of the automotive industry are expected across different OEMs as well. According to Mazzei et al. (2023), technological leaders in the ICE trajectory are also leaders on the hybrid, electric and fuel cell vehicles one (Toyota), thanks to past knowledge accumulated and following diversification strategies. At the same time, some specific players as Tesla, with a specialization

[3]For instance, Northvolt, a Swedish Gigafactory company, has based its gigafactories in Sweden, Northern Germany, but also in Poland, countries where wages where not necessarily so competitive and skilled workforce was available. For additional information, see https://northvolt.com/career/locations/.

strategy only on the electric segment, are not targeting high-volume markets, but rather high-price products. As we shall see, such heterogeneity across countries and car producers also reflects the existence of conflicting interests emerged during the definition of CO2 emissions targets and regulations by European authorities. Additionally, firm local trajectories add further uncertainty to the electrification path, given the choice of some players to keep producing components for ICEs, and ICEs cars to be sold where production bans do not apply, possibly conducting R&D in the hydrogen and alternative fuels paradigm, as more adaptable to existent manufacturing production lines vis-à-vis the electrification of production.

To give an account of the extent to which the transition toward electrification is ongoing in the automotive industry, in Table 1, we report some cases of OEMs shifting the production to the electric vehicle engine, together with other automotive suppliers and Gigafactories.[4] To take some examples, Audi has declared 9,500 jobs will be lost by 2025, by early retirement programs and through employee turnover, and 2,000 jobs will be created by the electrification and digitalization of production in the two plants in Ingolstadt and Neckarsulm. Seat instead is shifting the production to the electric engine in Martorell and El Prat where 2,400 and 1,000 jobs are at risk respectively, while no reallocation has been declared yet. Job losses are expected also for automotive supplier manufacturers, as Magneti Marelli in Italy. At the opposite, all examples of Gigafactories are expected to create new jobs.
As a result, we expect a deepening of the asymmetries between core and peripheral countries and plants as observed for the automation and digitalization process. To sustain the cost of electrification, OEMs and automotive suppliers will potentially further relocate low-value

[4]The cases are retrieved from Automotive Manufacturer Solutions and secondary data. For each case, the table specifies: the country of location of the plant, the OEM/company; whether the case we relate to is the outcome of the electrification shift of the production - YES, if the plant has shifted the production, NO, if the plant is a Gigafactory producing BEVs or other electric vehicles' components-; the expected job impact in terms of number of direct and/or indirect job losses; whether a reallocation of the dismissed workers has been considered -NO, if dismissed and/or early retired; YES, if reallocation has been declared; NA if no information are available-; whether the policy maker has intervened in terms of implementation and/or financing, reallocation of dismissed workers and the advancement status -LOW, if planned but not implemented yet; MEDIUM, if the implementation has begun; ADVANCED, if already completed.

added activities towards low-cost countries, leading to a cumulated loss in employment in EU (Pardi, 2022), while R&D activities will remain and keep developing in high-wage countries as Western Europe, the United States, Japan and South Korea (Pavlínek, 2023). Indeed, Asian BEVs manufacturers are investing in Europe and especially in CEE, but exclusively in assembly lines manufacturing (Pardi, 2022). Again, the role of bargaining coverage and strength of trade unions in contracting with the main OEMs is crucial to assure reallocation of dismissed workers. Relocation strategies will also depend on market segmentation, considering that a complete transition towards electric vehicles is unlikely to occur across the globe, given the heterogeneity in electricity infrastructure and provision. Quite probably, the coexistence of incremental and radical technological trajectories will materialize in the next decade, with large divides between urban and non-urban mobility within countries, and between high-income and low-income countries.

Policy regulations are pivotal to address the decarbonization process in the right direction, both in peripheral countries, to break the persistent asymmetry with core ones, and in peripheral plants in core countries. Policies should be managed at the European level considering the peculiarities and specific needs, otherwise asymmetries will keep reverberating: "virtuous" countries will put in place "virtuous" policies, but non-virtuous countries will not. For instance, on the one hand, in a multi-targets policy package, the German government by means of the sustainable battery cells production measure allocated 3 billion euros for the manufacturing of battery cells and research projects in 2021.[5] On the other hand, Slovakia mainly provides tax exemption and purchase bonuses translating past EU regulations of charging infrastructures,[6] but no ad-hoc plans are devoted to preserve and create new jobs within the automotive and batteries manufacturing.

Figure 5 summarizes the causes and consequences of two alternative scenarios, a positive vis-à-vis a negative one of the automation, digitalization and decarbonization trends in the

[5]For additional information and details about the sustainable battery cells manufacturing and research projects policy in Germany see https://www.bmwk.de/Redaktion/DE/Dossier/batteriezellfertigung.html.

[6]For additional information about the tax exemption in Slovakia see https://www.iea.org/policies/6776-registration-tax-benefits-ev. For additional information about purchase bonuses in Slovakia see https://www.iea.org/policies/6697-local-incentives-ev.

automotive industry outlined so far. Inside such potential scenarios, heterogeneity of car producers is also fuelled by non-neutral regulatory actions. Since the EU-CO2 regulations have shown different impacts on countries and car producers' competitiveness, on the one hand, and on the efficacy to reach sustainable and efficient targets, on the other, the evolution of the EU CO2 regulation and the response of the car industry are analysed in the next section.

4 A brief history of European regulations on CO2 emissions: the non-neutrality of the regulatory push

To assess whether and how the European regulation on CO2 emissions shaped the productive choices of automotive companies and affected their competitiveness, it is crucial to account for the presence of heterogeneous actors - both countries and car producers - whose conflicting interests emerged in the process of refining and strengthening targets on CO2 emissions.

Because of the divide between premium and mass cars producers, combined to asymmetries in country production capabilities, European CO2 regulations have so far acted in determining a purported ex-ante external push, which however turned out favouring some actors, while disfavouring some others, failing to pursue a comprehensive European perspective.

If compared to the US experience, where the first regulation over air pollutants - the Clean Air Act - was introduced in 1970, the European Union arrived quite late with the Euro Norm 1 and 2, respectively in 1992 and 1996. At the beginning, no institutional mechanism of control over car production was envisaged by European authorities and a cooperative approach was further pursued in 1998, with the agreement between EU and ACEA on reaching the voluntary target of 140 CO2 gr/km by 2008, then turned in 2007 into a mandatory target equal to 120 CO2 gr/km by 2012.

Despite presented as one size "fits for all" measure, the ways through which automotive producers could reach these goals were different and highly dependent on the type (and weight) of cars produced and, on the technology adopted to reduce CO2 emissions. As underlined by Pardi (2022), two main models were on stage. From the one hand, producers of premium (luxury and larger) cars mainly located in Sweden and Germany, pushing for more complex technological solutions and in particular for the use of diesel; on the other hand, producers

Country	Company	Electrification of the production	Expected job impact	Jobs' reallocation	Policy intervention	Advancement Status
Germany	Audi	YES	-9,500, +2,000 by 2025	NO	YES	LOW
Slovakia, Bratislava	Volkswagen	YES	-3,000	NO	NO	ADVANCED
Slovakia, Kechnec	Magna	NO (Manufacturing of EV's assistance components)	+100 by the 4th quarter 2022, +600 by 2027	/	NO	MEDIUM
Spain, Martorell	SEAT	YES	-2,400 direct jobs (Martorell)	NA	YES	ADVANCED
Spain, El Prat	SEAT	YES	-1,000 direct jobs (El Prat)	NA	YES	ADVANCED
Spain, Sagunto	Volkswagen	NO, Gigafactory	+3,000	/	YES	LOW
Italy, Bari	Bosch	YES	NA	NA	YES	LOW
Italy, Bari	Magneti Marelli	YES	-550	NA	NA	LOW
Italy, Bologna	Magneti Marelli	YES	-230	NA	NA	ADVANCED
Italy, Grugliasco	Stellantis (Maserati)	YES	-1.100	YES (1100 to Mirafiori)	NO	MEDIUM
Italy, Termoli Imerese	Italvolt	NO, Gigafactory	+13,000	/	YES	MEDIUM
Italy, Termoli	Stellantis	NO, Gigafactory	+2,400	NA	YES	LOW
Sweden, Trollhättan	NEVS	YES	+Thousands (since 2019)	NA	NO	ADVANCED
Sweden, Göteborg	Northvolt	NO, Gigafactory	+3,000	NO	YES	MEDIUM
Sweden, Skellefteå	Northvolt	NO, Gigafactory	+2,000	NO	YES	MEDIUM
Sweden, Borlänge	Northvolt	NO, Gigafactory	+1,000	NO	YES	MEDIUM

Table 1: Selected OEMs shifting to production of electric vehicles and manufacturers of electric vehicles components, as BEVs and assistance components. Main Source: Nelli et al. (2022) with some revisions: one case has been added (Magneti Marelli Bologna) and one has been revised (Italvolt will invest in Termoli Imerese, not in Scarmagno as originally planned).

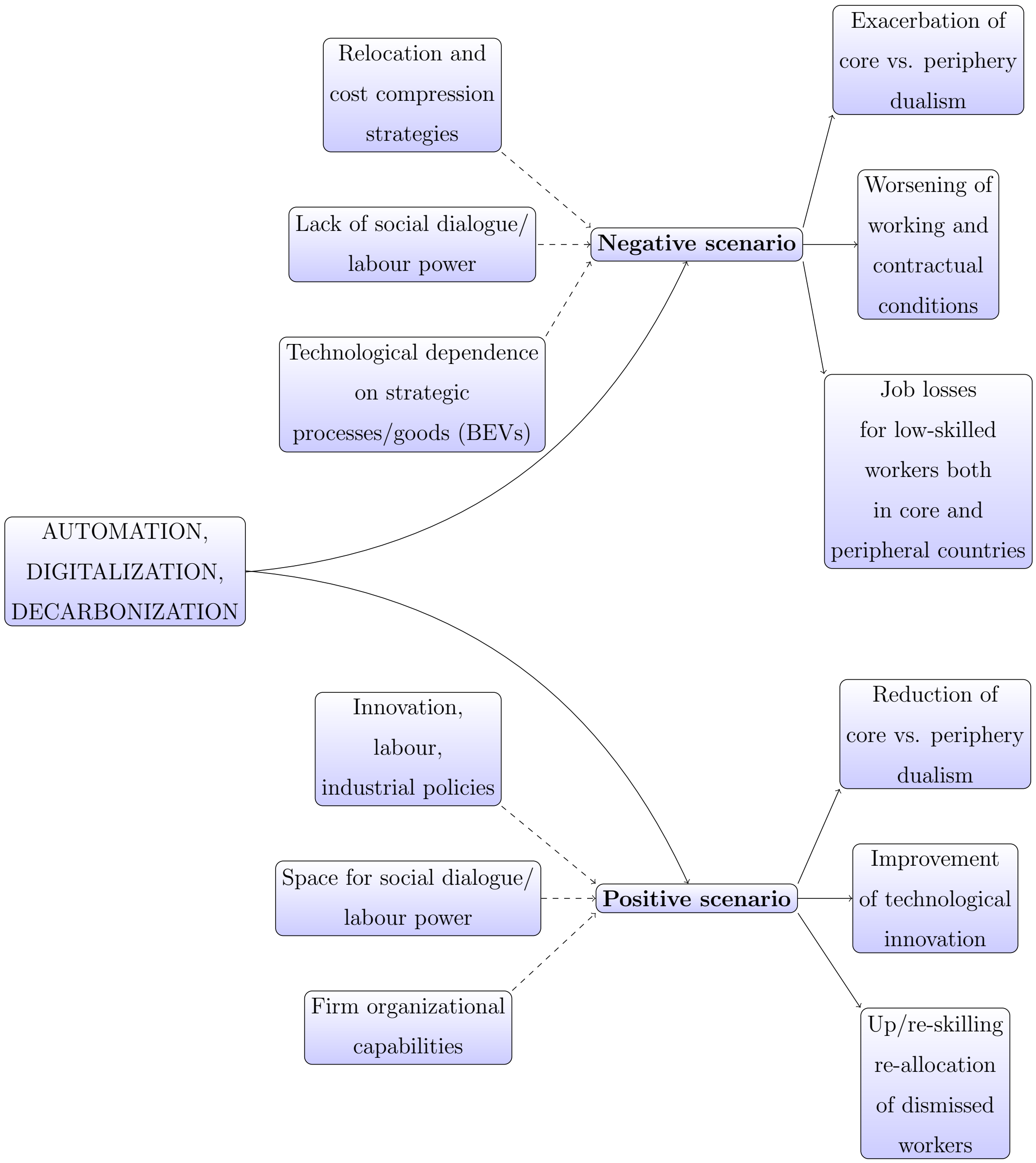


Figure 5: An illustration of positive and negative scenarios: causes and consequences.

of mass cars (smaller and lighter) located mainly in Italy and France, preferring cheaper solutions based on the improvement of fuel quality through lead traps and opened to the possibility of institutional constraints, such as the introduction of speed limits. The targets imposed turned quite early to be not sustainable, especially for premium car manufacturers that, despite important technological advancements such as the catalytic converter, were struggling more to reduce emissions because of the increasing weight and power of their engines. The development of diesel engines emerged as a solution, rather expensive, to the inherent contradiction between the expansion of the premium car market and the tightening of environmental constraints, causing however an increase in the cost of production and in the final price of the cars.

While premium producers could exploit a comparative advantage, as shown by their market expansion, generalist producers faced a major crisis of competitiveness. This paved the way to a more radical process of productive restructuring and delocalization in particular of French and Italian companies to reduce costs (Pavlínek, 2020).

After Euro 5 in 2009, Euro 6 in 2019 and stricter procedures on car test in 2017 following the Diesel Gate in 2015, the only possibility to comply with the new rules was to radically shift towards the production of electric cars - both BEVs and PHEVs – which until that moment were still marginal in the European car market. As previously experienced with diesel cars, the entire production of BEVs and PHEVs moved towards an "upward shift" documented by the rapid increase in their average weight and price (Pardi, 2022). The non-neutrality of the regulatory push clearly emerged in favour of new production models such as heavy and luxury cars, without the real sustainability of such production being accounted by the European Green Deal launched in 2019 and the Fit for 55 Package in 2021 (recently revised), which seems to further reinforce and accelerate this unbalanced process of electrification.
Conversely, major open issues remain in terms of sustainability:

- Still scarce attention is devoted to the pollution generated by the extraction of materials needed for the batteries, notwithstanding all the geo-political problems concerning the provision of raw materials, the energy required to produce batteries and the management of their disposals.
- The price and affordability of these cars keep targeting an ascendant luxury consumer

segment. They are still too expensive for the average European consumer, who have been experiencing a decline in purchasing power in the last decades, due to wage stagnation and inflation spike, especially after the Covid-19 pandemic and the Ukrainian war.

- The lack of infrastructure building, in order to ensure that electric vehicles do not remain a luxury choice for city inhabitants, but become a viable solution also for more remote areas.

Such contradictions are also revealed by the different country positions in their productive capabilities toward electric vehicles. The European Council in March 2023 has adopted the final regulation - with the abstention of Italy, Bulgaria, Romania, the vote against of Poland and the vote in favour of Germany - setting a 100% reduction of CO2 by 2035 for new cars and vans and granting the possibility of producing ICE cars that function exclusively with CO2 neutral e-fuels, stimulating new debates among European countries and environmental actors on their alleged climate neutrality and effectiveness (for previous evidence on automotive lobbying strategies see Transport&Environment, 2021).

Specific forms of regulations accounting for the heterogeneity of actors and conflicting interests at stake need to be identified to achieve efficient and sustainable targets. Among the actors involved, trade unions, workers' representatives and institutions play a crucial role to balance the risks -e.g., reconfiguration of value chains, technological substitution of the workforce, deskilling, work intensification, digital control of performance- and opportunities -e.g., increasing professionalism and qualification due to the interface with new technologies, ergonomic improvements, greater opportunities for employee participation- which the twin transition of the automotive industry entails for employment and working conditions. Collective bargaining on new technologies should be supported by ad-hoc regulations as well, given the asymmetries of industrial dynamics across countries, the reinforcement of structural asymmetries between employers and workers by the twin transition, and core and periphery dualism of protection of the workforce along the value chain.

We discuss the impact of the twin transition on the industrial relations system in what follows.

5 The role of trade unions in the digital and ecological transitions

To understand the relationship between workers and technologies, it is crucial to examine the possibilities for action opened up to trade unions and workers' representative bodies (Lucio et al., 2021; Cirillo et al., 2023), providing an analytical framework to study the role they play (or not) in transition processes in terms of (i) levels and spaces of intervention, and (ii) structures of interactions with other actors.

The automotive industry, the critical sector of the second phase of industrialisation since the early post-war period (Kurth, 1979), represents one of the industries in which collective bargaining has been most developed – especially in OEMs and larger suppliers – and in which industrial relations have shown to be resilient but also highly dependent on national historical paths (Jacobi et al., 1986). Despite their historical power, currently trade unions do not appear to be in a strong position to orient the twin transition. During the last three decades, in fact trade unions have suffered from the reconstruction of managerial hegemony in the workplace due to the adoption of the lean production model (Womack et al., 1990; Pil and MacDuffie, 1996), and from reforms that have liberalised the labour market and favoured decentralisation of collective bargaining under the threat of site closures and restructuring (Pedersini and Pallini, 2010).

To assess the role of trade unions, it is important to distinguish the specific forms of regulation that can help support collective bargaining on new technologies, together with the centrality of the industry within national economic systems.
Results from a diverse number of studies demonstrate the relative importance of labour market institutional factors in shaping technology implementation. In coordinated market economies, institutions support firms in the adoption of new technologies through the development of specific workers skills or social partnerships, while at the same time trying to use technological change as a mean to circumvent national and industrial arrangements (Doellgast and Wagner, 2022). At the opposite, in countries with liberal or embedded neoliberal market economies (such as the Visegrad countries, Bohle, 2017) the absence of these institutions ignites firms to formulate strategies based on short-term investments and re-

liance on cheap, unskilled labour (Krzywdzinski, 2017; Lazonick, 1979; Diessner et al., 2022).

While specific industry level studies on the twin transition are still missing, insights can be drawn from studies on the involvement of trade unions and works councils in the implementation of Industry 4.0 in the metalworking sector in Germany and in Italy. With respect to the German case, given the institutional entrenchment of German trade unions and works councils within the organisational structure of the metalworking sector, a so-called dual model of industrial relation (Müller-Jentsch, 2008), the introduction of new technologies is an important subject of negotiations between management and labour, both at industry and company level. However, even in this institutional environment in which the metal industry represents a core sector of industrial relations with respect to other sectors (Vandaele, 2018), the involvement of trade unions and works councils in technological innovation processes linked to Industry 4.0 has not been straightforward. On the one hand, IG Metall only recently has tried to take a proactive role in shaping technological change, by engaging in the promotion of social partnership framework agreements on digitalisation at company and plant level (Bosch and Schmitz-Kießler, 2020). On the other hand, the aim to raise the work councils' awareness of the impact of digitalisation required substantial investments on the burden of trade unions (e.g. through the provision of union officers and external experts) (Pulignano et al., 2023). Such result was successful mainly in those cases where a tradition of cooperative industrial relations already existed at factory or company level (Haipeter, 2020).
Nevertheless, discussions of Industry 4.0, together with the Covid-19 crisis, contributed to a more general resurgence of traditional corporatist coordination between state and corporate actors. This resurgence manifested itself especially in the development of the German government's strategy on artificial intelligence (AI), which includes a commitment to strengthen social dialogue in this area. Conversely, although the trade unions failed to obtain a general right of co-determination in the digitalization process, the Works Council Modernisation Act, enacted in June 2021, reinforced the consultation, information and co-determination rights of works councils in the field of AI (Krzywdzinski et al., 2023).

With reference to the Italian case, the auto industry is experiencing a severe downgrading trajectory, lacking any coordinated industrial policy to counteract the reduction in final car production and export. Trade union negotiation is regulated by a mandated industry-level collective bargaining plus an optional firm-level one. Cirillo et al. (2023) show that the introduction of Industry 4.0 technology opens a new space of action for trade unions in influencing firms' technological adoption decisions. However, large heterogeneity even among narrowly defined workplaces under the same trade union is manifested, with proactive strategies only in corporatist-oriented workplaces, generally under foreign ownership, and recording more resistant attitudes to technologies in the remaining cases. The results are however limited to a niche region, highly innovative and largely dependent from German FDI and ownership control, Emilia Romagna. In addition, the companies analysed are entirely under FIOM representation, an organization mixing both forms of corporatism (to a larger extent) and conflictual practices (to a minor extent). National and coordinated strategies fostering social dialogue in the domains of digitalisation and AI are completely missing, although scant initiatives have been activated by regional and national FIOM representatives.

5.1 A theoretical framework to map trade unions capacity in the twin transition

The surveyed German and Italian cases of Industry 4.0 allow thus to move away from a narrow view of the study of negotiation over technology and to frame the issue according to the broader perspective of the politics of "production" (Burawoy, 1985), framing the problem of negotiation over technology (the "technopolitics of production") within and across different 'arenas'(Schaupp, 2021):

- *The arena of regulation* involving the state, trade unions and employers' confederation, giving rise to the regulatory framework, acting at the macro-institutional level.
- *The arena of implementation*, wherein at the company and workplace level the process of technological adoption takes place.
- *The arena of appropriation* which refers to the practical use and misuse of technologies by workers, oriented by shared cultural schemes.

These arenas do not strictly correspond to the various levels of collective bargaining (country, sectoral, company/plant). In that, the framework is apt to analyse institutionally different national environments. Besides, a broader concept of negotiation that *"encompasses both cooperation and confrontational interactions"* (Schaupp, 2021, p. 75) is put forward: negotiation, in this respect, deals not only with formal collective bargaining, but also with informal ones, for instance through collective or individual practices of resistance and organisational misbehaviour enacted in reaction to the implementation of new technological artefacts (Hodson, 1995; Ackroyd and Thompson, 2022). Finally, using this broader analytical framework makes it possible to include those actors external to industrial relations but who can influence the negotiation outputs by exerting political, social or economic pressure (e.g. public institutions, social movements – especially those linked to the struggle against climate change - experts, etc.) (Parker et al., 2021; Garneau et al., 2023).

Whether and in which direction collective bargaining and trade unions will play a central role in influencing the twin digital and ecological transitions is still an open issue. However, their action has great potential to radically alter the current industrial relations systems by shifting their power relation. In a context in which we are witnessing a reduction in both associational power (steady decline in union density, weakening of corporatist structures) and structural power (dictated in particular by the fragmentation of the workforce and weakening of employment conditions), in order to influence the digital and ecological transition, trade unions could try to resort alternatively to their capabilities in exercising:

- *Institutional power*, i.e. the power to foster workers interests or constraining employers action through the use of institutional mechanisms or legal frameworks (Korpi, 1985).
- *Societal or coalition power*, i.e. the power to forge alliances and coalitions with other actors of society (Tattersall, 2010), as with climate justice movements and rediscovering their social-environmentalist roots in a working class ecology perspective (Barca and Leonardi, 2018; Feltrin and Sacchetto, 2021).
- *Ideational (or symbolic) power*, the capacity to influence actors' normative and cognitive beliefs, for instance (Carstensen and Schmidt, 2016), putting forward political agendas able to re-orient the public discourse on the world of work.

A case to the point is the inclusion of the notion of 'Just Transition' at the top of the international political agenda, since the UNFCCC COP held in 2010, which is partly the result of the efforts of the international trade union movement (Clarke and Lipsig-Mummé, 2020). Embedded in various institutional frameworks, such as the preamble of the Paris agreements and the ILO guidelines, the concept of just transition concerns not only outcomes of the decarbonization process, but also the management of the transition itself, which must involve significant forms of social dialogue at all levels, concerning both the distributional effects of climate policies and the management of the employment transition (Galgoczi, 2018).

Mobilizing symbolic power, i.e., the capability to put forward new ideologies and practices in addressing societal needs and challenges, is proving to be an effective way to regaining lost power for trade unions. The stability of current industrial relations systems is linked to the reproduction of existing negotiation practices, which currently seem to limit the role of workers and trade unions in the processes of technological change. By redefining the actors, the logic of action and the boundaries, both internal and external, of collective bargaining to adapt it to the challenges of the twin transitions, trade unions have a historic opportunity to change the balance of power in the automotive industry and beyond.

6 Conclusions

Automation and digitalization have a dual effect on employment, with the automotive industry being not an exception. The increase in complexity of technological innovations implies a decreasing share of manual tasks in plants, however accompanied by new functions, skills and occupations in emerging segments of production, such as research and development, installation and maintenance of machineries, robots and software systems, data analysis. The very same duality defines the employment effects of the decarbonization process. Because of the shift to the production of the electric engine and vehicles, value chain disruptions are expected together with consequent job losses. The manufacturing of BEVs is however expected to offset such job losses, together with ICT, engineering and indirect jobs.

All in all, the relation is all but straightforward. Asymmetries across core and peripheral countries, and plants, characterise all the trends at stake: relocation towards low wage countries, proximity to R&D centres, institutional factors as differences in vocational training programs and bargaining coverage are the main sources enhancing such asymmetries.

The direct effects of the above mentioned asymmetries are reflected in the ability to manage and govern the automation, digitalization and decarbonization challenges, especially in limiting massive unemployment and workplace inequalities. To manage the process of transformation brought about by new technologies adoption and decarbonization efforts in the automotive industry, we have outlined the importance of different factors at stake and the political economy of the actors therein, with particular reference to the role exerted by the regulatory push as a non-neutral institutional stratification of rules, and trade unions' actions in affecting the end results of such transformations. A framework of mobilization of trade unions' actions and social dialogue is spelled out, highlighting three parallel directions of power reconstruction, namely, institutional, coalitional and ideational.

Policy proposals pushing an alignment across European countries in R&D investments for technological innovation and ensuing programs for vocational training, labour market regulations to increase wages and labour rights, and limitations to pervasive control of worker management technologies and relocation of production activities, should be accompanied by a multi-level social dialogue framework. The social dialogue approach is deeply needed to conceive and imagine paths that make the twin transition a just one, addressing the negative distributional effects of blunt climate policies, and reorienting the public intervention toward a new path able to restore and support labour power. So far, the path of the transition has been slow and deeply affected by pre-existing power structures of the involved actors, particularly in the state-corporations binomial. Enlarging the sphere of public intervention toward a European industrial policy for social and climate justice should be an alternative direction to take.

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