TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 69, Issue I, March, 2026

STRATEGIC SCENARIOS FOR THE TRANSITION FROM INDUSTRY 4.0 TO INDUSTRY 5.0 IN THE AUTOMOTIVE INDUSTRY IN EUROPE

Gabriel SÎRBU, Adrian Ciprian FIRU, George DRĂGHICI

Abstract: *In the current geopolitical and technological context, the adoption of Industry 4.0 (I4.0) principles in the European automotive industry, especially in the segments with small production runs, has been delayed due to economic, technical, and structural barriers. In the coming years, the European Commission's strategy defines the transition to Industry 5.0 (I5.0), focused on sustainability and the integration of humans into the industrial cycle, based on the I4.0 infrastructure. In this context, the problem of ensuring the successful transition from I4.0 to I5.0 and of defining, adapting, and implementing the design and production methodologies necessary for this transition arises. At the same time, in China, the implementation of the "Made in China 2025" (MIC2025) strategy has allowed the development of its industrial model based on the adoption of advanced technologies. The global success of MIC2025 calls into question the industrial model of the European Union (EU). The article analyzes the current context, compares industrial models, describes the barriers to implementing the European strategy, and analyzes new opportunities and perspectives for bridging the technological gap necessary for the successful adoption of I5.0 principles.*
Keywords: *Industry 4.0, Industry 5.0, Made in China 2025, automotive industry, industrial model, small production, mass personalization*

1. INTRODUCTION. THE TECHNICAL-ECONOMIC CONTEXT IN THE AUTOMOTIVE INDUSTRY

Industry 4.0 (I4.0) is defined by ensuring efficiency in production through: large-scale automation, use of collaborative robots, making production more flexible by modular products, integrating the Internet of Things (IoT) coupled with 5G connectivity, collecting real-time data with sensors and analyzing it with Big Data (BT) tools and using Digital Twins (DT).

In the European automotive industry, especially in segments with small production runs (premium vehicles, niche electric vehicles, commercial vehicles, recreational vehicles (RV)), the adoption of I4.0 has been incomplete, being drastically limited by the high costs of implementation, lack of product design and production processes standardization and modularization, as well as the difficulty of bringing manufacturers into an commonly defined industrial ecosystem.

At the same time, China, through its strategic program “Made in China 2025” (MIC2025), has coordinated the integration of industrial policies and digital infrastructure, allowing the creation of integrated standardized production platforms. As a result, the time to market for new products has decreased to less than 1 year, compared to 2-3 years in EU27 [1].

For the automotive industry, this meant, on the one hand, increasing production costs in Europe and, on the other hand, a rapid penetration of Chinese brands in Europe.

Figure 1 presents the evolution of automotive production in the European Union (EU27) compared to China between 2020 and 2025. In Figure 2, we can see the **e**volution of the share of electric vehicle (EV) sales made in China in Europe between 2020 and 2025.

Car production in the EU27 remains at an almost flat volume, while electric vehicles produced in China are rapidly increasing their share in sales in Europe, with one in 4 electric vehicles sold being of Chinese origin in 2025.

Received: 17.01.26; **Similarities**: 10.02.26: **Reviewed**: 17.01. /17.01.26: **Accepted** 25.03.26.

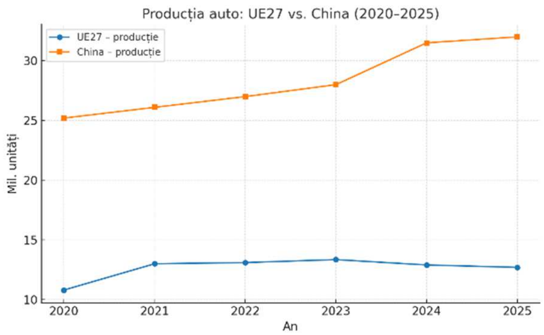

Fig. 1. Evolution of automotive production in the European Union (EU27) compared to China between 2020 and 2025 [1].

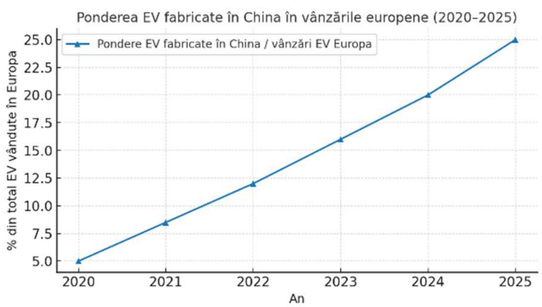

Fig. 2. Evolution of the share of electric vehicle (EV) sales made in China in Europe between 2020-2025 [1].

The paper presents the current context, compares industrial models, describes the barriers to implementing the European strategy, and analyzes new opportunities and perspectives for bridging the technological gap necessary for the successful adoption of I5.0 pr, based on available information from public, industry and consultancy companies' papers monitoring the status of industrial evolutions.

2. STAGE OF I4.0 ADOPTION IN EU27

2.1 Barriers to I4.0 adoption

In theory, I4.0 promised complete digitalization, interconnection, and flexibility, applicable to any production model. In practice, however, implementation in the European automotive industry, especially in the low-volume segments, has been limited by technological, structural and economic factors:

- **Investments cannot be amortized**

In small-scale production, the cost of implementing I4.0 is difficult to justify economically, as the amortization is made on a small number of units. A complete automation system with Artificial Intelligence (AI) and DT integration may require initial investments of €5–10 million, which are amortized on a volume of 5,000–20,000 vehicles/year [2].

- **Customized production processes and dependent on skilled labor**

Niche brands such as Bentley, Ferrari, and small electric vehicle manufacturers use manual and semi-automated processes to enable customization and/or reduce investments. Similarly, RV manufacturers have high degrees of customization, and it is difficult to automate [3].

- **Slow supply chain integration**

Unlike mass production, where suppliers are already prepared for real-time data exchange, in small-batch manufacturing, many suppliers are small, specialized workshops without an I4.0-compatible digital infrastructure. The result is a "digital island" in the factory, without data continuity throughout the supply chain [3].

- **Fragmentation of standards and lack of interconnection of production systems**

In the absence of common standards for interconnection and interoperability between production systems, digital factory management systems (Enterprise Resource Planning, ERP), and IoT at the industrial level, small-scale manufacturers face difficulties in choosing scalable solutions at both horizontal and vertical levels. This problem is amplified in the EU27, where each country has its own industrial policies and technical regulations [4].

- **Geopolitical and market volatility**

Recent crises (COVID-19 pandemic, semiconductor crisis, war in Ukraine) have drastically reduced the availability of capital for investment and forced companies to prioritize spending on maintaining supplies and the logistics chain at the expense of large-scale adoption of I4.0. Small-batch manufacturers are even more vulnerable to supply fluctuations, and in the absence of a stable medium-term order outlook, technology investment planning is deprioritized and considered risky.

In the EU27 countries, the degree of adoption of I4.0 technologies varies from one country to another. There is no monitoring of the adoption degree, no "official index" for the adoption of I4.0 in each country, and no integrated strategy at EU27 level to stimulate adoption and meet relevant objectives. The implementation of I4.0 results more as a natural evolution of the industry's needs for efficiency and transparency of production processes, than as the result of a horizontally and vertically coordinated effort, supported by relevant technological, economic and political policies.

2.2 The Stage in Germany

It is the EU27 leader in I4.0 adoption, with 62% of companies in Germany using I4.0-related technologies, with a preponderance in the automotive sector (along with machinery -and electronics) [5]. 42% of German industrial companies are using AI in production and an estimated 35% are planning to implement it in the next 3-5 years [6]. ACATECH, the German Academy of Technical Sciences, has monitored an I4.0 adoption parameter, called the "Industry 4.0 Maturity Index". This is used by thousands of companies to guide the transformation and transition to I4.0 digital services [7]. In addition, the Ministry of Economics (BMWK) emphasizes that the public agenda supports the transition from research to the use of I4.0 applications in companies [8]. However, small manufacturers are limited in their I4.0 adoption, and the industrial ecosystem does not allow horizontal nor vertical integration of technologies and platforms.

Under macro-economic pressures, BMW is innovating intensively towards I4.0: it uses virtual reality (VR) and advanced robots to plan the factories of the future, as is already happening at the Regensburg plant, preparing the new generation "NEUE KLASSE" [9].

At the Landshut plant, which specializes in components for the electric BMWi and BMW7 models, the "Nexeed Industrial Application System" software system was implemented, ensuring planning, monitoring and control of production processes while providing real-time data to personnel. Such platforms are available for integration into factories, but, for now, the costs are prohibitive for SMEs [10].

BMW uses sensor-driven predictive maintenance, BT and AI, replacing traditional maintenance methods, a clear example of successful adoption of I4.0 [11]. AI predictive maintenance has reduced assembly downtime by over 500 minutes/year, equivalent to savings of several million euros a. The payback period for the investment in AI and scanner systems has been estimated at 2–3 years, due to the reduction of scrap and improved cycle time.

2.3 The stage in the Netherlands

Recent academic analyses show that the presence of I4.0 technologies is strongly driven by the automotive industry, focused on IoT integration and data analytics. The article [12] emphasizes the idea that the adoption of I4.0 has occurred as a natural evolution of technologies rather than because of a coordinated implementation policy.

The same aspect of lack of coordination at the macro level is claimed in an independent study as the main negative factor in the lack of success in the implementation of I4.0 [13].

In the Netherlands, TNO, technical universities (TU Delft/Twente/Eindhoven) and "Fieldlabs" are the channels through which the industry rapidly tests I4.0 tech; the Netherlands emphasizes collaboration and piloting but does not have solutions for the adoption of I4.0 for SME. It recognizes the need to integrate companies into an I4.0 ecosystem, while providing an academic and governmental framework for piloting projects.

Driven by a challenging contract with BMW, VDL Nedcar automotive factory developed an I4.0 strategy in response to flexibility and transparency contractual requirements. With high investments and a long-term strategy, VDL integrated specific I4.0 software platforms. A factory DT was developed to reflect the production processes in real time, allowing simulations and virtualization [14]. It allowed the simulation of production before implementation, reducing factory modification times by 40%. VDL completely digitalized its operations, using the software solutions SAP Yard Logistics and SAP Fiori, collecting real-time data, automating truck flows, reducing waiting times and weekly manual inventory [15].

2.4 Stage in France

The I4.0 landscape in France is not much different from other developed European countries, with giant manufacturers (Stellantis, Renault, Michelin) leading the way in integrating I4.0 technologies. However, the situation is different in the supply chain, with many industries having difficulty meeting requirements. In terms of SME (vehicles, prototypes, special bodies), full adoption of I4.0 is hampered by costs and standards that manufacturers cannot afford [16]. "Industrie du Futur" programs are trying to correct this gap, but with a low degree of confidence to achieve an integrated ecosystem [17].

The Stellantis plant in Sochaux (formerly Peugeot) uses autonomous robots, collaborative robots, real-time data collection with sensors, IoT technologies, and Big Data analysis, and is considered "one of the most efficient 4.0 factories in the world" [18], [19]. Investments in autonomous and robots were linked to an energy efficiency program; the cumulative savings from reduced water, energy, and raw material consumption shortened the investment amortization to approximately 4 years, in the context of the transition to electric vehicles (EV).

These three examples demonstrate that the success of adopting I4.0 in Europe and extending the adoption of technologies to SMEs depends not only on the available technology, but also on:

- Economic efficiency of investment – justification of investments for management and shareholders.
- Supply chain integration – standardization and digitalization of relationships, expansion of modular production platforms.
- Systematic professional retraining – preparing the workforce for digital skills and human-machine collaboration.

3. STAGE OF I4.0 ADOPTION IN CHINA

3.1 Made in China 2025 (MIC2025)

Launched in 2015, MIC2025 is the State Council's first 10-year strategy dedicated to manufacturing modernization, to increase product value and reduce dependence on foreign technologies. The framework documents provide for a three-step approach until 2049, defining "domestic content" targets for components, materials, and technologies used in industrial production (40% in 2020 and 70% in 2025), targets that have since disappeared from official rhetoric but have defined the industrial policy toolkit [20].

For the automotive industry, the MIC2025 strategy brought a concentration of design and industrialization activities around "key" sectors of activity: new energy vehicles (especially EV), robots, advanced materials, IoT, and 5G equipment, and the realization of the "smart manufacturing" (SM) concept. In addition, the Chinese state has prioritized the financing of key sectors by providing subsidies for these key sectors. Local companies have formed strategic partnerships with the state and have prioritized local investments and horizontal and vertical technology transfer. At the same time, there has been an increased emphasis on the creation of national innovation centers and the launch of SM pilot projects [21].

MIC2025 was complemented by programs on the large-scale integration of 5G and 5G+, as well as IoT in thousands of factories. These initiatives have reduced the time for process automation and allowed the rapid scaling of production lines for EVs and subassemblies (batteries, motors, inverters) [22]. Through strategy, China has become the world leader in EV and battery sales, while the EU has stagnated [23]. Independent assessments show tangible progress in key sectors (EV, robotics), increased industrial efficiency, but also risks of overcapacity, especially in the EV area [21].

MIC2025 has enabled the integration of technologies into modular production platforms, which accelerate the development and launch of new products [24].

3.2 The stage at BYD (Build Your Dream)

BYD is the largest Chinese manufacturer of EV and hybrid vehicles, the global leader in EV sales in 2023–2024. Working closely with the government and adopting MIC2025 principles, BYD has developed a unique production model, characterized by a complete vertical integration of subassembly production and final assembly. Through complete control of the production chain, coupled with the integrated adoption of I4.0 technologies (advanced robotic automation, IoT integrated operations, AI analysis of deliveries and automated testing of products and systems), BYD has created an efficient production model, which allows it to be scalable, integrated and fast in launching new products and production lines [25].

3.3 The stage at NIO

NIO is a premium, high-tech EV manufacturer. The NeoPark Factory in Hefei is designed to fully adopt I4.0 technologies: flexible assembly lines, IoT sensors, AI control for efficiency, and digitalized processes integrated with customer orders. The company's most remarkable achievement is the definition and implementation of a production platform capable of automatically producing unique customized vehicles (the "lot-size-one" concept). NIO's production model already incorporates specific I5.0 elements, including large-scale customization and sustainability, and is an early example of the transition to I5.0 [26].

4. COMPARISON MIC2025 VS. EU27 IN I4.0 ADOPTION

4.1 New Products launch speed

The Chinese ecosystem (manufacturers - suppliers - equipment integrators) can put an EV line into operation in quarters, thanks to a continuous effort to standardize products and operations, availability of investment capital and the vertical integration of suppliers of standardized components and services available at short notice. The use of IoT, AI and modular platforms allow for accelerated start-up of production.

The adoption of I4.0 in Europe allows large manufacturers to launch new products in a short time, but incomparably larger than their Chinese competitors. In contrast, in Europe, small-series automotive SMEs remain captive in "digital islands" created around their factories, do not integrate technologies horizontally or vertically and fail to adopt I4.0.

From a financial point of view, for these companies, in the current ecosystem, the adoption of I4.0 is difficult to demonstrate.

4.2 Economy based on modularity

MIC2025 has stimulated modular EV platforms and tier 1 suppliers that offer complete packages, reducing the cost of configuration for local automakers. In contrast, in Europe, such platforms are not available, and small-series manufacturers rely heavily on imported technology and products, which increases costs and delivery times.

4.3 Focus on equipment and software

The MIC2025 target to purchase manufacturing technology and software locally has boosted domestic production of robots, controllers, making a wide range of modular automation solutions available. In contrast, in small European firms, the acquisition and integration of automation remain costly.

4.4 Market volatility

MIC2025 ensured its success by creating overcapacity in production, which led to price pressure and limited exports of rare materials. In the Chinese economic framework, there were complaints of dumping practices, restricted exports, and government policies that would be impossible to implement and sustain in Europe.

5. COMPETITIVE ADVANTAGES OF THE EU27 AND POSSIBLE TRANSITION SCENARIOS TOWARDS I5.0

In the context of the uneven adoption of I4.0 in the EU27, of the global pressure created by Chinese manufacturers stimulated in the MIC2025 program, the European automotive industry, especially that focused on small-scale production, is facing a difficult situation, which leads to the following questions:

- How will it manage to make the strategic transition from I4.0 to I5.0?
- Does the EU27 have enough strategic advantages to counter the Chinese model?
- What are the possible transition scenarios from I4.0 to I5.0?

5.1 Competitive advantages of the EU27

In the context of the transition from I4.0 to I5.0, Europe starts with a set of competitive advantages that, if exploited intelligently, can provide it with increased resilience even under the pressure of the Chinese model:

- **Existing and diversified industrial infrastructure**

  Europe has a dense network of manufacturing centers with multi-sector expertise (automotive, aeronautics, energy, and medical). Existing factories are already partially digitalized and can adopt I5.0 elements (collaborative AI, mass customization). In this way, the transition time is much shorter than building from scratch.

- **Technological innovation ecosystem**

  Europe has a high density of research and development (R&D) centers and top technical universities (Germany, France, the Netherlands, Sweden). These in turn provide access to advanced know-how in robotics, automation, new materials, and green energy.

Through the Horizon Europe, IPCEI programs, the European Commission is stimulating emerging technologies associated with I5.0 and the integration of AI in industry. By using this ecosystem in an integrated way, the EU can develop unique solutions and patents that can create technological barriers and a significant competitive advantage.

- **Specialized workforce**

  Europe has a long tradition of training specialists in technical fields and has a workforce experienced in introducing highly complex production systems and technologies. In addition, a work culture oriented towards quality, safety, and standardization can ensure the successful implementation of mass customization models without compromising operational safety and reliability.

- **Regulatory and Sustainability Leadership**

  The EU is world leader in defining environmental and safety standards (Euro NCAP, REACH, CE), exactly the area where I5.0 places the greatest emphasis: sustainability and human needs. Through this approach, the EU can define the needs of I5.0 and force the alignment of international competitors

- **Integrated framework for transnational collaboration**

  EU27 facilitates partnerships between states, industries, and academia and has a long experience in complex transnational projects (Airbus, Galileo). This can stimulate the rapid integration and scaling of product platforms, facilitating the integration of product and production models, both vertically and horizontally. These advantages do not fully compensate for the speed and cost of the Chinese model, but they can give Europe an advantage if the transition to I5.0 is made quickly and in a coordinated manner, with investments oriented towards modular platforms, customization, and sustainability.

5.2 Transition scenarios from I4.0 to I5.0

In the above-defined context, we have identified 3 possible scenarios to ensure the transition from I4.0 to I5.0 in EU27:

- **Completing I4.0 adoption before starting I5.0 adoption**

  This scenario allows for the maximization of the existing investment recovery but has a major risk of competitive lag. In this context, large manufacturers would maximize their production efficiency and benefit from the cost reductions promised by the I4.0. For SMEs, this would entail prolonged adoption efforts, delays in aligning with the new standards for launching new products in series, and continued limitation of customization possibilities. These SME would spend the next 10 years reaching I4.0, with reduced productivity and adaptability. They would also delay any I5.0-related improvements (like human-centric workstations or sustainable processes), which could lock them out of emerging markets.

- **Hybrid transition 5.0 over 4.0**

  I5.0 principles (sustainability, human-centricity, AI implementation) are adopted on an I4.0 skeleton, from which implemented technologies are extracted and I5.0 elements are added. It requires accelerated standardization, creation of modular platforms and micro-factories [27], and large-scale AI adoption to compensate for the shortcomings of the lack of missing data in I4.0. In this context, both categories of manufacturers will benefit from the advantages of mass customization, the implementation of regulatory programs oriented to human needs and sustainability. Large investments remain necessary for automation and vertical and horizontal modular platforms integration. In this scenario, the execution risk is high: when new technologies are not implemented properly (bringing the right AI over I4.0 data collection structures) would lead to wasted investment.

- **I5.0 European Design- China Production**

Here, SMEs can benefit from the speed and cost advantages of the Chinese production, while offering I5.0 product concepts. However, the sustainability of the model and how product platforms can be integrated are questionable. This also raises ethical issues, compliance with European regulations, and major risks of creating a strategic dependence on China.

When looking at the 3 possible scenarios, the balance between expected payback and implementation risks must be carefully evaluated. Also, based on the status of adoption, the planned investments (industry and state-backed), the timeline for each scenario implementation shows a preference for scenario 3, with the high risk of becoming highly dependent on China. Blue bars show the central estimates of when the first I5.0 benefits emerge and when full maturity is reached.

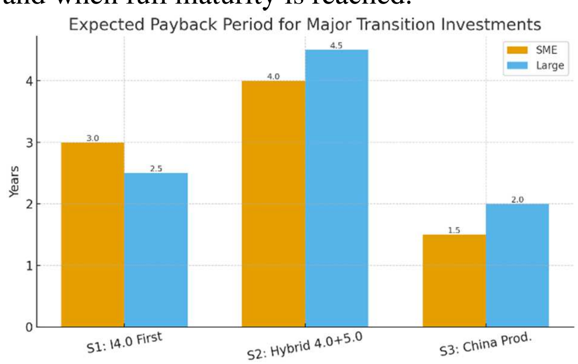

Fig. 3. Expected payback for a similar investment intensity for the proposed scenarios for Small Manufacturing Entities (SME) and large manufacturers

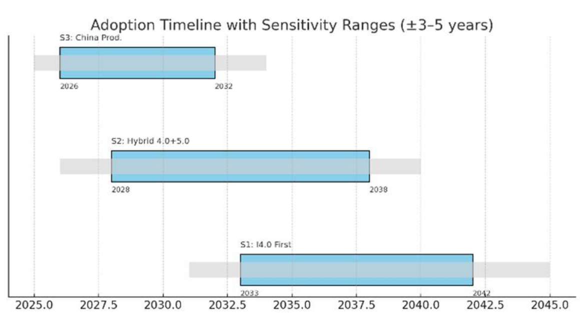

Fig. 4. Adoption timeline with sensitivity ranges for the transition from Industry 4.0 to Industry 5.0 under three strategic scenarios.

In Fig. 4, grey bands represent a ±3–5-year range reflecting uncertainty due to investment cycles, regulatory shifts, technological readiness, and geopolitical volatility. Scenario 1 (I4.0 First) implies that first I5.0 benefits come only after I4.0 is finished ~2033 (for large firms) since 2025–2030 is dedicated to finishing I4.0. We can estimate full maturity adoption around ~2042, as I5.0 investments start late (mid-2030s) and take ~10 years to complete. Scenario 2 (Hybrid 4.0+5.0) accelerates the timeline, achieving maturity in the late 2030s with first I5.0 benefits arriving earlier (~2028) since hybrid pilots begin while I4.0 is still underway. Full maturity could be reached by ~2038, i.e. 5–7 years earlier than Scenario 1, reflecting overlapping adoption. Scenario 3 (China Production + EU I5.0 Design) brings earlier benefits but raises dependency risks, with maturity possible as early as the early 2030s. Here, first I5.0-like benefits come almost immediate (~2026), because Chinese partners already operate advanced lines and EU design can plug into them quickly. Full maturity could be reached ~2032, depending on how fast EU27 design and Chinese production integrate, but still shorter because investment barriers are low and infrastructure already exists.

5.3 Proposals for overcoming barriers to the transition from I4.0 to I5.0

Europe's competitive advantages in product and process design can be strengthened and expanded by updating traditional design methods, in line with I5.0 principles.

Regardless of the chosen scenario, defining a product that meets the requirements of I5.0. is the basis of the set of measures necessary for the successful transition from I4.0 to I5.0. The proposals below aim to integrate human values, sustainability, flexibility, and resilience in the design phase, not just in execution:

- **Integrated design in the context of I5.0**

Model-Based Systems Engineering (MBSE) is a methodology that transforms the engineering of complex products from a paper-based process to a digital model-based process, making it an essential pillar for the transition to Industry 5.0. In I4.0, MBSE is used to integrate via IoT: sensors, robots and software into the same product architecture. In I5.0, MBSE became even more important because it enables mass customization and the integration of humans with AI, in a continuous development loop: flexible, adjustable digital models serve as a common platform where humans and algorithms collaborate.

Through the high degree of regulation, extensive experience in the production and development of complex systems, the EU27 could define a single framework platform on the ISBM model, in which the inclusion of requirements for human orientation, sustainability and human-AI collaboration would define the design methods of the future, easily accessible to small series manufacturers, offering a significant competitive advantage.

- **Interdisciplinary collaboration at the industrial level**

Different industrial sectors in the EU have different degrees of adoption of I4.0, as well as different transition plans towards I5.0. In a coherent transition strategy, different industrial sectors could create European modular micro-factories [27] that provide production lines with standard processes ready for immediate operation – "plug & play", scalable, backed by a "virtual" simulation with DT. The commissioning of new lines, the adaptation for small production runs, especially with mass customization functions, could be faster, providing an unrivaled competitive advantage.

- **Using AI-powered product configurators**

Classic product configurators work by combining predefined solutions, are usually limited to the models and solutions available at the time of commissioning the selection platform and can economically cover a limited range of combinations.

Through a coordinated transnational and multidisciplinary approach, in which product configurators have continuous access to newly launched products, can predict new combinations through BT analysis with AI tools and considering unique factors of I5.0 technologies, user needs and sustainability, the EU could lead the I5.0 configurators market.

- **Intellectual property protection**

Gaining competitiveness through innovation advantage is an underestimated factor of Industry 4.0. The focus on achieving the highest level of efficiency in I4.0 has limited the evolution scenarios of the EU industry, in the EV area, and especially in the area of SME. Constantly under pressure from costs and the penetration of Chinese competitors, manufacturers have innovated and collaborated less to exploit the few innovations obtained.

Through a common strategy to create a single European hub, based on principles of sharing innovations horizontally and vertically in industry (unitary patents), the EU27 could become an undisputed leader in Industry 5.0, regardless of the chosen adoption model.

6. ANKNOWLEDGEMENT

The content of this article is related to the DigiFunCollab project – "Developing Digital-Self-learning Courses in Social Entrepreneurship for the future of collaboration between University and Community" implementation activities (Erasmus+ KA220-HED - Cooperation Partnerships in Higher Education, 2023-1-IT02-KA220-HED-000158730, https://digifuncollab.eu/), which was co-financed by the European Commission. Thus, the content of the article reflects only the views of the authors, and the Commission cannot be held responsible for any use that may be made of the information contained therein.

7. CONCLUSIONS

The transition from I4.0 to I5.0 in the EU27 automotive sector represents not just a technological evolution but a strategic imperative shaped by global competition, sustainability goals, and human-centric innovation. While China's MIC2025 initiative has demonstrated the power of centralized industrial policy and rapid technological integration, Europe's path forward must leverage its unique strengths: a robust innovation ecosystem, a highly skilled workforce, and leadership in regulatory and sustainability standards.

The analysis reveals that European SMEs face significant barriers to adopting I4.0 technologies: economic constraints, fragmented supply chains, and lack of standardization. Yet, these challenges also present opportunities. By embracing hybrid transition models, fostering interdisciplinary collaboration, and investing in modular platforms and AI-driven configurators, Europe can accelerate its shift toward I5.0.

Industry 5.0 offers a vision of manufacturing that is not only efficient but also ethical, inclusive, and resilient. To realize it, stakeholders must adopt coordinated strategies that integrate design, production, and policy across borders and sectors. The creation of shared innovation hubs, digital micro-factories, and human-AI collaborative frameworks will be essential to maintain competitiveness and ensure long-term sustainability.

Ultimately, the success of this transition hinges on Europe's ability to transform its industrial culture: moving from isolated digital islands to a connected, adaptive, and human-centered ecosystem. If executed with foresight and unity, the European automotive industry can not only bridge the technological gap with global competitors but also define the future of manufacturing in the age of Industry 5.0.

8. REFERENCES

[1] European Automobile Manufacturers Association (ACEA). China Passenger Car Association (CPCA), BloombergNEF, https://www.acea.auto/.

[2] Senna, PP, Ferreira, LMDF, Barros, AC, Roca, JB, Magalhães, V., *Prioritizing barriers for the adoption of Industry 4.0 technologies*, Computers & Industrial Engineering, Volume 171, ISSN 0360-8352, ScienceDirect, 2022.

[3] Milosavljevic, M., Mousavi, A., Moraca, S., Fajsi, A., Rostohar, D., *Revealing the Supply Chain 4.0 Potential within the European Automotive Industry,* Sustainability, 16(4), 1421, 2024.

[4] European Commission: Directorate-General for Research and Innovation, Breque, M., De Nul, L. and Petridis, A., *Industry 5.0 – Towards a sustainable, human-centric and resilient European industry*, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/308407.

[5] Germany - The World's Leading Industrie 4.0 Nation, https://www.gtai.de/en/invest/industries/industrial-production/industrie-4-0

[6] Bitkom: Industry 4.0 – 42 percent of companies are already using AI in production, https://silicon-saxony.de/en/bitkom-industry-4-0-42-percent-of-companies-are-already-using-ai-in-production/.

[7] Schuh, G., Anderl, R., Gausemeier, J., Wahlster, W., Kagermann, H., Dumitrescu, R., Hocken, C., Winter, J., Blocher, A., *The acatech Industrie 4.0 Maturity Index - Managing the Digital Transformation of Companies*, Munich: Herbert Utz Verlag, ISSN 2192-6174, 2017.

[8] Consent management, https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Dossier/industrie-40.html.

[9] Law, M., *BMW & Industry 4.0 Revolutionising Automotive Manufacturing*, https://technologymagazine.com/articles/bmw-industry-4-0-revolutionising-automotive-manufacturing.

[10] Bosch Connectivity Case Study, https://www.bosch-connected-industry.com/de/media/en/allgemein/refrences/bmw/casestudy_bmw_group_landshut_ger.pdf.

[11] BMW Press Club, https://www.press.bmwgroup.com/global/article/detail/T0338859EN/predictive-maintenance%3A-when-a-machine-knows-in-advance-that-repairs-are-needed.

[12] Martinetti, A., Nizamis, K., Chemweno, P., Goulas, C., van Dongen, LAM, Gibson, I., Thiede, S., Lutters, E., Vaneker, T., Bonnema, GM, *More than 10 years of industry 4.0 in the Netherlands: an opinion on promises, achievements, and emerging challenges*, International Journal of Sustainable Engineering, 17:1, pp. 1-12, 2024.

[13] Yagafarova, A., Stolwijk, C., Ott, D., *Digitalization of the manufacturing sector in the Netherlands- Smart Industry impact: looking back and forward*, white paper 2024, https://www.tno.nl/publish/pages/10643/tno._whitepaper_smart_industry_impact.pdf

[14] Perspective Software Case Studies https://prespective-software.com/case-studies/case-study-vdl-nedcar.
[15] SAP News Center, https://news.sap.com/ 2021/ 12/vdl-nedcar-digitalized-yard-operations-to-boost-efficiency/.
[16] Courbe, T., Charron, F., Toe, S., Janneteau, B., *La digitisation des entreprises industrielles en France: un soutien à la demande et à l'offre de solutions technologiques, DGE - 61, ISSN: 2803-9254,* Paris, 2024.
[17] Industry 4.0: technologies, enjeux en entreprise, où en est-on? https://bigmedia.bpifrance.fr/nos-dossiers/industrie-40-technologies-enjeux-en-entreprise-ou-en-est
[18] Synox Industry 4.0, https://www.synox.io/en/industry-4-0/automation-and-autonomous-systems-in-factory-4-0-towards-self-directed-production/.
[19] Mattern Lab Stellantis, https://www.youtube.com/watch?v=dTstWU9Pd3Y
[20] Institute for Security and Development Policy, *Made in China 2025,* 2018, https://www.isdp.eu/wp-content/uploads/ 2018/06/Made-in-China-Backgrounder.pdf.
[21] Wübbeke, J., Meissner, M., Zenglein, MJ, Ives, J., Conrad, B., *MADE IN CHINA 2025 The making of a high-tech superpower and consequences for industrial countries,* Mercator Institute for China Studies, ISSN 2509-5862, https://merics.org/sites/default/files/2020-04/Made%20in%20China%202025.pdf.
[22] Wu, Y*., Industrial Internet in China: How Policies Enable Latest Stage of Industry 4.0, https://www.china-briefing.com/news/industrial-internet-in-china-how-policies-enable-latest-stage-of-industry-4-0.*
[23] IEA (2025), *Global EV Outlook 2025*, IEA, Paris https://www.iea.org/reports/ global-ev-outlook-2025.
[24] Boullenois, C., Black, M., Rosen, DH, *Was Made in China 2025 Successful, https://rhg.com/research/was-made-in-china-2025-successful/.*
[25] Sinsmart Case Studies, https://www.sinsmarts. com/blog/industry-40-byd-s-automated-production-line-adopts-ipc-for-comprehensive-upgrade.
[26] NIO website, https://www.nio.com/innovation#smartManufacturing.
[27] Knaufautomotive website https://knaufautomotive.com/microfactories-how-will-new-technologies-shape-the-automotive-industry/#:~:text=Cost[28]

Scenarii strategice pentru tranziția de la Industria 4.0 la Industria 5.0 în Europa

În contextul geopolitic și tehnologic actual, adoptarea principiilor Industriei 4.0 (I4.0) în industria auto europeană, în special în segmentele cu serii mici de fabricație, a fost întârziată din cauza barierelor economice, tehnice și structurale. În următorii ani strategia Comisiei Europene definește tranziția către Industria 5.0 (I5.0), axată pe sustenabilitate și integrarea omului în ciclul industrial, având la bază infrastructura I4.0. În acest context, apare problema asigurării tranziției cu succes de la I4.0 la I5.0 și a definirii, adaptării și implementării metodologiilor de concepție și producție necesare acestei tranziții. În același timp, în China, aplicarea strategiei „Made in China 2025" (MIC2025), a permis dezvoltarea unui model industrial propriu bazat pe adoptarea tehnologiilor avansate. Succesul global al MIC2025 pune la îndoiala modelul industrial din Uniunea Europeana (UE). Articolul analizează contextul actual, compară modelele industriale, descrie barierele în calea implementării strategiei europene și analizează oportunități și perspective noi pentru reducerea decalajului tehnologic necesar adoptării cu succes a principiilor I5.0.

Gabriel SÎRBU, PhD. student, Politehnica University Timisoara, Materials and Manufacturing, Engineering Department, E-mail: gabrielsirbu@yahoo.com, Phone: +40752267001, Address: Bd. Mihai Viteazu No.1, 300222, Timisoara, Romania, Head of Research and Development Department, HELLA Romania SRL

Adrian Ciprian FIRU, PhD. student, Politehnica University Timisoara, Materials and Manufacturing, Engineering Department, E-mail: firuadriancíprian@gmail.com, Phone: +40734001488, Address: Bd. Mihai Viteazu No.1, 300222, Timisoara, Romania, General Manager, HELLA Romania SRL.

George DRĂGHICI, PhD., Professor Emeritus, Politehnica University Timisoara, Department of Materials and Manufacturing Engineering, Email: george.draghici@upt.ro, Phone: +40740348430, Address: Bd. Mihai Viteazu No.1, 300222, Timisoara, Romania.