

# **From The Industry 5.0 Paradigm To The Formalization Of Industry 6.0: Generative Capacity, Governance And Safeguards In Governing The Industrial Ecosystem**

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## **Abstract**

*The Industry 1.0–6.0 sequence is often presented as a technological progression. This reading is useful but not sufficient when the object of analysis becomes the governance of transformation into complex and interdependent socio-technical systems. This contribution takes as its normative pivot the definition of Industry 5.0 contained in UNI/PdR 155:2023, including its interpretative framework, to show how the 5.0 paradigm introduces a governance criterion that integrates human centrality, sustainability and evolutionary resilience, orienting prosperity beyond growth alone and anchoring choices to safeguards and legitimacy constraints. On this basis, and in coherence with the institutional documents of the European Commission and the European Economic and Social Committee, an operational definition of Industry 6.0 is proposed as an organizational and governance mode of the industrial ecosystem founded on generative capacity, decision traceability and responsible control of technological autonomy, within sustainability and circularity constraints oriented to shared value and the common good. The definition is accompanied by four interpretative notes and is contextualized with respect to the recent literature on Industry 6.0, including contributions on roadmaps, scenarios, skills, sustainability and energy, in order to strengthen its scientific robustness and its translatability into verifiable criteria. [1–6]*

**Keywords:** *Industry 5.0, Industry 6.0, generative capacity, governance, distributed autonomy, sustainability, circularity, antifragility, common good, Harmonized Structure.*

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## **I. Premise And Rationale**

The Industry X.0 labels have taken on a role as narrative infrastructure and as an orientation device for investments, with a mobilizing capacity that often precedes conceptual stabilization. The literature that reconstructs the evolution from Industry 4.0 to Industry 6.0 highlights how these concepts can behave as management fashions, generating a gap between discursive popularity and actual transformation. This risk increases when the definition is reduced to a technological catalogue and does not include governance criteria, safeguards constraints and conditions of verifiability. The European shift to Industry 5.0 constitutes a significant discontinuity, since it explicitly introduces three pillars, human centrality, sustainability and resilience, and connects industrial innovation to prosperity beyond growth, job quality and the legitimation of transformation. The aim of this contribution is to use the formalization of Industry 5.0 as the basis for a definitional proposal of Industry 6.0 that maintains continuity with that framework and, at the same time, makes explicit the change in the guiding criterion towards generative capacity, understood as the capacity to produce futures that are feasible and governable over the long term. [2–4, 7]

## **II. Method And Reference Corpus**

The method adopted is conceptual and comparative. First, the Industry 5.0 definition in UNI/PdR 155:2023 is taken as the normative basis, since it formalizes the paradigm as an organizational mode and clarifies its scope and interpretative conditions. Second, the European institutional framework is reconstructed through the white papers and reports of the Directorate-General for Research and Innovation and the Joint Research Centre, as well as through the opinion of the European Economic and Social Committee, with the aim of preserving coherence with the policy lexicon and with the orientation towards a sustainable, human-centric and resilient industry. Alongside this institutional core, a portion of the literature on Industry 6.0 is considered which, in outlining visions, technical landscape and opportunities, explicitly resumes the constitutive characteristics of Industry 5.0 and takes its three pillars as design constraints, helping to clarify which aspects should be preserved and made operational in the transition towards subsequent paradigms. [8] Third, the proposal is contextualized

with respect to the emerging literature on Industry 6.0, including contributions of a bibliometric nature, technological and organizational roadmaps, scenarios, skills, sustainability and energy dimension. Fourth, a set of industrial reports and guidance documents on Industry X and factories of the future is used to discuss operational translatability and lock-in risks. The selection aims to obtain a set of at least twenty sources and to keep a limited share of self-citations, to strengthen the neutrality of the supporting framework. [1–21]

The work uses definitional derivation logic. The UNI/PdR 155:2023 definition is treated as the semantic and operational core, since it integrates purposes, constraints and governance conditions. The interpretative notes are taken as construction criteria, in particular the evolution of the paradigm and compatibility with a management architecture consistent with the Harmonized Structure. This methodological choice makes it possible to avoid descriptive definitions and instead to orient the text towards verifiable formulations. [1] The European framework is read as a set of policy requirements and not as a mere value-based framework. The documents of the Directorate-General for Research and Innovation and of the Expert Group on Economic and Societal Impact of Research and Innovation, together with the Joint Research Centre report on the future of work, provide a shared lexicon on the three pillars and on the conditions for implementation, including the need to govern systemic transitions, attention to SMEs and the need for new skills for human-technology collaboration. [2–4] The opinion of the European Economic and Social Committee is used to make explicit the implementation dimension, since it connects the 5.0 vision to its enforceability in terms of instruments, incentives and multi-actor governance, highlighting that the paradigm requires coherence between industrial policies, skills, safety and sustainability. [5]

The Industry 6.0 literature is used with a dual purpose. On the one hand, to reconstruct recurring technical trajectories, such as digital twins, data architectures, distributed autonomy and new factory models, which recur across different contributions. [8, 11] On the other hand, to identify the risks of conceptual ambiguity and technologist drift, highlighted both by bibliometric readings of management fashions and by scenario exercises that show diverging futures. [7, 10]

Within the UNI/PdR 155:2023 framework, human centrality is not treated as a simple procedural safeguard, but rather as a design condition for work systems, skills and human-technology interfaces. The definition and the interpretative notes assume that the quality of transformation depends on the ability to preserve wellbeing, safety and dignity, avoiding innovation being paid for avoiding innovation being paid for through new forms of precarization and loss of agency. [1] The European report on the future of work makes this implication explicit. Human-technology collaboration is presented as a policy and organizational design theme, which requires investments in skills, social dialogue and tools to anticipate impacts, particularly in contexts where automation and artificial intelligence redefine tasks, responsibilities and forms of control. [4]

The first element that distinguishes Industry 6.0 from previous narratives is the centrality of decision. If Industry 4.0 made data a lever for efficiency and coordination, the subsequent phase tends to transform data and models into decision infrastructures. This implies that the quality of governance depends not only on the availability of information, but on the traceability of decision processes, on the management of trade-offs and on the capacity to challenge and correct choices when unforeseen impacts emerge. [8]

A second element concerns the asymmetry between technological acceleration and institutional maturity. European documents on Industry 5.0 insist on the need to govern systemic transformations and to avoid the transition being driven exclusively by market dynamics or proprietary solutions, especially when supply-chain infrastructures and essential services are involved. [3, 5]

On the sustainability side, contributions that discuss Industry 6.0 in a global perspective highlight that expected benefits depend on the capacity to incorporate environmental and social constraints into the architecture of the production system and the supply chain, avoiding additive approaches and aiming instead at life-cycle design criteria. [12] The energy dimension is read as an enabling condition and at the same time as a feasibility constraint. The transition towards more intelligent and connected models can increase energy demand and dependence on critical infrastructures, making it necessary to integrate efficiency, reliability, safety and sustainability in system governance, in particular for digital services and platforms. [15]

Works on impacts on SMEs further recall the need for a sustainable adoption trajectory also from an economic and organizational standpoint, since transformation can amplify gaps in skills and investment capacity. Readiness therefore becomes a theme of ecosystem governance, with support instruments and pragmatic standardization to reduce asymmetries and foster interoperability. [14, 16]

Finally, the discussion on leadership and skills highlights that Industry 6.0 requires figures capable of integrating technological, organizational and institutional responsibilities. Leadership is called upon to safeguard limits, risk thresholds and accountability, avoiding distributed autonomy translating into opacity. [13] In this context, generative capacity is proposed as the guiding criterion because it makes it possible to assess the quality of the trajectory and not only the level of technological adoption. Generative capacity concerns the preservation of options, the reversibility of certain choices, the reduction of lock-in and the management of critical dependencies, themes that become central when competitiveness is a property of the ecosystem and not of the single plant. [7, 17] As argued by Casale, Rinaldi, Monti and de Falco (2026), “productivity exhibits structural

limits that undermine its analytical adequacy”, which supports adopting generative capacity as a governance criterion. [22]

### **III. From The Cycle Of Industrial Revolutions To The 5.0 Perimeter**

An evolutionary reading of the industrial revolutions makes it possible to treat Industry 1.0–4.0 as a progressive extension of the sphere of governance, from the machine to the factory, from the factory to the supply chain, and from the supply chain to the informational ecosystem. Industry 1.0 can be interpreted as the formalization of the factory as a coordination architecture enabled by mechanization and by the availability of concentrated energy. Industry 2.0 stabilizes the rationale of mass production through electrification and standardization, making scalability a guiding criterion and transforming quality into a compliance constraint. Industry 3.0 introduces the programmability of production and makes information an operational element, shifting governance towards process control and reliability. Industry 4.0 brings pervasive connectivity, cyber-physical systems and data as the infrastructure for vertical and horizontal integration. In the Italian context, UNI/PdR 121:2021 defines Enterprise 4.0 as an organizational mode of business processes based on the circulation and management of information among interconnected components of the enterprise system, highlighting that the leap concerns the operating model and not the single technology. However, the emphasis on efficiency and productivity as prevailing criteria often leaves safeguards, wellbeing and legitimation aspects in the background, preparing the ground for the 5.0 turn. [7, 23]

### **IV. Industry 5.0 In UNI/PDR 155:2023 And In The European Framework**

UNI/PdR 155:2023 defines Industry 5.0 as an organizational mode of doing business that strengthens the role and contribution of the productive sector towards society and the environment, placing workers’ wellbeing and the ethical use of technologies at the centre of processes and aiming to be a resilient source of prosperity also under conditions of discontinuity and disruption, generating shared value beyond growth while respecting the limits of the planet, future generations and the common good. The definition is accompanied by notes that make explicit its evolution, its compatibility with a systemic approach also through the Harmonized Structure, the assumption of sustainability as a constraint and not as a separate chapter, and the prerequisite of subordinating technology to people and the environment. This approach is convergent with the European institutional narrative that introduces Industry 5.0 as a human-centric, sustainable and resilient paradigm and that places industrial transformation within the framework of prosperity beyond growth, the attraction and quality of work, and the resilience of the economic system. The report on the future of work further underlines that human-technology collaboration must be designed, governed and made compatible with skills, dignity and job quality, while the opinion of the European Economic and Social Committee insists on the need to make Industry 5.0 actionable and to translate the paradigm into operational measures for enterprises and supply chains. This reading finds further confirmation in a recent technical-systematic review of Industry 6.0, which reconstructs limits and criticalities of Industry 5.0 in terms of scalability, costs, workforce transition, and security and privacy in the post-quantum era, using them as an explicit motivation for the leap towards a more ubiquitous, hyper-connected and sustainability- and responsibility-oriented paradigm. [1–5, 24]

### **V. Why Industry 6.0 Requires A Governance Formalization**

The literature on Industry 6.0 shows a concept that is still in a consolidation phase. On the one hand, approaches that list technologies and trajectories are frequent, including digital twins, artificial intelligence, more dynamic supply chains, cybersecurity, and data-driven platforms. On the other hand, contributions emerge that signal a risk of indeterminacy, since Industry 6.0 can be invoked as a rhetorical successor without a stable guiding criterion. Bibliometric works that interpret the Industry 4.0–6.0 sequence as management fashions offer a useful interpretative key, insofar as they recall the need for verifiable definitions and for governance architectures capable of reducing the distance between narrative and implementation. In parallel, scenario contributions show that the futures of Industry 6.0 can diverge significantly, from biofused manufacturing to eco-symbiotic production or post-work configurations, suggesting that the issue is not to predict a single outcome, but rather to govern alternative trajectories while preserving options and continuity. It follows that Industry 6.0 must be defined primarily as an organizational and governance mode and only secondarily as a technological cluster. [7, 10, 11]

### **VI. Technical And Socio-Organizational Contextualization Of Industry 6.0**

Roadmaps and technical contributions on Industry 6.0 tend to converge on some enablers. The digital twin is often proposed as an infrastructure that connects observation, simulation and action, reducing reconfiguration costs and making complexity more governable. Works that describe the technical landscape also emphasize data architecture, advanced automation and orchestration capabilities, within a framework in which production becomes increasingly software-defined and in which models and platforms assume a decision role. Alongside this dimension, contributions emerge that highlight the centrality of sustainability, circularity and

energy infrastructures as feasibility and safeguarding constraints. The sustainability of Industry 6.0 is discussed as a set of benefits and challenges, recalling the need to integrate environmental and social impacts as design variables. The skills and leadership dimension also appears decisive. Works on future skills and organizational readiness indicate that, in addition to technical competences, systemic thinking capabilities, governance of human-technology interaction, ethical leadership and the management of responsibilities in the presence of increasing autonomy are required. This evidence reinforces the thesis that Industry 6.0 must incorporate requirements of traceability, auditability and contestability of decisions when data and models become operational infrastructures. [8–10, 12–15]

**Taxonomy of recurring concepts in the Industry 6.0 literature**

In order to make the documentary basis of the discussion explicit, Table 1 summarizes a taxonomy of the terms and concepts that recur in contributions specifically devoted to Industry 6.0, highlighting how these recurrences are distributed across the technological dimension, the governance dimension, the human-organizational dimension and the safeguarding dimension. The taxonomy is used as a reading device to connect the proposed definition and the interpretative notes to a set of recurring and therefore observable elements in literature. [7–21, 24–35]

The taxonomy shows that, alongside technical enablers, elements of governance, safeguarding and job quality recur. It follows that a definition of Industry 6.0 is more robust when it incorporates requirements on decision, responsibility and the preservation of options, rather than limiting itself to describing a technological threshold. [3, 5, 7, 24] In particular, some recent contributions extend the taxonomy towards managerial and data governance dimensions, including supply chain traceability and upskilling, while others propose conceptual pillars that emphasize data sovereignty and the ethics of robotics, useful as a comparison to strengthen the proposed operational definition. [33, 34]

Document	Prevailing focus	Key terms and concepts	Implications for the discussion on Industry 6.0	Analytical dimension
[9]	Roadmap	future manufacturing trends, roadmap, technology convergence	need to move from a technological list to governance and integration criteria	TECH
[10]	Scenarios	diverging futures, anthropocentric, post-work, eco-symbiotic	Industry 6.0 as governability of alternative trajectories	TECH HUM
[8, 11]	Technical landscape / strategic outline	digital twin, AI, data platforms, cyber-physical systems, orchestration	data and models as decision infrastructures, traceability and accountability	TECH
[12]	Sustainability	benefits and challenges, life cycle, environmental and social impacts	sustainability as a structural design constraint	TUT
[15]	Energy	energy 6.0, enabling infrastructures, reliability	energy and critical infrastructures as feasibility constraints	TUT
[16]	SMEs	MSME, adoption capacity, skills gap	readiness and instruments for ecosystem support	ECO
[13, 14]	Skills and leadership	human-technology collaboration, organizational readiness, leadership	skills and governance capabilities as implementation conditions	HUM GOV
[27, 28]	Quality 6.0 and Society 6.0	quality evolution, smart quality, Society 6.0, socio-technical quality infrastructures	extension of the paradigm to socio-technical infrastructures and quality metrics	TECH HUM GOV
[25]	Anthropocentrism / paradigm vision	wise anthropocentric revolution, edge intelligence, socio-technical convergence	human centricity as an architecture of responsibility and control	TECH HUM GOV
[30]	Manufacturing transformation	transforming manufacturing, Industry 4.0 to 6.0	technological continuity and governance discontinuity	TECH GOV
[31]	Environment	environmental paradigm shift, safeguarding, sustainability	environmental constraints as structural drivers, not additive	TUT
[32]	Intelligent automation in manufacturing	intelligent automation, manufacturing systems, automation architecture	supports the automation dimension but requires governance criteria beyond technological adoption	TECH GOV
[24, 34]	Theoretical / governance framework	decentralized control, AI-driven manufacturing, socio-technical architecture	strengthens the move from technological threshold to governance formalization	GOV TECH HUM
[35]	Management and commerce	management, commerce, organizational impacts of Industry 6.0	supports the organizational and managerial translation of Industry 6.0	GOV ECO
[33]	Pillars taxonomy	data sovereignty, ethical robotics, emotional literacy, procedural intelligence, Education 6.0	alternative lexicon useful to distinguish descriptive vs governable definitions	GOV TECH HUM

Legend Analytical dimension. GOV governance and responsibility. TECH technical enablers. HUM work skills human centrality. TUT safeguarding sustainability circularity. ECO ecosystem interoperability trust. ANT antifragility. CG common good and shared value.

## **VII. Definitional Proposal For Industry 6.0 And Interpretative Notes**

### **Proposed definition of Industry 6.0.**

Industry 6.0 is an organizational and governance mode of the industrial ecosystem through which enterprises, supply chains and institutions design and run socio-technical systems capable of producing feasible and governable futures, preserving options over the long term and maintaining continuity and legitimation of transformation, translating technological autonomy, data and models into traceable and responsibly controlled decisions, within sustainability and safeguarding constraints, oriented to the generation of shared value and the common good.

Note 1. Industry 6.0 is an evolutionary paradigm and does not coincide with a closed set of technologies. The distinctive trait lies in the shift from optimization of the existing to generative capacity understood as a systemic property of maintaining and expanding possibilities for action over time, including preservation of options, selective reversibility of choices and reduction of critical dependencies.

Note 2. Industry 6.0 requires a systemic approach of integration between technology, organization and governance, applicable to enterprise, supply chain and ecosystem. Structures consistent with the ISO Harmonized Structure can support such integration, making responsibilities, competences, controls and continual improvement governable.

Note 3. In Industry 6.0, sustainability and circularity operate as design and supply-chain constraints and not as separate objectives. Conformity requires life-cycle management, reduction of externalities and the adoption of verifiable criteria for the permanence of resources in the system.

Note 4. In Industry 6.0, distributed autonomy, including that based on agent architectures and cyber-physical systems, is admissible only within an architecture of responsibility and human control that ensures traceability, verifiability, contestability and safeguarding of risk thresholds.

Note 5. In Industry 6.0, externalities are addressed as governance issues of impact allocation across actors and time horizons, not as after-the-fact corrections. Decision rules and accountability are designed to distribute costs and benefits coherently within the industrial ecosystem, strengthening the legitimacy and continuity of transformation.

[1, 2, 5, 6, 9, 12–14, 26, 36]

## **VIII. Discussion, Operational Criteria And Coherence With Orientation To The Common Good**

The proposed definition shifts the unit of analysis from the enterprise to the ecosystem configuration, assuming that competitiveness is a collective property and that the continuity of transformation requires interoperability, trust and distributed responsibilities. In this perspective, generative capacity operates as a governance criterion that makes it possible to assess the quality of the trajectory, not only short-term performance. Industrial reports on Industry X and on factories of the future show how platforms, data and end-to-end integration can accelerate reconfigurations, but also introduce lock-in and dependencies, making a decisive governance framework that makes purposes, constraints and risk thresholds explicit. The SME dimension and supplier networks also require progressive implementation instruments, as recalled by the literature on the impacts of Industry 6.0 on small and medium-sized enterprises and on organizational readiness. The connection to the common good is not an abstract ethical reference, but a criterion of legitimation and continuity that can be translated into management choices, because it links innovation governance to impact allocation, stakeholder trust, and the long-term preservation of social and environmental operating conditions. This reading is consistent with the Industry 5.0 and generative-capacity framework, with innovation-management principles that explicitly connect value realization to stakeholders and context, and with the emerging SDG management-system approach, which frames performance, compliance obligations, selected objectives, trust and confidence as organizational outcomes to be governed systematically rather than treated as external communication claims. It is also coherent with the broader governance literature on the common good in socio-technical transitions, which emphasizes that public value, democratic legitimacy, and implementation capacity must be designed together. Within this framework, orientation to the common good and antifragility can be treated as design properties, coherent with a governance of complexity that learns, reconfigures itself and preserves options, in continuity with reflections on innovation oriented to the common good and with the need, highlighted by European sources, to govern systemic transformations and not only technological projects. [1, 3, 5, 16–21, 36–39]

## **IX. Conclusions**

Industry 5.0, as formalized in UNI/PdR 155:2023 and in European institutional sources, introduces a paradigm shift that brings purposes and constraints back to the core of industrial transformation. To avoid being

reduced to a cumulative label for technologies, Industry 6.0 requires a formalization that extends this framework to the governability of data-driven ecosystems and distributed autonomy. The definitional proposal presented here adopts generative capacity as the guiding criterion, integrates sustainability and circularity as structural constraints, and requires traceability, auditability, and contestability of decisions. Its contextualization with respect to roadmaps, scenarios, sustainability, energy, and skills strengthens the robustness of the definition and supports its translation into verifiable criteria for enterprises, supply chains, and institutions. The work of operationalization remains open and can be further developed through management system requirements consistent with the Harmonized Structure, as well as through policy instruments capable of supporting a legitimate and durable transformation. [1, 2]

The transition to Industry 6.0 requires a definition that makes technological autonomy governable and that treats data and models as decision infrastructures, introducing traceability and accountability requirements that reduce opacity and lock-in. [8, 17] The definitional proposal adopts generative capacity as the guiding criterion and integrates sustainability and circularity as structural safeguarding constraints, in coherence with the sustainability literature and with the European emphasis on making the paradigm actionable. [5, 12]

## **X. Limits And Future Developments**

The contribution deliberately delimits its own field of action and, precisely for this reason, reinforces the solidity of the proposed definition. The choice of a normatively oriented framework privileges governance criteria and conditions of verifiability, avoiding cumulative definitions and leaving to the technological taxonomy the role of an updatable repertoire as a function of sectoral contexts. This approach is coherent with the objective of making Industry 6.0 an organizational and governance mode of the industrial ecosystem, rather than a list of solutions. [7]

The literature on Industry 6.0 is still in a consolidation phase and presents heterogeneous approaches and sometimes diverging scenarios. Such plurality does not weaken the proposal but makes explicit the need for cross-cutting criteria capable of maintaining coherence across different technological and institutional contexts. From this follows an empirical and contextualized line of work. To validate the definition with respect to use cases and real supply chains, and to translate the interpretative notes into shared indicators and maturity models, keeping the criterion of generative capacity central as a guide to the preservation of options over time. [10]

To support operational implementation, the paper connects the definition to a framework of requirements that makes the implications of governance, safeguarding and ecosystem readable, also through management architectures compatible with the Harmonized Structure. In this framework, generative capacity is read together with a coherent set of antifragile capacities and is articulated into families of requirements on trajectory, decision, safeguarding and ecosystem, in line with the European need to move from vision to implementation through common instruments, interoperability and trust among actors. [3, 5, 6, 36]

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