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Smart robotics and embodied AI: Future outlook, risks and responsibilities as we move toward 2050

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Abstract

Robotics and artificial intelligence are moving AI from software into the physical world: into the workplace, care settings and our daily lives. it's the so-called embodied AI[1].

As we set our sights on the year 2050, we must ask ourselves what long-term structural impact systems that are embodied, autonomous and capable of interaction will have on the organization of work, care models, trust-based relationships and the distribution of responsibility.

In Europe,[2] these transformations are intertwined with processes already underway: aging demographics, stressed welfare systems, the redefinition of human work and increasing global rivalry in strategic technology sectors.

This Future brief explores the possible future scenarios of smart robotics[3] through an exercise in foresight, shedding light on critical uncertainties and alternative trajectories that can be oriented by choices of governance, investment and innovation management.[4]

Our aim is to encourage a shift in perspective from robotics as a single technology to robotics as long-term social infrastructure. Robotics does more than pose questions regarding technological development, regulatory balance and economic implications. It calls for our civilization to choose how to organize, over time, the relationship between humans, machines and society.

Key words

SMART ROBOTICS, AUTOMATION, CO-EVOLUTION, GOVERNANCE, RESPONSIBILITY.

1 By “embodied AI” we mean a paradigm of smart robotics where perception, action and learning are closely integrated and the system’s capabilities are the result of continuous interaction between the embodied agent (either physical or simulated) and the environment.

2 The main frame of reference for this analysis is Europe. However, it does take into account global dynamics insofar as they impact the development trajectories of smart robotics in Europe.

1 For the purposes of this brief, by “smart robotics” we mean autonomous robotic systems capable of sensing their surroundings, processing information, planning and carrying out actions aimed at reaching one or more objectives, integrating control methods, planning and artificial intelligence.

4 There are two principal limits to this analysis. One relates to method, because the scenarios offered are only hypotheses and not the result of a comprehensive exercise in foresight. The other relates to scope, because it is neither a roadmap for industrial policy nor an investment plan. It is a strategic orientation brief geared mainly toward public decision-makers, although it also offers food for thought for the scientific community and the production ecosystem. The frame of reference for Future brief may be found here

The Stakes

When Artificial Intelligence Becomes Embodied: From technological promise to social infrastructure

When smart robotics becomes a permanent feature of the workplace, care settings and services,[5] it will shift from being an experimental technology to an integral part of the infrastructure regulating the everyday functioning of society. It is in this transition from prototype to "normalization" that we encounter the greatest risks. Choices that today we consider purely technological tend to accumulate over time, generating overall effects that are difficult to reverse. We cannot see the real impact during the experimental phase. We see it when these technologies become permanently embedded in the social apparatus.

Toward 2050

When it comes to robotics, their large-scale adoption will become plausible around 2050, which is far enough in the future to allow for technological maturity[6] in a variety of areas – from manufacturing to healthcare, from logistics to agriculture, from emergency management to personal assistance, up to urban services and environmental protection – but close enough to be shaped by today's decisions. If we look at this target through the lens of technology foresight,[7] we have to ask ourselves today not only what technologies will be available but also what organizational, social, economic and institutional models they will help build, in addition to what models will emerge and how they will impact decision-making processes, skills and social relations.

2050 is a crucial deadline for the main global strategies, from the climate challenge to the energy transition and up to the implementation of sustainable development models. It is also a deadline that is aligned with the European approach to strategic foresight, which encourages us to begin immediately assessing the long-term effects of our technological choices to avoid becoming locked in and dependent on specific technologies or platforms that will make it difficult to adopt alternative solutions.

2050 is also the 100-year anniversary of the publication of *Computing Machinery and Intelligence*, an essay by British mathematician and logician Alan Turing, one of the founders of modern computer science. In his paper, Turing lays the conceptual groundwork for artificial intelligence and its embodiment. If we envision the future of embodied robotics, what we see is the manifestation of **Turing's dream**: the idea that, in order for intelligence to be truly intelligent, it must have a body, experience the physical world and interact with its surroundings. This has been the theoretical trajectory of AI from its very outset, and today, thanks to the convergence of robotics, machine learning and computing power, it is beginning to emerge from the laboratories. If seen from this vantage point, robotics is more than just an application. It is the point at which long-term research **shifts from industrial and precision robotics toward more quotidian environments** that are unstructured and entail a great deal of human interaction.

Key aspects

This research topic is vast and complex. This brief focuses on three main aspects:

One key nexus regards **work**. The adoption of autonomous, embodied systems fits into already existing dynamics: labor shortages, an aging workforce, security requirements and the reorganization of production and logistical processes. Smart robotics may result in some tasks being displaced, but it will compensate for labor shortages and reconfigure roles, skills and responsibilities, mainly impacting work quality [1][8] [2], not only employment rates. It would be misleading to reduce this transformation to an issue of productivity or net substitution. What matters is what space remains for humans within a context where automation is pervasive and whether it has been designed to offer passive supervision, subordinate adaptation or real co-evolution between human capability and robotic systems.

Without a clear trajectory for the **co-evolution of work and technologies**, we risk the progressive undermining of human agency: the less decision-making power and learning power humans have, the less their work feels meaningful. However, well-designed robotics can foster the mutual benefits of automation

5 Here we explore the civilian applications of smart robotics. The implications of dual use and applications in defence and security are only briefly mentioned, as they require a dedicated analysis.

6 By "technological maturity," we mean the progressive advancement of a technology according to Technology Readiness Levels (TRL), a standardized scale with nine levels measuring a technology's degree of development, from basic scientific principles (TRL 1) to actual proven systems operating in real-world environments (TRL 9).

7 "Technology foresight" is the branch of foresight that anticipates possible evolutions in technologies and their impact.

8 Please refer to the bibliography at the end of the brief.

while boosting wellbeing, ergonomics and the active role of workers, strengthening their physical and cognitive capacities. So, what is at stake is not merely how much work will be automated but the quality of that work, how the value it generates will be distributed and what impact it will have on human skills, capabilities and agency.
In the medium- to long-term, once we have gotten past the collaboration stage where robots work alongside operators, the increased autonomy of machines will radically redefine task distribution. Unless conscious choices are made, human work risks being quantitatively and qualitatively redimensioned, with effects that go far beyond the realm of employment. In the future, automation might require us to **rethink the distribution of wealth** and how society attributes value to human activities, both in economic terms and in terms of social recognition.
Therefore, the potential separation of work, income and the distribution of the value generated by automation deserves strategic attention. The extent and effects will depend on industrial, fiscal and social policies and how innovation is governed, making sustainable co-evolution between automation and new social and economic models critical. We can see a similar dynamic in the use of **large-language models (LLMs)**: systems that do more than just carry out tasks. They influence learning, writing and reasoning. We improve these models as we use them, but we also learn or, at times, unlearn from them. According to the literature, the effects are ambivalent [3]. On the one hand, these tools can boost productivity and work quality. On the other, they can foster forms of cognitive offloading and, in some cases, deskilling processes, with implications for the development and maintenance of some skills.

The second aspect regards **health, care and assistance**, areas that are bound to grow throughout Europe due to an aging demographic and pressures on welfare systems. Robotics is often offered as a response to these needs. However, having high-quality technology does not necessarily mean that it will be used well. And this is not just a technological risk. Solutions geared toward efficiency and sustainability can silently redefine what is considered “acceptable care,” diminishing its more relational and empathetic features.
In more general terms, artificial intelligence, when applied to biological and biomedical processes, could lead to more effective, personalized treatment options, with potential effects on healthy lifespans. However, this is only a potential trajectory, not a guaranteed result. The impact will depend on technological maturity, as well as on accessibility, sustainability, investment and the organizational and policy choices guiding its spread and adoption.

The third aspect regards **trust, responsibility and social acceptance**. When artificial intelligence becomes embodied, decisions become physical actions with immediate consequences. Its acceptance depends less on technological performance and more on transparency, predictability and the clarity of responsibilities. Even design matters: with humanoids, their more intuitive interactions with anthropomorphic systems may be met with resistance, expectations and substitution perceptions that impact the extent to which they become integrated into society.
These technologies also entail intense industrial and symbolic competition. **Market potential and the pressure to compete may come before social reflection**, encouraging adoption driven more by hype than by a mature assessment of their performance and implications. Being the first to introduce a humanoid on the market means **having to protect a powerful image**, with the risk that spectacular demonstrations and claims about its imminent availability act as a cover-up for problems that have yet to be solved regarding its reliability, safety, economic sustainability and social integration. So, the issue regards not only how quickly robotics will move forward, but the criteria that will guide its design, spread and use. There is also a strategic side involving our **ability to make collective choices**. The spread of robotics depends on platforms, standards and development models that are coming together on a global scale. Who will control the infrastructure and data? How will the economic value generated be distributed? Who will be responsible for its risks and safety? Europe’s vulnerability is not its lack of scientific skills but the challenge of converting these skills into an ecosystem that can support development, adoption and strategic autonomy, also due to a lack of investment needed to turn research into products. This vulnerability goes hand in hand with the relationship between experimentation and risk. Smart robotics requires hands-on learning, margins of error and progressive adaptation. It requires **a culture of innovation geared toward curiosity** that accepts uncertainty and balances regulation and experimentation. The challenge is not to dodge risk but to manage it inside spaces of governed experimentation, preventing those who control the platforms, capital and markets from shaping the trajectories. Some transformations are inevitable, especially when it comes to work. What we need to decide is whether to prepare for new work structures or to try to create guardrails using a system of preventive rules, with the risk that they will prevent action, not guide them.
The same goes for **dual use technology**. The capabilities that enable care, support and resilience can also be redirected and used for surveillance or coercive military action, just as technologies created for defense can also be applied in the civil sphere with great social impact. Governing this ambivalence means that advance responsibility must be taken in the face of demands for effective global competition, not just regulatory guardrails.

So, we should **not be asking whether smart robotics will become part of our world but rather under what conditions it will transform it**. In this brief, this reflection mainly regards work, care and services, although it is also relevant to other sectors. Our decisions regarding investments, experimentation and regulation mark the perimeter of future possibility. Not only in terms of what technologies will be available, but also in terms of who will benefit from them, with what guarantees and according to what idea of society.

The State of Play

Between technological maturation, systemic fragmentation and global pressure

Right now, robotics is in an intermediate phase. It is no longer a promise, but it has yet to become a widespread infrastructure. Convergence between artificial intelligence, advanced sensors, computing power and robotics has generated systems that can operate in unstructured environments and adapt over time. However, technological maturity does not also mean large-scale scalability.

In Europe, this gap is structural. Europe might excel in research and advanced robotics, but it struggles to convert skills into scalable industrial platforms and integrated supply chains. What matters is not just proving a technology works but creating the conditions for it to become part of a business, production or social ecosystem that supports its creation, growth and functioning. Otherwise, it will remain a prototype and be implemented based on models developed elsewhere.

This vulnerability also arises in **connection with the great transitions**, starting with the climate transition. According to the International Energy Agency (IEA), if we want to achieve climate neutrality by 2050, today only 30% of the necessary technologies are mature and standardized. An additional 40% has been demonstrated but not yet scaled. The remaining 30% is proven in principle but lacks established industrial supply chains. The limit is not scientific. It is systemic: investments, production and integration.

The dynamics of smart robotics are similar. Some applications – from collaborative robotics to autonomous logistics and specific clinical settings – have already been proven but have yet to become widespread. Other key components, especially linked to general-purpose autonomy, continuous human interaction and safe use in everyday settings, still need to be developed. Their contribution will depend not only on technological advancement, but on the ability to turn potential into supply chains, standards and reliable adoption models.

This picture is complicated by **global competition**. The United States and China are investing heavily in general-purpose platforms, humanoids and advanced automation, bringing together research, industry and private capital. Irrespective of current market applicability, this competition is already shaping the value chain of future robotics. The robots that will be the most widely available by 2050 might not be humanoids, but the capabilities developed today are creating a significant competitive advantage for these two countries.

Europe operates within a more limited area, characterized by a cautious regulatory stance, limited public and private investment and fragmented production. The variable is not a lack of solutions, but rather **the challenge of building critical mass** and transforming experimentation into impact, with the risk of remaining on the sidelines of the global market.

There is also still a disconnect between **technological development and social discourse**, which also fuels unrealistic expectations that are often linked to spectacular demonstrations. However, the true testing ground for embodied AI is how it operates in critical situations, where being able to turn off a faulty valve in extreme situations matters more than seeing the spectacle of a humanoid doing flips on a stage.

On top of this, Europe is **less inclined to take technological risk and entrepreneurial initiative**, which in Europe tends to favor innovation that is incremental rather than radical. Public policies can help to change this dynamic by creating environments that foster experimentation, ambition and the transformation of research into innovation. Hence, it becomes very important to promote forms of healthy competition to stimulate ambition and diligence without creating distorting mechanisms like social scoring. Taken all together, these elements indicate a **phase of high potential but with great directional uncertainty**. Robotics is advanced enough to impact work, healthcare, sustainability and competitiveness, but not yet stable enough

to set down a single path. This combination of partial maturity, production chain gaps and global pressure make this current moment crucial in order to direct future development.

Alongside technological dynamics, there is also a **structural limit imposed by the European system of research and innovation**. Large collaborative projects financed by the European Commission tend to **dilute technological focus** through large, unwieldy consortia, generating solid initiatives in terms of form that are however less effective at focusing resources, skills and visions on clear technological objectives.

This uncertainty does not regard the quality of European research, but rather its organizational and financial architecture, which has an impact on its ability to build shared technological infrastructure and influence the development of robotics. Frequent calls for proposals and very low success rates push groups and laboratories to chase emerging trends rather than strengthen high-potential lines of research, fueling research that is often guided by hype and unlikely to translate into robust platforms and systemic impact. Therefore, the European Union should not only **support innovation past the research phase**, it should remove obstacles to growth and commercialization such as market and financial fragmentation, high energy costs and the lack of a true single market for knowledge.

In the last twenty five years, technological capabilities – from digital capabilities to artificial intelligence - have skyrocketed while the real European economy has remained stagnant and, in Italy, lacked a forward-looking design. This divergence signals a **challenge of translating technological progress into productivity and new work models**. In this way, robotics risks becoming another scientific excellence that has not been fully absorbed by the economic and social system.

Right now, the main bottleneck is not the tech but the ability to **act on two complementary fronts**: promoting **targeted research** that is continuous and capable of taking on risk and facilitating **technological transfer** so that research results can be turned into industrial applications and social benefits. Here, Europe has the opportunity to direct smart robotics toward truly transformative development.

Possible future scenarios for smart robotics

In this brief, we have decided to focus on a few critical uncertainties, which may be found in Table 1. After mapping these variables, we began to identify two fundamental dimensions that, more than the others, shape the future possibilities of smart robotics: **how the relationship between humans and smart machines is governed (human-machine relationship)**, and the **socio-technological framework**[9] **guiding development and diffusion (research and development ecosystem)**. These two dimensions form the axes of Figure 1 and establish the interpretive framework used in the brief. After cross referencing them, four scenarios began to emerge, which are not intended to be predictions but plausible configurations for the possible future evolution of robotics. [4] [5] [6] [7]. Although it does not capture the true complexity of this topic, the dimensions selected were considered the most relevant to our analysis. Future exercises in foresight would broaden the picture to include additional critical uncertainties and variables.

		Incertezze Critiche		
Centralized and proprietary ecosystems	←	R&D ecosystem	→	Distributed and interoperable ecosystems | Open and integrated supply chains
Substitution-based automation	←	Human-machine relationship	→	Human enhancement/Augmentation | Co-evolution and mutual adaptation
Reactive and scattered research driven by hype and the pressure to compete	←	Research & innovation	→	Targeted research | Forward-looking perspective on research
Regulatory control and preventive limitation	←	Risk management	→	Responsible innovation and governed experimentation | Trust, transparency and shared responsibility | Enablement of decision-making power
Market-driven consumer good | Optimization of efficiency and performance	←	Underlying vision /Role of Technology	→	Collective interest infrastructure | Fostering relationships, quality and wellbeing
Selective and stratified access	←	Socio-technological equity	→	Inclusive access and equal distribution of benefits

Table 1 – Critical uncertainties that can influence the future of robotics

9 By "socio-technological framework" we mean all the institutional, industrial, regulatory and organizational conditions that direct the development and spread of robotics: the research and innovation ecosystem, platform control, the prevailing platforms, supply chain organization, investment models and governance and how access, responsibility and benefits are distributed.

For each scenario,[10] we describe the context of reference ("what this evokes"), the main drivers for change and the expected effects on the three key dimensions considered here (work, care and trust/social acceptance). There is also a fourth dimension, climate, which we introduced to highlight the role of smart robotics as an enabling technology for ecological transition and sustainability. None of these future scenarios is predetermined, and each is shaped by the decisions made over time, such as choices regarding research, industrial models, regulatory frameworks, investments and cultural attitudes to risk and innovation. Since robotics has yet to fully mature, these future scenarios are still open, politically contestable and capable of being guided by today's choices.



Figure 1 – Four possible scenarios for the future of smart robotics

Scenario 1 — *Star Trek*: Technology as civil augmentation

Dimension	Star Trek
Development ecosystem	Open, interoperable ecosystems all down the technological chain | Open standards, hardware/ software modularity
Human-machine relationship	Co-evolution
Research & innovation	Continuous, mission-oriented programs with curiosity-driven R&I areas
Risk management	Explored and governed risk | Forward-looking governance
Underlying vision/Role of technology	Technology as enabling civil infrastructure | Public AI strategies /Robotics as infrastructure| Public good with accountability
Socio-technological equity	Broad, progressive access | Widespread distribution of benefits | Active inclusion and reduction of inequalities

10 As often occurs in the exercise of foresight, the names of the scenarios are meant to be evocative and are only used for purposes of identification and discussion.

What this evokes – In the imaginary world of *Star Trek*, technology neither substitutes nor marginalizes humans. It frees them. It is invisible when it needs to be but extremely powerful when it matters. It is not a gadget. It is an infrastructure of civilization. In this scenario, robotics and AI are designed to be **enabling public goods**: they augment physical and cognitive capabilities, support work, care and resilience and strengthen collective decision-making. Humans remain at the center because they have agency. Experimental risk is not avoided. It is assumed and governed. Benefits are broadly and progressively distributed, strengthening inclusion and collective capability.

Drivers for change – Europe transforms scientific excellence into open socio-technological platforms. Research shifts from fragmented initiatives heavily conditioned by non-technological restrictions, to targeted, cumulative and continuous trajectories. The regulatory framework favors transparency and accountability, maintaining structured spaces for experimentation and restricting technological lock-in.

Co-evolution is the guiding principle: robotics is a civil infrastructure that augments humans and supports systemic transitions in key areas such as work, care and climate.

Medium- to long-term effects – Broad, progressive diffusion of benefits.

- **Work**: Augmented roles, increase in advanced maintenance, complex logistics and new professions in human-robot interaction (HRI);
- **care**: Integrated robotics as support without diminishing relationships; greater accessibility due to the scaling of technological solutions;
- **trust, responsibility and social acceptance**: High social acceptance of robotics, underpinned by transparency, predictability and the clear attribution of responsibility. Technology is perceived as a tool that augments humans and the collective interest;
- **climate**: Robotics and AI become enabling infrastructure for the climate transition, fostering adaptation and mitigation.

Scenario 2 — *Her*: Algorithmic intimacy, infrastructural dependence

Dimension	Her
Development ecosystem	Closed platforms | Lock-in, reconversion costs
Human-machine relationship	Asymmetrical co-evolution
Research & innovation	Innovation driven by adoption
Risk management	Reactive regulation | Post-crisis intervention
Underlying vision/Role of technology	Personalized, pervasive service | Individual UX centrality | Technology as a private good
Socio-technological equity	Access conditioned by platforms and income | Unbalanced but widespread benefits | Infrastructural dependence and growing asymmetries

What this evokes - *Her* is the story of the pervasive, reassuring relationship with a smart system and the slow, frictionless shift of human agency toward the infrastructure that makes the relationship possible. The technology augments humans on the emotional, cognitive and operational level, but on proprietary platforms. Robotics becomes a continuous, personalized service that is easy to adopt and difficult to replace. Dependence is not coercive. It is convenient, invisible and normalized. The central question is not is it efficient but rather who controls its functions, data and development trajectories.

Drivers for change – Innovation is swift, opaque and driven mainly by external players, with success measured mainly in terms of adoption and customer loyalty. Only a few global players control the platforms and the Robot-as-a-Service (RaaS) model is widespread. The role of Europe is mainly as a user of infrastructures designed and governed elsewhere, with limited margins for standards, architecture and terms of use.

Adoption accelerates because the solutions meet urgent needs in healthcare, welfare and assistance, but access is not uniform and highly income-contingent. Individual augmentation grows as people's collective awareness of their choices diminishes; there is an increase in extra-EU dependence and technological lock-in.

Medium- to long-term effects – The beneficiaries are those with access to the platforms, generating new inequalities and risks connected to technological dependence and the implicit delegation of care roles.

- **Work**: Selective augmentation connected to platform access, with the emergence of new asymmetries and forms of infrastructural dependence;
- **care:** The spread of companions and embodied assistance; the implicit redefining of what is considered "acceptable care";
- **trust, responsibility and social acceptance:** High social acceptance of robotics, driven by the quality of user experience more than by transparency and accountability. Trust is centered on the platforms, whereas responsibility and control are progressively less visible;
- **climate:** Robotic applications and AI contribute directly to the efficiency and management of emergencies, but are still restricted to platforms dominated by a single supplier.

Scenario 3 — *Metropolis*: Concentrated automation, broken society

Dimension	Metropolis
Development ecosystem	Technological oligopoly | Low interoperability, heavy concentration of control and capital
Human-machine relationship	Hierarchical
Research & innovation	Scattered and hype-driven | Lack of continuity | Brain drain and external dependence
Risk management	Reactive and security-driven, geared toward containing conflict
Underlying vision/Role of technology	Machine as master: efficiency and control are the main goals
Socio-technological equity	Highly unequal access | Concentration of benefits | Explicit exclusion and social polarization

What this evokes – *Metropolis* is the archetypal city/machine, with spectacular automation on the outside and substitution-based work and a deeply broken society underneath. It is the dystopian scenario par excellence where humanoids and advanced automation prosper but only for the few. Efficiency grows, but not access. Work is substituted rather than redesigned, care is reduced to the bare minimum and automated and there is a rise in social conflict. It is not the tech that is lacking but the collective ability to govern it, while benefits and control become concentrated and inequality spreads.

Drivers for change – Technological hype, industrial centralization and a lack of European critical mass lead to structural dependence and polarization. Large oligopolistic players control platforms, data and infrastructure, with low interoperability and little room for alternatives. Robotics is adopted mainly to maximize efficiency and substitute human work in logistics, security and industry.

The regulatory framework is weak or reactive and risk management occurs after the fact, often in the name of security; dual-use applications, surveillance and centralized control of data are expanding. Humans are relegated to a residual role, with a drop in economic and social agency. Institutional distrust, social tensions and security-driven responses rise; innovation continues but without legitimacy or inclusion.

Medium- to long-term effects – Robotics intensifies economic and social inequalities, fueling tensions and conflict. Europe has little strategic autonomy: technological dependence is combined with political and institutional fragmentation.

- **Work**: Human labor is substituted outright; professional jobs become hollow and social conflict rises;
- **care**: Technological excellence for the few; automated, standardized and unequal baseline care for the majority;
- **trust, responsibility and social acceptance**: Low social acceptance of robotics, which is perceived as a factor of exclusion and control. Distrust of the institutions and of tech rises, fueled by poor transparency and ambiguous accountability;
- **climate**: Selective use of robotics to protect strategic assets and critical infrastructure; lack of a systemic transition.

Scenario 4 — *Gattaca*: Order, control and automation "by the book"

Dimension	Gattaca
Development ecosystem	Infrastructure is governed but rigid; conformity as a guiding principle | Cautious innovation, with restricted sandboxes
Human-machine relationship	Humans as conformity watchdogs | Strict standards | Limited co-evolution
Research & innovation	Incremental and prudent, with little space for curiosity-driven R&I
Risk management	Risk and uncertainty reduced through pre-emptive control with risk of gridlock
Underlying vision/Role of technology	Regulated, certifiable system, oriented toward stability rather than transformation
Socio-technological equity	Selective, standardized access | Conditioned inclusion | Incorporated, normalized discrimination

What this evokes – The *Gattaca* scenario evokes an orderly, efficient, perfectly regulated world. The systems work, the rules are clear and uncertainty is reduced to the bare minimum, but there is not much space for the unexpected, learning and the human exception. Security grows as human-machine coevolution diminishes. Socio-technological equity is only superficial because access is structurally selective and based on technical criteria that generate systemic exclusion.

Drivers for change – Europe puts stability, control and predictability first. Technological infrastructures are based on strict standards, conformity and pre-emptive control. Risk management is aimed at preventing and reducing uncertainty, which also slows innovation. Research and innovation proceed incrementally, with limited space for experimentation and highly regulated sandboxes. The overall picture is coherent and stable but not very adaptable, because innovation is only allowed if it is predictable and certifiable. Humans are kept in the loop as token requisites for supervision and compliance more than as learning and co-evolving individuals. Robotics is mainly adopted in highly regulated contexts, such as critical infrastructure and healthcare, where there is stronger security but weaker systemic learning and transformative capability.

Medium- to long-term effects – High stability and limited friction but little collective enthusiasm. Europe's strategic autonomy remains intermediate. It is solid in terms of regulation and conformity but weak in terms of its ability to transform and adapt.

- **Work**: The main roles are: supervision, control and validation;
- **care**: Robotics is adopted in highly controlled, standardized settings; services are safe and reliable but tend to be impersonal;
- **trust, responsibility and social acceptance**: High social acceptance of robotics in regulated contexts, underpinned by strict standards and clear accountability. Trust is based on regulatory conformity rather than the ability of the technology to evolve and adapt;
- **climate**: Robotics is used to monitor and manage critical environmental infrastructure; a conservative approach limits benefits.

Vision

If we look at these four scenarios all together, we do not see clear alternatives but rather tensions that must be governed. The most evident risk is presented by the *Metropolis* scenario, where increased automation results in work that is hollow and an uneven distribution of benefits. However, this trajectory has one capability we cannot overlook: solutions can be swiftly implemented and scaled, which is crucial when quick transformation is required.

The *Gattaca* scenario represents the other side of the coin. Here the problem is not unchecked acceleration but rather control as an end in itself, resulting in inflexible innovation, limited learning and structural barriers to access. At the same time, it underscores the value of reliability, security and formal responsibility, which are essential when smart robotics becomes part of critical infrastructure and everyday life.

The *Her* scenario represents a more subtle dynamic. Infrastructural dependence on proprietary platforms undermines collective choice and shifts agency away from humans, often in ways they cannot see. However, in Her we also see something the other scenarios struggle to ensure: quality interactions, widespread accessibility and adoption based on the tech's real response to perceived needs, not just regulatory or industrial requirements.

Finally, the *Star Trek* scenario is not an automatic endpoint but rather a direction that entails risks, the first being idealization. Its strength lies in its ability to keep together what the other scenarios drive apart: technology, institutions and collective wellbeing. It is not a promise of utopia but rather a balance that must be built over time by combining scale, reliability, accessibility and human agency.

Dimension	Metropolis – Concentrated automation	Gattaca - Order and Control	Star Trek – Civil augmentation	Her – Dependence on infrastructure
Idea of progress	Increase in production	Stability and predictability	Collective wellbeing and shared capabilities	Personal comfort
Purpose of smart robotics	Human substitution	Reduce risk and uncertainty	Augment human capabilities	Accompany and assist
Humans' role	Residual, surveillance	Formal supervision	Active, augmented, co-decision-maker	Dependent user
Human-machine relationship	Hierarchical	Procedural	Co-evolutionary	Warm but asymmetrical
Ecosystem model	Closed oligopoly	Governed but rigid infrastructures	Open, interoperable platforms	Proprietary platforms
Metric of success	Efficiency	Conformity	Social impact + performance	Adoption and retention
Access to benefits	Highly unequal	Selective	Broad and progressive	Income-dependent
Dominant image	Machine as master	System as judge	Technology as public good	Technology as companion
Economic model / value distribution	Industrial control Economic exclusion	Conditioned opportunities Regulated value	Value distributed Public economy	Proprietary services Platforms dominant
Environmental sustainability	Resource intense Environmental degradation	Controlled optimization Regulated sustainability	Sustainable transition Circular economy	Systemic rebound of energy consumption
Systemic resilience and security	Extreme centralization Systemic weakness	Poor adaptability Controlled stability	Robust supply chains High adaptability	Concentrated supply chains Systemic vulnerability
Ethics and rights	Reduced, unclear agency Limited rights	Formal transparency Differentiated rights	High agency Extensive rights	Delegated agency Mediated rights

Table 2 – Comparison of these four scenarios to encourage an overall vision

When seen from this perspective, what matters is not to choose a scenario but to recognize what elements to retain, transform or avoid. The future of robotics will be based on our cumulative choices, not one, single ideal model. Since the infrastructure has yet to become widespread, these scenarios are still just anticipatory configurations that are open and capable of being influenced by today's choices.

Policy orientations

Smart robotics as civil infrastructure in Europe

Smart robotics is still in the open development phase. It is not fully mature or stable, but it is already capable of impacting work, care, services, and critical infrastructure. This combination of application potential and evolving trajectories makes this an especially important time for public action.

The future of robotics depends, not only on technological progress but on institutional, regulatory and investment choices that will guide its integration into society. Therefore, it should be thought of not as a sectorial technology but as a long-term socio-technological infrastructure that will potentially become deeply integrated with more widespread infrastructure (IoT, services, etc.), with implications that are similar to those of energy, healthcare and mobility.

We also need to look beyond the logic of short-term return. Robotics includes deep, infrastructural technologies, with **long development and diffusion cycles** that are often measured in decades. So, economic returns are progressive, because they depend not only on technological maturity but on their integration into production and social settings, organizational adaptation, validation, standardization and the building of markets and supply chains. For this reason, they are not very compatible with traditional ROI (return on investment) models which have short-term aims and directly measurable financial returns. Policies and investments must adopt patient, strategic approaches that recognize value that is initially more systemic and transformative than financial

After analyzing the various scenarios, one desirable direction for public action is clear: that of robotics as civil European infrastructure that reinforces human agency, supports work and care, ensures equal access and strengthens strategic autonomy, avoiding systemic dependence, marginalization of human labor and sterile control. More than an ideal model it is a trajectory that combines innovation, interoperability, governed experimentation, the safeguarding of rights and the broad distribution of benefits.

Within this landscape, it is essential that we ensure equal access to technology and the safeguarding of rights so that robotics does not generate new exclusions but rather strengthens widespread capabilities and opportunities. Therefore, the measure of the success of smart robotics is not just how well the machines work but how much better society works because of them.

1. Direct research toward cumulative, high-impact trajectories

The architecture of European research must be balanced through programs, assessment criteria and financial instruments that are aligned with long-term technological goals in order to reduce project fragmentation and ensure continued investment. The challenge is not just resources, but the ability of the research and innovation ecosystem to support technological development and translate it into real-life applications. Assessment frameworks must acknowledge the cumulative, cyclical nature of these technologies and reward the accumulation of capabilities, the continuity of lines of research and their conversion into operating systems. Protected spaces for experimentation are essential to hands-on learning and informed risk management.

2. Treat smart robotics as strategic infrastructure

Open standards, interoperability and robust technological supply chains that can support long evolutionary cycles must become the structural prerequisites for public support. Shared European platforms – hardware, software and data – are a way of preventing technological lock-in and systemic dependence. Public procurement can also strategically guide development, not just serve as a purchasing mechanism.

3. The integration of human labor as a design criterion

Smart robotics policies must include clear objectives regarding human wellbeing, learning and agency, promoting solutions that are inclusive by design. This means investing in training for augmented roles, tools that anticipate the job transition and success metrics that go beyond productivity to include work quality, co-evolution and social sustainability.

4. Govern risk as a part of innovation

Regulation should differentiate between risks that must be avoided and those that must be governed so that caution does not devolve into paralysis. Effective governance does not eliminate risk. It makes it transparent, monitorable and reversible, setting aside space for hands-on learning and progressive adaptation.

In this context, technological literacy and maturity is crucial in order to recognize and assess the potential dual use of embodied technologies without reducing them to taboos. It is not about denying its ambivalence but rather about developing institutional and social capabilities to weigh its uses, guide its application and prevent its abuse without renouncing innovation.

5. Global competitiveness and the choice of civilization

Finally, the direction of robotics must be interpreted within the broader context of global competition, where Chinese and US models – marked by the deep integration of research, industry and capital - are very prone to risk. For Europe, the danger is not so much technological as strategic: losing the ability to choose, becoming users of non-domestic ecosystems.

After comparing the scenarios above, a vision begins to take shape suggesting that supporting robotics that is aligned with European values does not mean pursuing an ideal model but rather building a balance between competitivity, **governance, inclusion and responsibility**. It is within this space of choice and accountability that we can see the dream of embodied intelligence for what it is: not just technological innovation but a political, ethical and cultural choice.

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