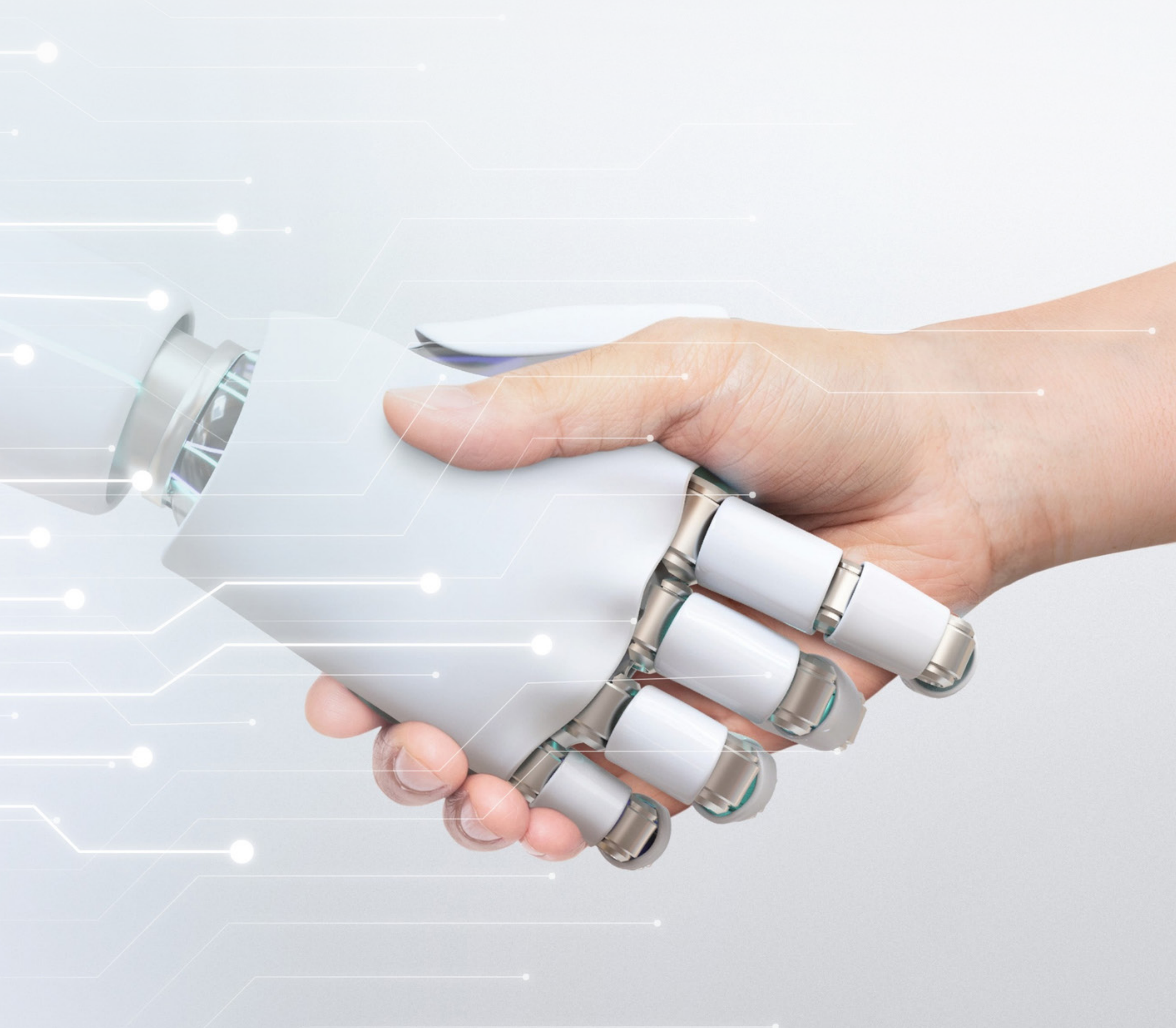
Global Future Council on Autonomous Systems

Next-Generation Physical Autonomy: Advancing Intelligent Systems for a Thriving and Resilient Society

BRIEFING PAPER

APRIL 2026



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Introduction

Autonomous robots are no longer confined to factory floors. They are entering daily life – driving on public roads, delivering goods, assisting in healthcare, supporting facilities management and operating in hazardous environments.

Physical autonomous systems integrate artificial intelligence (AI), information processing, sensing and electro-mechanical capability to perceive, decide and operate in complex environments. This paper focuses on robots operating in semi-structured and unstructured settings, where they interoperate with other systems and interact, co-work and cohabit with people. These can range from autonomous vehicles and drones to quadrupeds and humanoids.

Unlike digital AI systems that operate solely on information, physical autonomous systems must contend with the continuous, uncertain and unforgiving dynamics of the physical world. They must predict motion, manage forces, interpret ambiguous cues, adapt to novelty and maintain safety in environments they cannot fully script. This places unique demands on their underlying intelligence: models that reason over time, understand physics, learn at the edge and can operate reliably even without connectivity. Physical autonomy is therefore not simply applied AI, but a distinct scientific and engineering frontier.

Robots have reached a technological inflection point just as demographic, economic and environmental pressures intensify. As physical autonomous systems move into shared environments, they will reshape how societies live and work. Their trajectory will be shaped by technological, economic, societal and geopolitical forces, and should be guided by design principles that promote safety, inclusion and trust. Figure 1 outlines foundational values and key implementation attributes for responsible deployment which, alongside compliance with applicable policies and regulations, can help ensure these technologies serve people and societies.

If developed responsibly, these systems could reduce injury and burnout, expand health care access, accelerate resilient infrastructure, enable precision agriculture and strengthen environmental stewardship. By automating undesirable tasks and augmenting human capability, they could, among other things, support safer mobility, cleaner energy and faster emergency response.

This paper outlines four potential scenarios for the state of physical autonomous systems by 2031 and sets out eight objectives to guide responsible design, development and deployment.

FIGURE 1 | **Foundational values and key implementation attributes for physical autonomous systems**

Foundational values

Trustworthy design and operation

Safety	Reliability	Transparency	Accountability and responsibility
Ensure and prioritize human well-being	Ensure consistency with dependable performance within operational design domains (ODDs)	Make system operations clear and open to scrutiny	Enable traceability and clearly define organizational accountability for impacts across the robot lifecycle

Human empowerment

Human agency	Protection from manipulation	Dignity and social justice
Ensure individuals retain control and remain central to core decision-making	Safeguard users against coercion, deception and undue influence	Uphold human dignity and social justice as core principles

Key attributes for implementations

Human-centred integration	No over-automation/ over-reliance on robots	Inclusivity	Affordability
Design robots to fit smoothly and intuitively into human environments and workflows, prioritizing human needs and comfort	Deploy robots in proportion to task complexity, risk and expected value, rather than by default; focus on meaningful, value-adding applications	Ensure accessibility across abilities and socioeconomic conditions, empowering people with disabilities, mental and cognitive differences, and underserved populations	Design robotics to be broadly accessible, keeping costs fair and reasonable

Source: World Economic Forum

1 Key trends shaping the future of physical autonomous systems

The development of robotics and autonomous mobility will be driven by progress across four interconnected dimensions: technological, economic, societal and geopolitical. Together, these will determine not only how fast autonomy advances, but how broadly its benefits are shared.

Technological dimension

Multiple breakthroughs must converge for physical autonomy to reach full maturity. Progress depends on AI models that can reason over continuous space and time (capturing spatial–temporal correlations), contact dynamics and the subtleties of real-world uncertainty. These models must be trained on (or distilled from) sufficiently rich real-world datasets to build world representations that understand physics – not only where objects are, but how they move, deform, collide and resist, including forces, torques and constraints.

Robotics will also require major advances in manipulation and dexterity, enabling machines to grasp, adjust, repair, assemble, clean and assist with a level of safety and adaptability appropriate for unstructured human environments. Equally important is progress in social and situational intelligence to create systems that can interpret intent, negotiate shared space and operate intuitively alongside people, animals and other machines.

The surprising rise of generative AI revealed how quickly expectations can shift when underlying technologies reach a tipping point. Robotics may undergo similar discontinuities: sudden leaps in materials, actuation, perception, or embodied intelligence could accelerate capabilities faster than institutions can respond. This possibility requires proactive readiness across governments, industry and civil society to ensure that breakthroughs in physical autonomy are integrated safely, ethically, and in ways that support human and societal well-being.

Economic dimension

The economic value of these technologies spans across sectors, including logistics, mobility, manufacturing, healthcare, agriculture, construction, retail and public services. Adoption will depend on affordability – including total cost of ownership, not just upfront price – for industries, governments and consumers, as well as clear returns on investment. Supply chain readiness for critical components such as actuators, sensors and edge compute will also be a major determinant of economic feasibility and speed to scale.

Investment patterns also matter. Today, most capital flows to humanoid systems, while other types of robots could offer greater near-term value. Ensuring continuity from research and development through deployment will require attention to resourcing across stages and time horizons, supporting both foundational research and scalable applications.

Beyond adoption and investment choices, the broader implications of automation, including effects on taxation, labour markets and productivity, will require rethinking how economic value is created and measured in increasingly automated economies.

Societal dimension

Societal attitudes towards physical autonomous systems are evolving as exposure increases. Early scepticism is gradually giving way to curiosity and cautious acceptance for those who experience practical applications, from drones supporting agriculture to autonomous vehicles in urban mobility. These interactions are normalising coexistence with machines in shared environments and shaping expectations for safety, utility and behaviour.

In parallel, concerns around privacy, dignity and cybersecurity are intensifying. As systems gain autonomy and physical reach, the potential for misuse, malfunction, or malicious interference becomes a defining issue. This is driving greater emphasis on cybersecurity-by-design, transparency in operation and public communication about risk.

To ensure these technologies are understood and adopted responsibly, awareness and education initiatives are essential to enable informed and inclusive decision-making. In parallel, regulations and policies adapted to local realities will be critical in determining where and when robots are deployed, and in supporting sustainable implementation and integration where their use is deemed appropriate.

Geopolitical dimension

The development of physical autonomous systems is unfolding in a fragmented geopolitical context. Robotics and autonomous systems are increasingly viewed as strategic technologies, central to national competitiveness and security. Many applications are dual-use, serving both civilian and defence purposes, which is blurring the boundaries between commercial innovation and strategic control. This trend is driving new industrial policies, export regulations and alliances focused on securing access to data, compute power and critical materials.

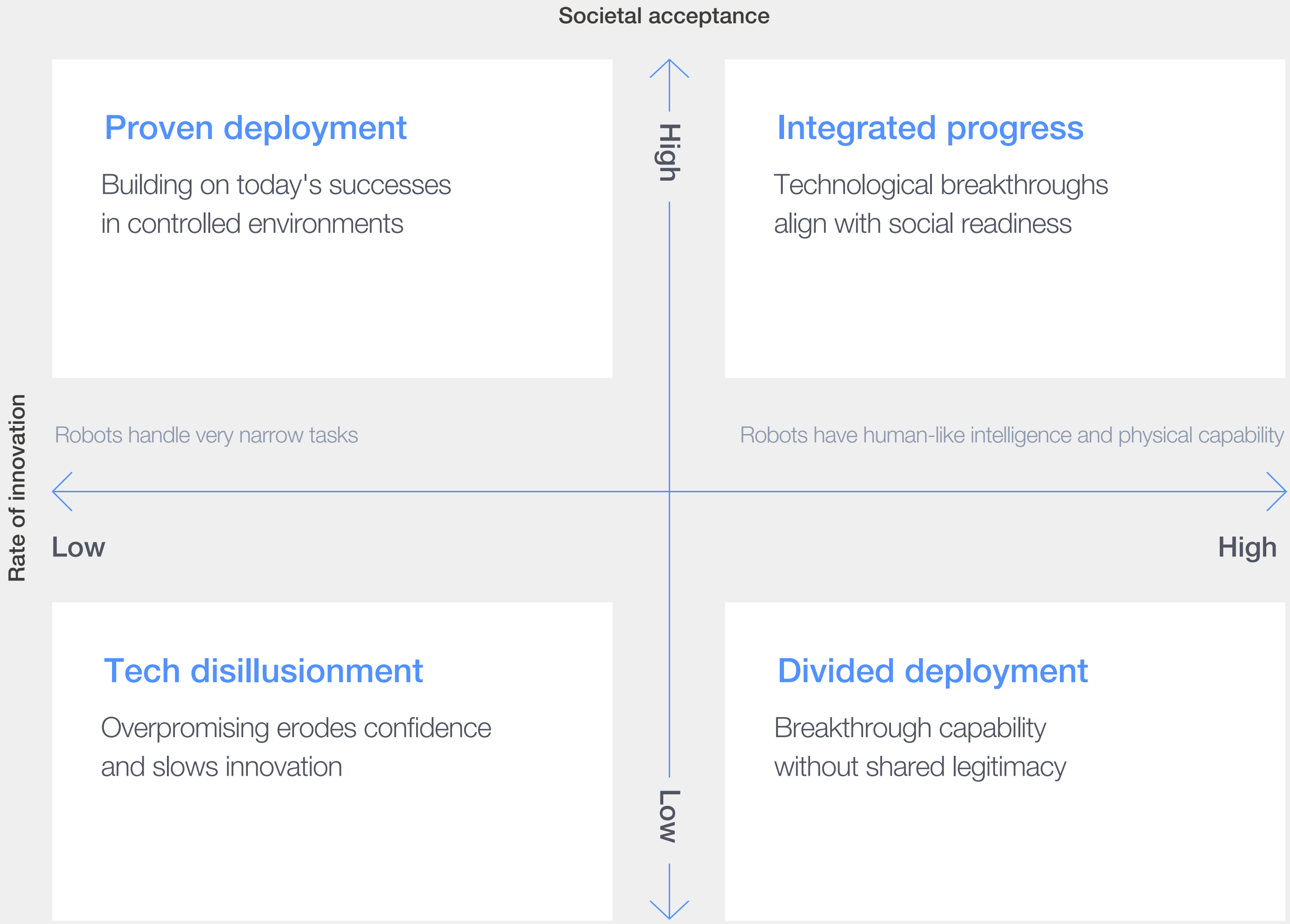
In parallel, multilateral cooperation is weakening, and divergent regulatory and technical standards are emerging. Different regions are already developing separate technology stacks, as seen in software-defined vehicles, signalling a more fragmented path for physical autonomy. Discussion of the potential implications of this situation should take place at global, regional and national levels, in all applicable domains (e.g., healthcare, agriculture, security) to determine how to deal with shared and specific risk, and mitigate potential harm.

2 Four scenarios for physical autonomous systems by 2031

Following current trends, the development of physical autonomous systems could take multiple paths over the next few years. Scenario analysis helps explore these alternatives, test assumptions, anticipate risks and inform strategic choices.

This paper adopts a five-year horizon – short enough to stress that action cannot wait, as the foundations of these technologies are laid in a context where, as ChatGPT showed, breakthroughs can emerge unexpectedly and outpace preparedness. The rate of innovation, together with societal acceptance, will be a critical factor in shaping outcomes. Their interaction defines four plausible futures for the role of physical autonomy by 2031.

FIGURE 2 **Four scenarios for the future of autonomous systems by 2031**



Source: World Economic Forum

Integrated progress: Technological breakthroughs align with societal readiness

Robotics is advancing through steady innovation and shared oversight, driven by both cumulative progress and innovation leaps. Improvements in both hardware and software (the robot body and brain), including movement, perception, reasoning and manipulation, are allowing robots to better support people in healthcare, construction, logistics and environmental work. Collaboration between public and private sectors, backed by clear yet flexible rules, helps maintain acceptance through transparency and accountability.

High societal acceptance – built on trust and repeated, transparent evidence that systems behave safely – makes it easier to bring robots and autonomous systems into daily life and across industries. Circular manufacturing and recycling help reduce environmental impact and secure materials, while solid data governance keeps users safe and responsible. Education and reskilling ensure people remain at the heart of this change.

Robots enhance human ability rather than replace it. As robotics becomes a shared public resource, productivity and acceptance grow together, supporting human work while protecting human agency and well-being.

This scenario represents the most desirable, but currently distant one.

Proven deployment: Building on today's successes in controlled environments

Robotics advances steadily, and it does so where systems have already proven reliable. Adoption grows in ports, logistics, mining and energy, sectors with structured operations and predictable outcomes. Maintenance drones, inspection robots and collaborative arms improve safety and efficiency, expanding quietly but effectively.

Governments set sector-specific rules, and investors back proven applications with clear returns. Innovation is gradual yet very slow: somewhat better sensors, stronger materials, smoother integration, but the world is not yet able to capitalize on the promised potential of the technology. Public acceptance stays stable: robotics is viewed as dependable infrastructure, not a disruptive force.

Progress builds without headlines. There are some improvements in productivity, with gains mostly benefiting established industries. Society values reliability and risk control over novelty, seeing success as consistency rather than change. In this environment, early-stage projects often receive less attention and support, which can slow experimentation and temper the pace of capability development, even as innovation continues in areas where it may be most needed.

This scenario, alongside the following one (tech disillusionment), reflects one of the most plausible reference futures for 2031, with reality likely blending elements across all four scenarios.

Tech disillusionment: Overpromising erodes confidence and slows innovation

After years of overpromising and failed global accessibility, confidence in robotics declines. Disillusionment is not driven by failure but by a growing mismatch between expectations and achievable timelines. Household assistants and delivery robots stay stuck in small pilots, while lawsuits over accidents and misuse slow progress. Even modest incidents overshadow thousands of safe operations, skewing perception and further accelerating disillusionment. Public interest fades, media coverage turns negative, and robotics retreats to niche industrial uses.

Investment shrinks and markets consolidate. Many start-ups disappear and larger companies limit robotics to small research projects. As funding contracts, opportunities narrow, pushing emerging researchers and engineers towards other industries and slowing progress over the long term. Governments avoid new policies or funding amid low public acceptance. Oversight weakens, and ethical discussions lose weight as frustration with slow progress grows.

The field continues, but momentum is gone. Robotics becomes a background technology, useful but uninspired, and society largely stops asking what robots could do beyond existing, proven use cases. Innovation narrows to what is safe, known and incremental, showing how quickly acceptance can fade, and how hard it is to rebuild once lost.

This scenario, alongside the previous one (proven deployment), reflects one of the most plausible reference futures for 2031, with reality likely blending elements across all four scenarios.

Divided deployment: Breakthrough capability without shared legitimacy

Advanced robotics reaches remarkable levels of autonomy, but deployment becomes fragmented across global power blocs and large private players. Governments and corporations use robotics to strengthen security and control, while public oversight struggles to keep up. A few major actors hold most of the data, compute and supply chains, making the system powerful but opaque. When such concentration persists, robotics becomes not only a strategic asset but also a potential single point of failure.

Innovation moves fastest in the military domain, surveillance and strategic industries, while everyday and civic uses fall behind. International coordination weakens, and legal and ethical standards evolve slowly, often trailing behind rapid advances in technology.

Robotics delivers major productivity gains, but also widens gaps in influence and opportunity, widening economic disparities in ways that strain the social fabric. Societies depend on systems they do not fully shape, creating tension between technological progress and public accountability. It is a world of impressive capability, but one still searching for shared purpose and legitimacy.

This scenario links low societal acceptance with rising geopolitical volatility and fragmentation. While the two do not necessarily move together, connecting them here helps simplify the framework and reflect the main risks currently perceived amid ongoing global tensions.

3 Strategic objectives for a more thriving, resilient society

The future will not mirror any single scenario. Instead, elements of each are likely to coexist and evolve over time. The following objectives outline the actions and principles that can help steer development towards the most desirable pathway, one of integrated progress that combines innovation with broad societal benefit.

Figure 1 sets out the foundational values and implementation attributes that guide responsible autonomy. Building on this foundation, the objectives that follow outline four operational and economic priorities and four societal priorities to support a thriving, resilient society. The eight objectives assume clear safety standards, validation processes, continuous monitoring and accountability as baseline conditions.

Operational and economic objectives

1. **Deploy and advance high-value use cases that deliver measurable societal and economic benefits**. Success will depend on visible, practical applications that solve real problems across sectors such as agriculture, transport, construction, retail and disaster resilience.

2. **Redirect investment flows toward high-impact applications rather than hype-driven ventures**. Balancing enthusiasm for frontier technologies with support for proven, ROI-positive use cases will ensure meaningful progress.

3. **Design human- and robot-friendly environments that enable safe, efficient collaboration**. As autonomous systems enter workplaces and public spaces, physical and digital infrastructures will need to evolve to support interoperability, safety, predictable and understandable system behaviour, and user comfort.

4. **Scale adoption through coordinated, cross-sectoral strategies**. Deployment must align with policy, regulation and public engagement to facilitate scaling, trust building and avoid future setbacks. A network of living labs could support testing, learning and adaptation across contexts.

Societal objectives

1. **Ensure equitable outcomes from the deployment of autonomous systems**. Impacts on employment, taxation, access, human agency and broader social outcomes should be monitored across regions, with feedback mechanisms in place to address positive and negative effects, prevent widening divides, and ensure accessibility of these systems.

2. **Automate repetitive and hazardous tasks to improve safety and well-being**. Robots can strengthen job security when they fill labour gaps, improve safety and productivity and are introduced alongside clear commitments to reskilling, upskilling and internal mobility, preparing the workforce for new roles emerging from autonomy.

3. **Redefine productivity models to capture and distribute the value created by automation**. Economic metrics and policy frameworks should reflect how physical autonomy contributes to growth and shared value, which may require moving beyond traditional measures of productivity.

4. **Strengthen awareness and literacy among citizens and policy-makers**. A broader understanding of how autonomous systems work, including how people can interpret and anticipate their behaviour in shared environments, is essential. Inclusive governance, shaped by a broad range of stakeholders, will help sustain informed acceptance and trust.

4 Accelerating collective action

The coming five years will be pivotal in shaping the trajectory of physical autonomy. The choices made today – in investment, governance and collaboration among industry, government, academia and civil society – will determine whether autonomous systems enhance productivity and inclusion or deepen existing divides.

To ensure a positive trajectory, stakeholders must work together to translate the mentioned objectives into practice through specific mechanisms. This requires aligned incentives that reward safety, transparency, interoperability and long-term value, rather than relying on goodwill alone. Mechanisms such as coordinated experimentation, evidence-based policy-making and shared learning are most effective when embedded in collaborative environments that bring together technology developers, operators, regulators and end users to test solutions, surface best practices and build trust through transparency and results.

Rather than assigning responsibility to a single group, progress depends on each actor recognizing their role in advancing these mechanisms within their own sphere of influence.

From objectives to practice

While shared objectives provide direction, their impact depends on how they are operationalized in real-world contexts. Effectiveness is contingent on the mechanisms used to bring objectives to life, particularly in complex environments where safety requirements, human interaction and contextual constraints intersect. This necessitates ongoing initiatives that extend beyond high-level normative frameworks towards tangible execution, encompassing structured experimentation, peer-reviewed validation processes and the development of real-world cases.

Use-case-driven approaches facilitate the expansion of how values and objectives translate into operational practices, considering physical constraints, human interactions and institutional responsibilities. Such approaches enable early identification of trade-offs, promote experimental learning among the various parties involved in the lifecycle of the technology, including developers, operators and regulators, and establish feedback mechanisms that enhance both technical designs and governance structures. Grounding objectives in practical deployments enable stakeholders to convert aspirational objectives into actionable, measurable and adaptable practices, thereby fostering sustained trust in the systems.

Across all these actors, a common thread emerges: preparation is about strengthening the systems around the technology as much as the technology itself. The scenarios described earlier show that high capability alone does not guarantee positive outcomes; alignment with societal expectations, institutions and incentives is equally decisive.

Physical autonomous systems are likely to become part of the infrastructure of modern life, much like energy, transport and digital networks before them. The choices made in this formative period – in governance, investment, design and inclusion – will determine whether autonomy deepens existing divides or expands opportunity. By acting with foresight and coordination now, stakeholders can help ensure that physical AI evolves as a trusted and widely beneficial foundation for safer work, more resilient societies and shared prosperity.

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The Global Future Council on Autonomous Systems, part of the Robotics and Autonomous Mobility Platform under Centre for Frontier Technologies and Innovation of the World Economic Forum, focuses on accelerating the responsible advancement of physical autonomous systems across sectors.

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