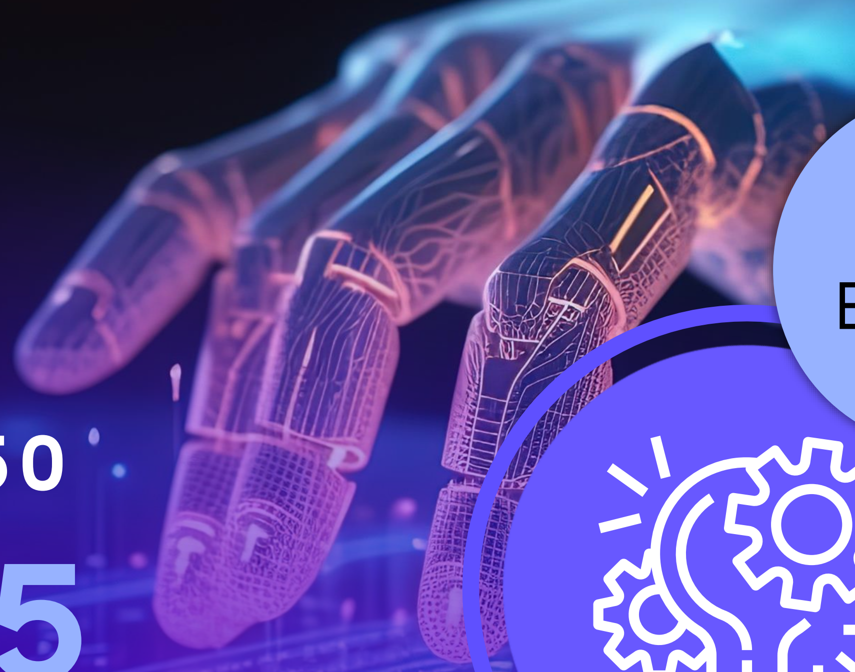
Trend Compendium **2050**

Megatrend 5
Technology & Innovation

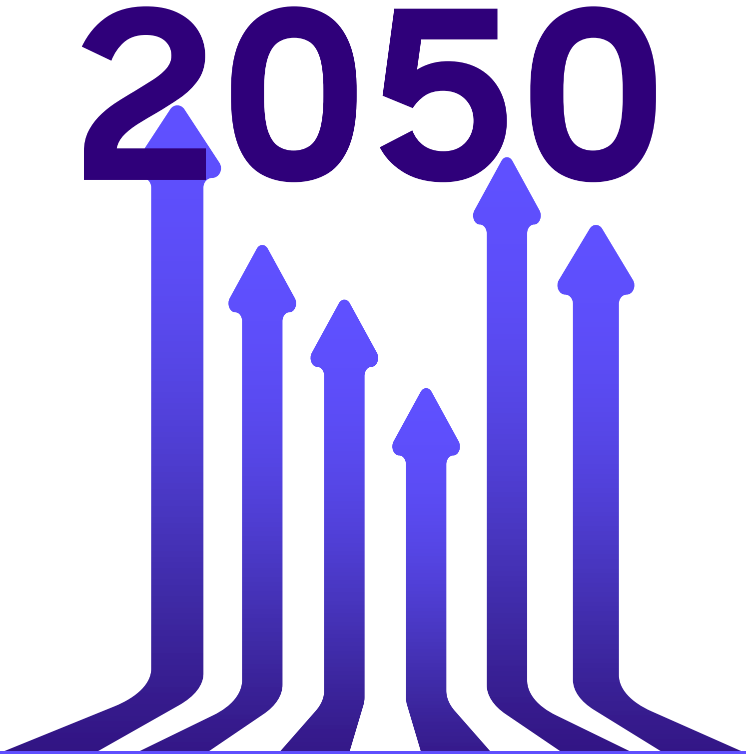


2025 Edition

Roland Berger

The Roland Berger Trend Compendium 2050 focuses on stable, long-term developments ...

- The **Roland Berger Trend Compendium 2050** is a global trend study compiled by **Roland Berger Institute (RBI)**, the think tank of Roland Berger. Our Trend Compendium 2050 describes the **most important megatrends** shaping the world between **now and 2050**
- Our **trend views are based on most recent studies, data and analyses.** We critically examine the results for relevance, plausibility and reliability
- We deliberately use **publicly available sources** to make our analyses verifiable
- To incorporate today's uncertainties into strategic planning, we recommend **combining the megatrends of the Roland Berger Trend Compendium 2050** with the **Roland Berger scenario planning approach**



Is it worth dealing with megatrends when globally impactful events such as the COVID-19 pandemic or the war in Ukraine are taking place?

Of course! The coronavirus pandemic and the war in Ukraine had far-reaching consequences and deeply affected people, economies, and politics but neither event has derailed the megatrends analyzed herein – such is the inherent nature of megatrends: climate change, societal aging, or technological innovations do not lose their momentum, their direction, or their importance. To cope with such challenges and to master resulting opportunities, our awareness and our understanding of megatrends is vital – not least to develop sustainable answers.

… and covers six megatrends that shape the future development of our world to 2050

1 People & Society
- Population
- Migration
- Education & Labor
- Values

2 Politics & Governance
- Global Risks
- Geopolitics
- Future of Democracy

3 Environment & Resources
- Climate Change & Pollution
- Biodiversity
- Water
- Resources & Raw Materials

4 Economics & Business
- Global Economics
- Power Shifts
- Energy Transformation
- Debt Challenge

5 **Technology & Innovation**
- Value of Innovation
- Frontier Technologies
- Humans & Machines

6 Health & Care
- Global Health Challenges
- Healthcare of the Future
- Caregiving

Innovation is the key to sustainable growth – Frontier technologies promise vast future potential while raising concerns about human values

Subtrends of megatrend "Technology & Innovation"

1

Value of Innovation

2

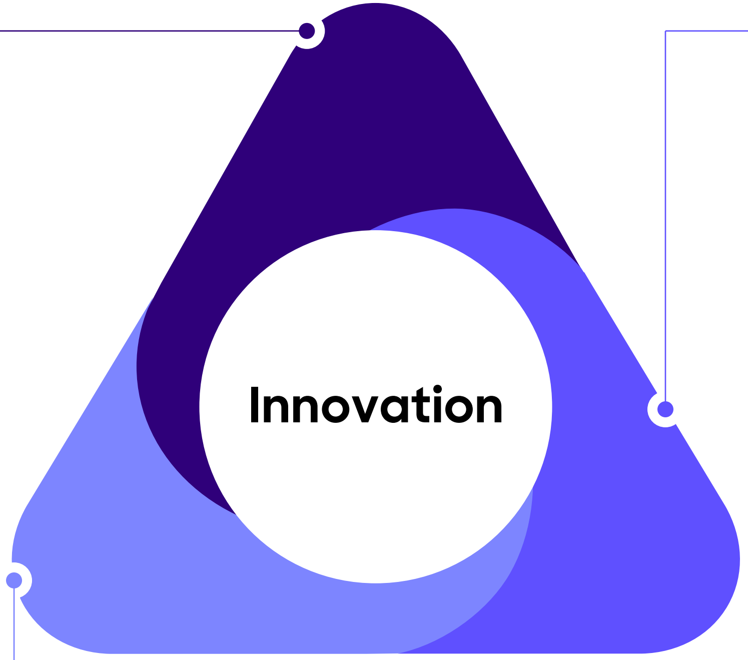
Frontier Technologies

3

Humans & Machines

The value of innovation can be seen in various important areas – Economically, socially, and in terms of sustainability

Key areas where innovation adds value



Drives the economy

Attracts consumers and creates new markets. Through new offerings/new ways of payment

Transforms business models. With a new product-/ market approach, value chain, revenue model

Drives the foundation of start-ups. An innovative idea is a core pillar of a start-up

Attracts investors. Innovations have the potential to generate high returns

Increases productivity. By optimizing processes

Drives economic growth. In addition to increases in the factors of production labor and capital, technological progress is the third driver of economic growth

Drives social welfare

Drives prosperity. Economic growth (driven by innovation, not population growth) increases welfare (GDP per capita). Innovation-driven companies can provide more and better job opportunities with higher pay

Reduces inequality. When innovations are widely accessible (low prices, good availability), they have the potential to improve the lives of poor people (e.g. microcredit, smartphones, solar energy systems)

Drives sustainability

Lowers GHG emissions. Green innovations can reduce greenhouse gas emissions from all sectors (energy production, industry, transportation, buildings), thus contributing significantly to the fight against climate change

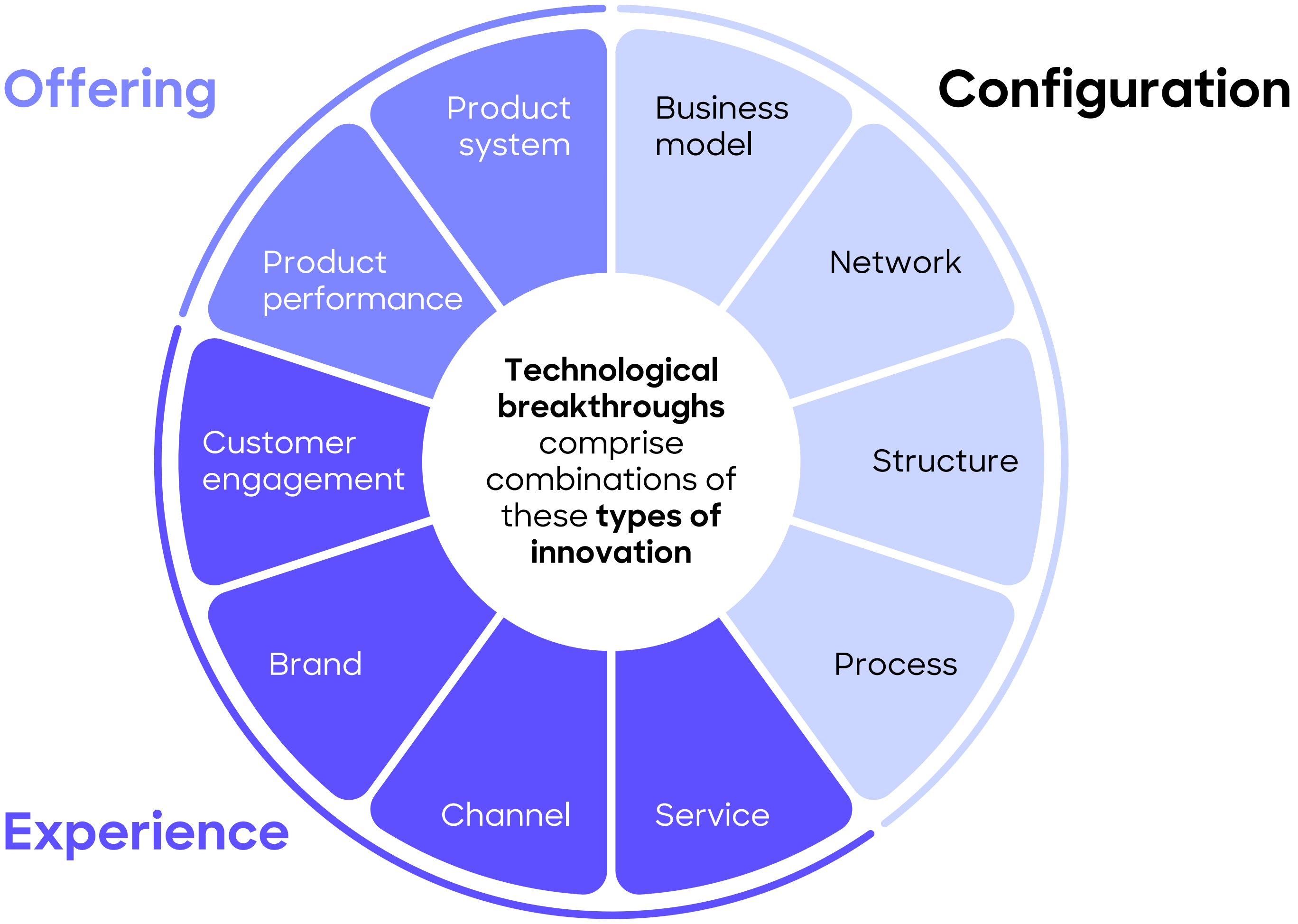
Decouples output from resource-intensive inputs. Innovations can lower the amount of (natural) resources needed throughout the value chain

Enables circularity. Innovation is a cornerstone to advancing the principles of the circular economy: reduce, reuse, recycle

Source: Roland Berger

Innovation combines value-adding inventions with successful market penetration, and can be categorized into different types

Types of innovation



- Innovation is the process of **turning new ideas into value,** in the form of new offerings, a new configuration or a new user experience
- Innovation is complex and goes beyond mere creative **inventiveness;** innovation includes essential, practical steps to **facilitate adoption and market penetration**
- Innovations can be categorized into **different types**
  - **Product offering innovations** can be subdivided into product performance and product system innovation, leading to more differentiated products and – potentially – to an ecosystem of associated services and products
  - Innovation regarding the **configuration of a company** can be subdivided into business model, network, structure, and process innovation. Such internal innovations provide crucial downstream effects, enabling innovation in other areas
  - Innovations in **user experience** affect customers directly, such as public appearance or reputation of a company. Innovations in areas of service, channels, branding, and customer engagement fall under this category of innovation

Source: WEF; Roland Berger

5.1 Value of Innovation

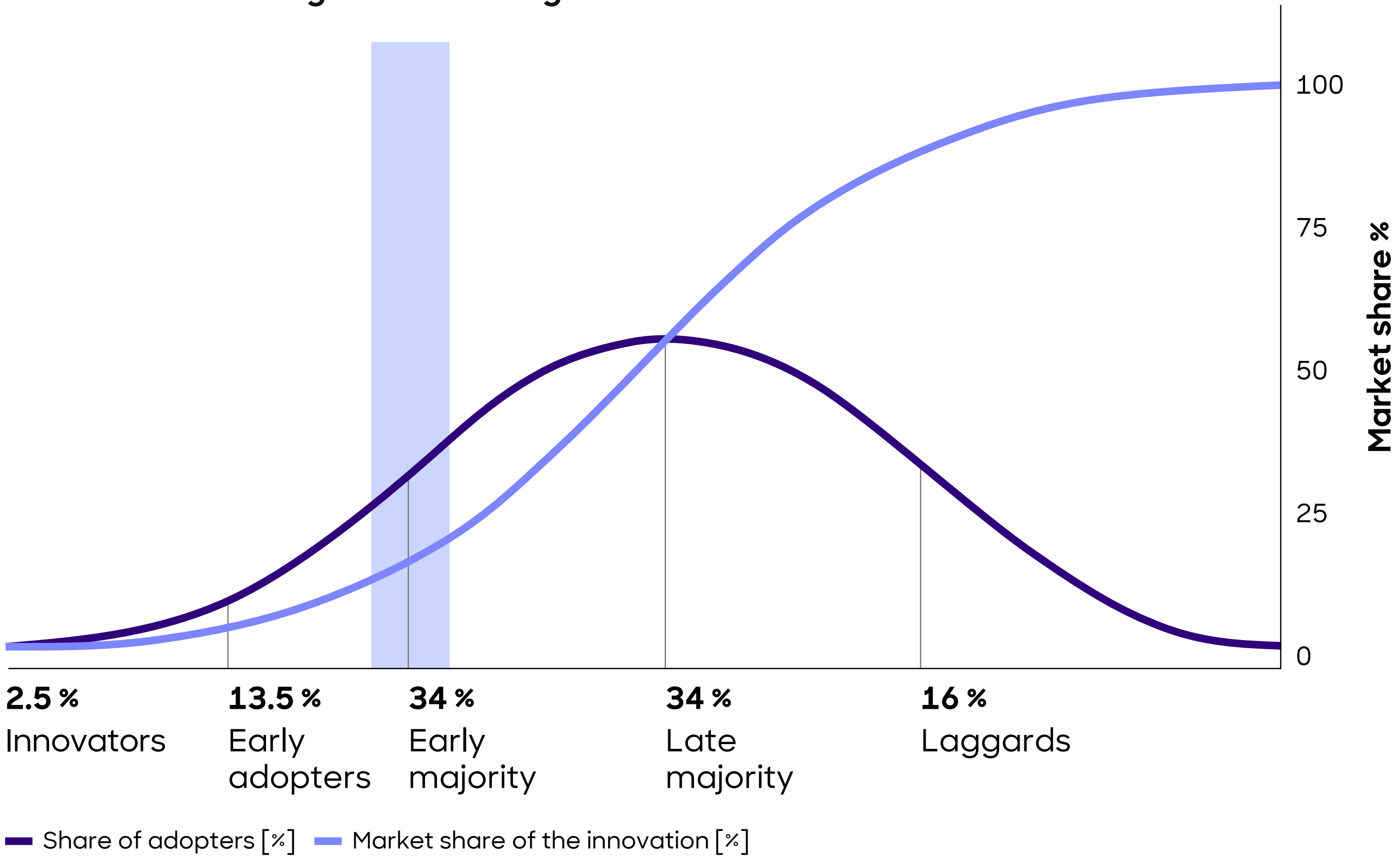
5.2 Frontier Technologies

5.3 Humans & Machines

To have an impact on the society and the economy, innovations need to reach critical mass

Diffusion of innovations according to Rogers

Reaching critical mass (early majority): Overcoming the "marketing chasm"



- In 1962, **Everett Rogers,** a US communication theorist and sociologist, produced a still widely used **theory of the adoption of innovations** among individuals and organizations
- Rogers identified **five kinds of adopters: innovators** (willing to take risks), **early adopters** (opinion leaders), **early majority** (having contact with early adopters and above average social status), **late majority** (high degree of skepticism), and **laggards** (aversion to change-agents)
- To **reach critical mass,** an innovation must make the transition **from early adopters to** the **early majority** (overcoming the "marketing chasm")
- The **five stages of adoption** are knowledge/awareness, persuasion, decision, implementation, and confirmation
- The question whether the **diffusion** of innovation has **accelerated over the time is still open.** Some analyses suggest that this is the case, but they have analytical weaknesses

Source: Rogers, E.; Roland Berger

Innovation is hard: Top innovating countries remain broadly the same over the past decade – South Korea and Germany are the only top 10 newcomers

Global innovation index ranking, by country rank, 2014 vs 2024

Country	2014	2024	Country
Switzerland	1	1	Switzerland
UK	2	2	Sweden
Sweden	3	3	USA
Finland	4	4	Singapore
Netherlands	5	5	UK
USA	6	**6**	**South Korea**
Singapore	7	7	Finland
Denmark	8	8	Netherlands
Luxembourg	9	**9**	**Germany**
Hong Kong (China)	10	10	Denmark
Ireland	11	11	China
Canada	12	12	France
Germany	**13**	13	Japan
Norway	14	14	Canada
Israel	15	15	Israel
South Korea	**16**	16	Estonia
Australia	17	17	Austria
New Zealand	18	18	Hong Kong (China)
Iceland	19	19	Ireland
Austria	20	20	Luxembourg
Japan	21	21	Norway
France	22	22	Iceland
...	...		
China	29		

- The **innovation process** is **complex, hard** and **time intensive:** changes can be slow
- At first glance, the **most innovative countries** in the top segment **appear broadly the same over the past decade** – with few exceptions. Only **South Korea** and **Germany** have advanced (in Germany's case it is a comeback) into the **top 10** of the WIPO's global innovation index ranking
- **Below the top 10,** there is more room for movement: the ones to watch include **France** and **Estonia** – the former has gained momentum, up from 22nd place ten year ago, now in 12th place, while the latter has risen through the ranks, from 24th place in 2014 to 16th in the current ranking. **Japan** is also back in this group
- Overall, **China** has made incredible progress, slowly rising from 29th to 11th place, while Hong Kong (China) has lost 8 places, just staying in the global top 20
- By contrast, Luxembourg and Ireland just manage to cling on to their positions among the top 20, while Norway has fallen out of this group – in stark contrast to its **Nordic neighbors,** which have solidly been part of the **most innovative top 10 countries** for decades

Source: WIPO; Roland Berger

A country's ability to innovate is determined by a complex combination of enabling factors – Top 10 innovative countries are advanced economies

WIPO Global Innovation Index (GII) rankings overall and by innovation pillar, 2024[1)]

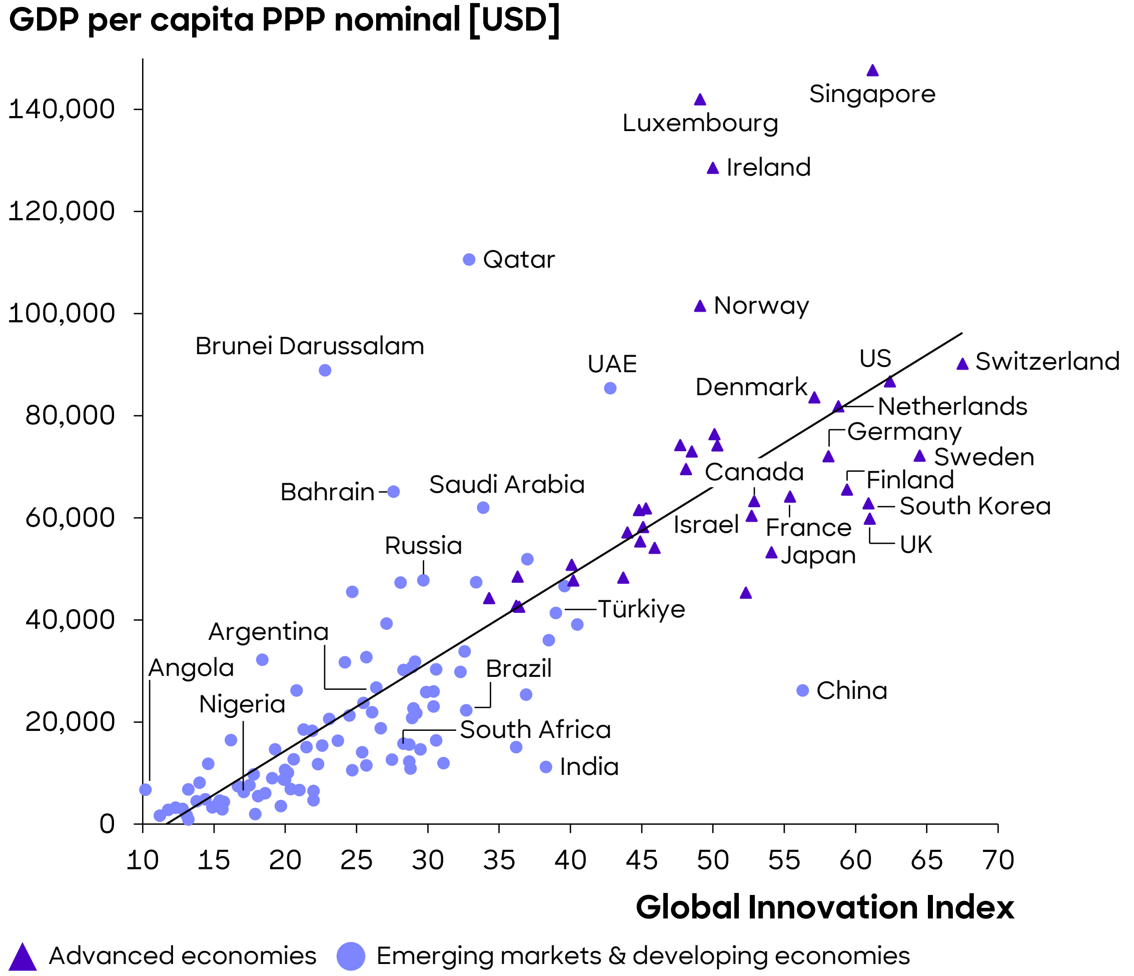
Country	GII (overall)	Institutions	Human capital & research	Infrastructure	Market sophistication	Business sophistication	Knowledge & technology outputs	Creative outputs
Switzerland	1	3	4	7	5	4	1	1
Sweden	2	16	3	1	9	1	2	6
US	3	17	12	30	1	2	4	8
Singapore	4	1	2	11	7	3	9	19
UK	5	26	7	18	3	14	5	3
South Korea	6	24	1	9	15	5	10	2
Finland	7	4	6	2	11	8	6	17
Netherlands	8	9	14	25	14	7	8	7
Germany	9	19	5	27	13	18	11	5
Denmark	10	2	9	8	21	12	13	10
China	11	44	22	5	16	11	3	14
France	12	29	16	19	10	17	16	4
Japan	13	23	19	13	8	6	12	22
Canada	14	14	11	21	4	13	20	25
Israel	15	34	18	41	12	9	7	30

1) The pillars of the GII are measured in the following categories and contain 78 indicators in total. Institutions: Political environment, Regulatory environment, Business environment; Human capital & research: Education, Tertiary education, R&D; Infrastructure: ICTs, General infrastructure, Ecological sustainability; Market sophistication: Credit, Investment, Trade & diversification & market scale; Business sophistication: Knowledge workers, Innovative linkages, Knowledge absorption; Knowledge & technology output: Knowledge creation, Knowledge impact, Knowledge diffusion; Creative outputs: Intangible assets, Creative goods and services, Online creativity

Source: WIPO; Roland Berger

Innovation drives the prosperity of nations – Many developing countries lack the capacity to innovate

WIPO Global Innovation Index (GII) and GDP per capita PPP, 2024 [Index, USD]



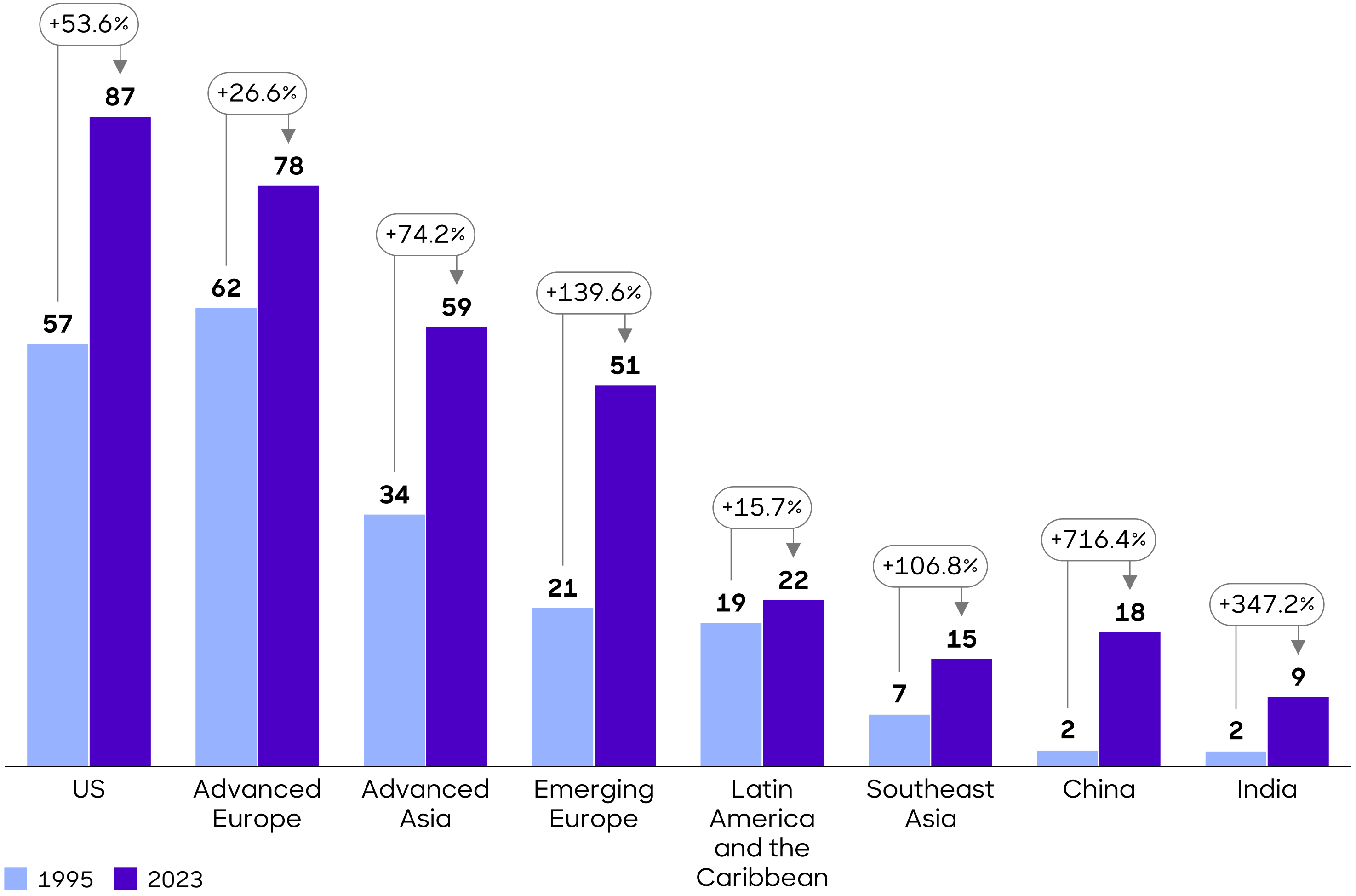
- A nation's **innovativeness** is a key driver of **productivity, growth, and prosperity**
- The **Global Innovation Index (GII) scores countries** from 0 to 100 based on their **ability to innovate.** The index analyzes countries on **a variety of metrics,** including R&D intensity, patent applications, tertiary education efficiency, regulatory environment, productivity, high-tech density, and researcher concentration
- Looking at the Global Innovation Index from a GDP/capita perspective, the message is clear: **the higher (lower) countries score on innovation the higher (lower) their GDP/capita.** China is an exception in that it has successfully built up its innovation strength, but still has a lower GDP/capita than developed countries
- Many **developing countries lack the capacity and access to institutions and skills** to better position themselves in the global innovation race. Proven networks of higher education and research institutions, as well as technology companies engaged in R&D - both well established in developed countries - are particularly lacking
- To gain a comprehensive picture of a country's innovation capabilities, different innovation indices should be used. In addition to the GII, the **"Innovation Indicator"**, an innovation index jointly developed by **BDI, Fraunhofer ISI, ZEW, and Roland Berger,** delves deeper into this topic. It measures the **innovation capability of 35 developed and emerging markets.** The criteria include the **ability to foster innovations,** the position in **key technologies,** and the strength in terms of **sustainability**[1)]

1) See BDI/Fraunhofer ISI/ZEW/Roland Berger: Innovation Indicator 2024

Source: WIPO; World Bank; Oxford Economics; Roland Berger

Innovation strength impacts productivity – Again, advanced economies are in the lead, but important EMs have caught up over the past three decades

Productivity: Real GDP per hour worked, 1995 and 2023 [USD PPP, %]



- **Productivity** measures the **efficiency** with which **inputs** such as labor, capital, and technology are **converted into outputs,** namely goods and services
- **Labor productivity,** measured by **GDP per hour worked,** shows how efficiently labor inputs are utilized in the production process
- Based on their **lead in economic structures** and driven by their **innovation strength, advanced economies** have built up most efficient production processes leading to their **high labor productivity**
- In the last three decades **emerging markets (EMs)** in Asia and Europe **have caught up** by outperforming the productivity growth rates of advanced economies by far
- Despite the catch-up process, the **gap** between advanced and emerging economies is **still significant.** This is not only due to a gap in innovation strengths but also due to a **large number of jobs with low productivity** in emerging markets (e.g. in agriculture)

Source: The Conference Board; Roland Berger

Human capital and R&D are particularly important levers for the improvement of a country's innovation performance

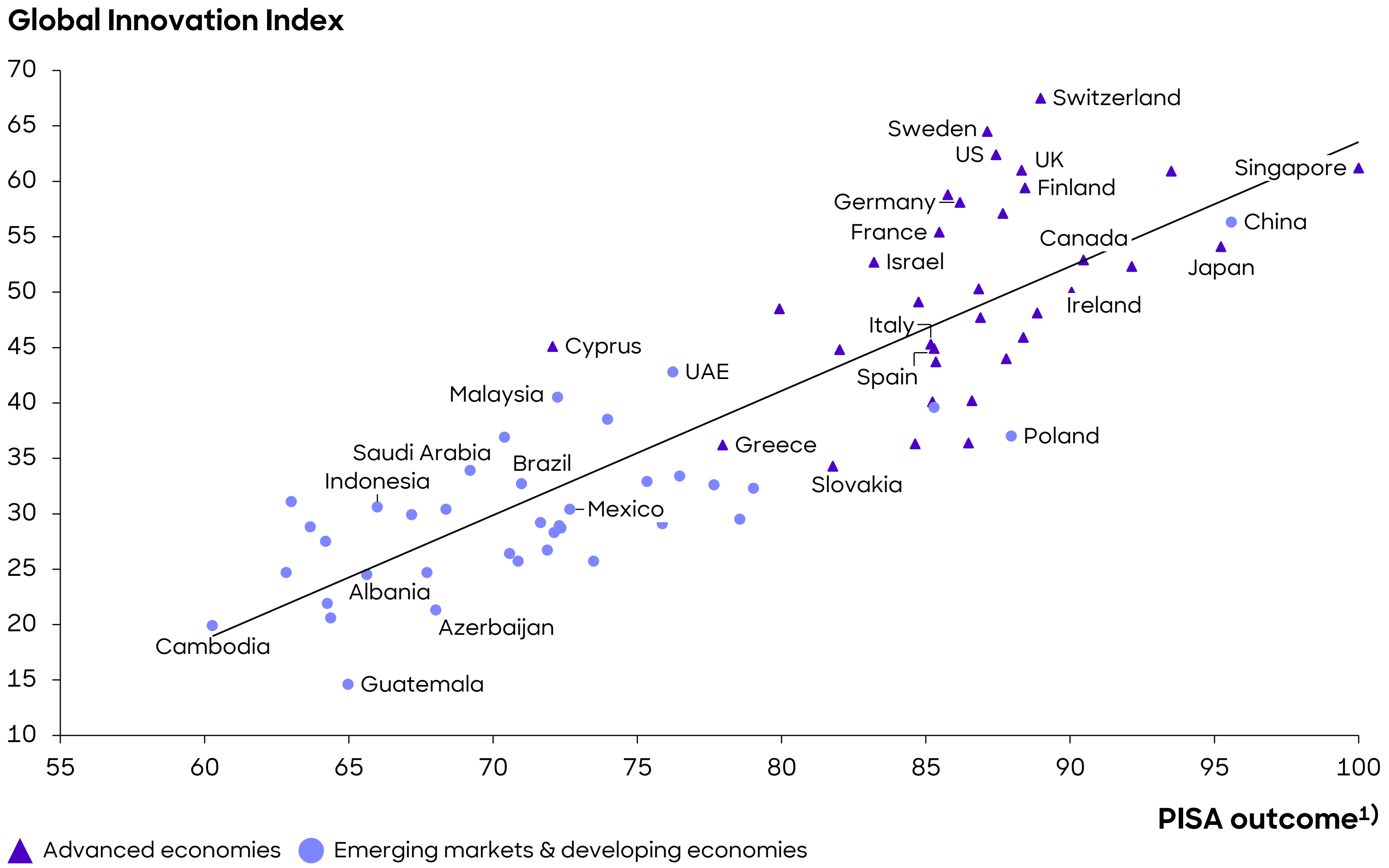
Human capital and R&D: Selected levers and measures for improvement

School education		Higher education		Research & development	
Lever	**Example of measures**	**Lever**	**Example of measures**	**Lever**	**Example of measures**
Government expenditure on education	Shift budget priorities, focus on funding education	**Tertiary school enrolment**	Improve transition from secondary to tertiary education (e.g., by supporting poorer students)	**Researchers per million population**	Make R&D as attractive as possible, e.g., by lowering legal barriers, reducing administrative burdens, providing sufficient funding
School life expectancy	Increase the number of years of compulsory education	**Graduates in science and engineering**	Attract more students to these disciplines; raise the attractiveness of these courses	**Gross expenditure on R&D**	Introduce tax incentives for business R&D investment, increase government funding
PISA scales in mathematics, reading and science	Set priorities for core school subjects	**Tertiary inbound mobility**	Attract and support foreign students, e.g., by finding a flat, learning the language and culture	**Average score of a country's top 3 universities (according to best-in-class rankings)**	Promote academic excellence (e.g., through excellence initiatives)
Pupil teacher ratio	Train and recruit more teachers; make the profession more attractive (e.g. through better pay)				

Source: WIPO; Roland Berger

Winning at innovation starts in the classroom – Becoming a future leader in innovation requires investment in education ...

WIPO Global Innovation Index (GII) 2024 and average PISA outcome score 2022 [Indices]



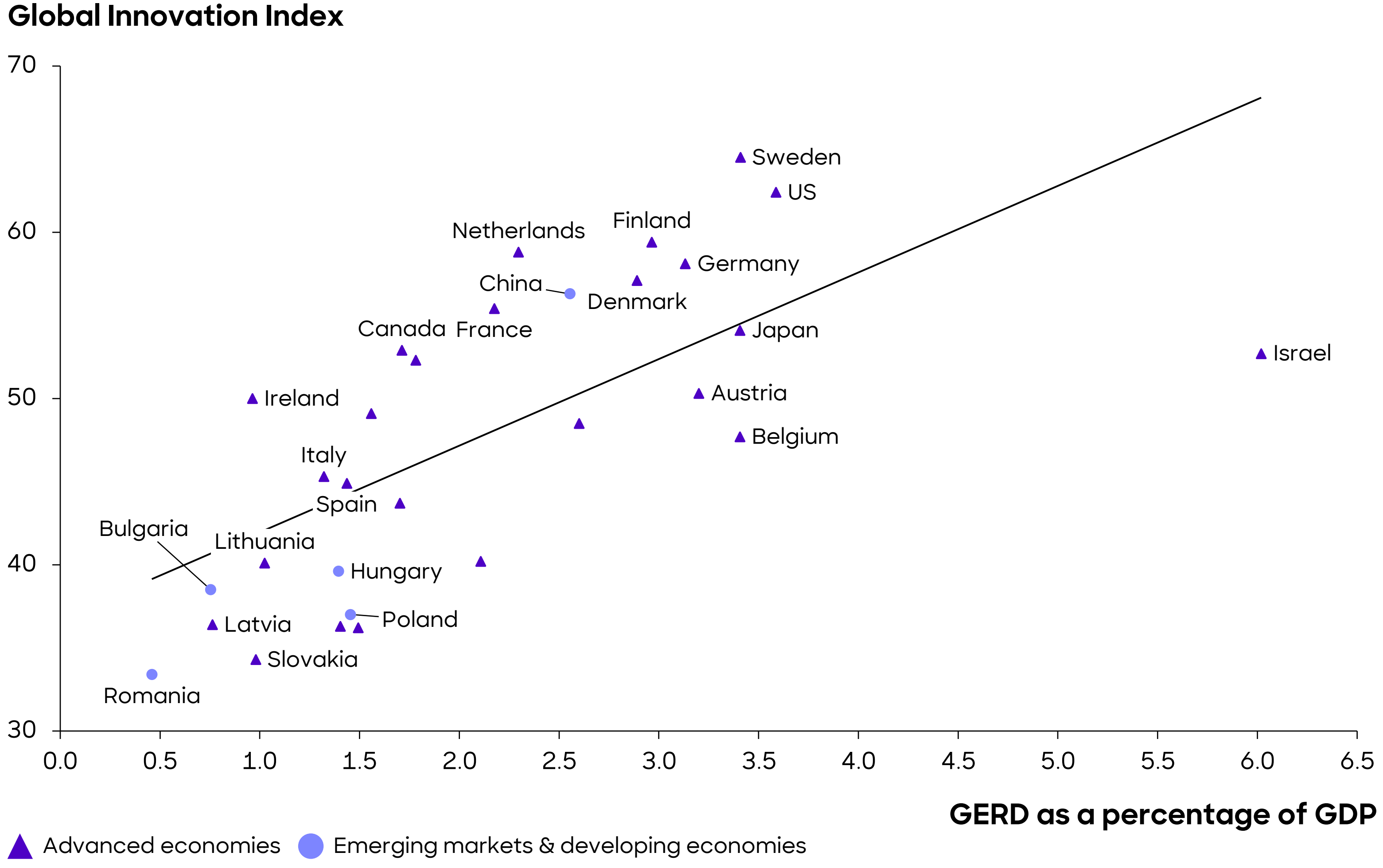
- Innovation is driven by a variety of factors, one of which is the **educational base** of a country
- Innovation requires **high-quality human capital** that can **think beyond the limits of existing technologies** and creatively turn ideas into reality
- Models of economic growth suggest that countries with **better education systems** have **better innovation capabilities**
- Empirically, countries with **higher scores** in the 2022 **PISA** study have, on average, **higher** scores in the **Global Innovation Index**
- Improving a country's future **ability to innovate** therefore starts in the classroom and requires the **best possible educational resources** as well as **sufficient investment** in students, teachers, and facilities

1) The value represents the country's average outcome in the PISA study (OECD Programme for International Student Assessment) in all three disciplines of reading, mathematics, and science relative to Singapore's outcome (Singapore = 100) in 2022 and were edited as such by WIPO

Source: WIPO; Roland Berger

… as well as investment in R&D – As a key driver of best-in-class innovation, R&D expenditure levels signal confidence in the future

WIPO Global Innovation Index 2024 and Gross Expenditure on R&D 2022 [% of GDP, Index]

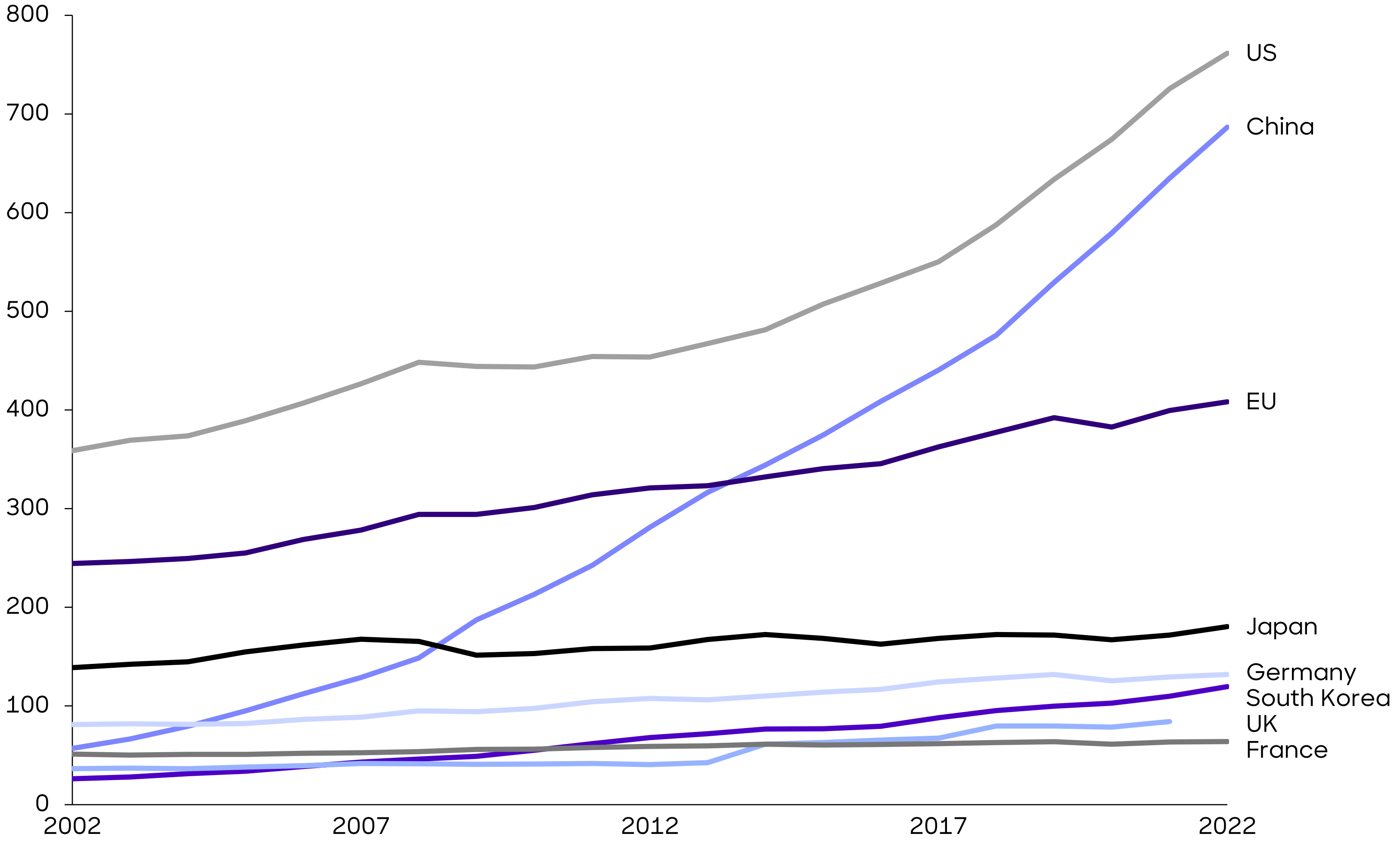


- Investing financial resources in **R&D** seems as obvious as it is **essential** for a country to remain or become more innovative
- **Innovation processes are resource intensive** and subject to uncertainties such as failure and sunk costs
- However, R&D investment and innovation are positively correlated: **funding and fostering innovation yields future rewards**
- Looking at the process at a microeconomic level, investment decisions signal **expectations about the impact of innovation** and **potential future returns:** highly funded innovative ideas signal future promise to stakeholders and **confidence** in the **successful completion of the innovation process**

1) Here, we use the GII results from 2024 and GERD data for the latest available year of 2022
Source: WIPO; OECD; Roland Berger

The US and China are the leading players regarding R&D expenditure - EU lacks similar growth rates

Gross domestic expenditure on R&D of selected economies, 2002-2022 [USD m, constant 2015 PPP prices]

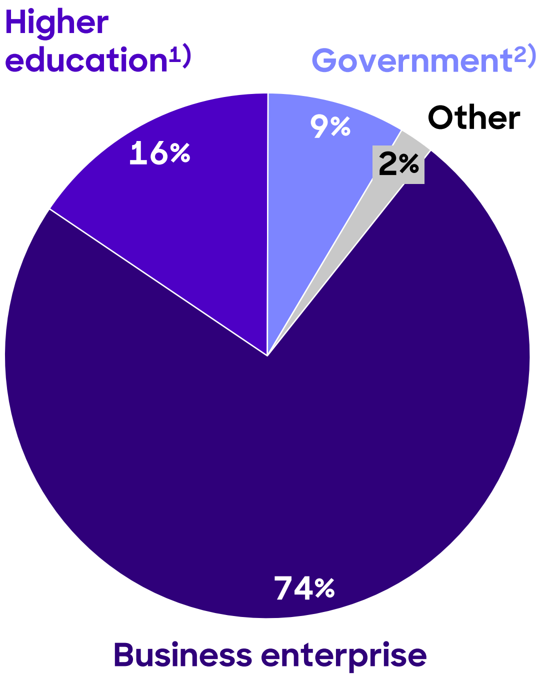


- While the **EU** is experiencing **slow growth in R&D spending**, the **US** and especially **China** are allocating **increasing resources** to research and development
- Moreover, **China was able to catch up to the US by shrinking the investment gap** from 16% of US investments in 2002 to 90% in 2022, simultaneously overtaking Japan and the EU
- In comparison, while **China** increased their R&D expenditure by **13% annually,** the **EU** could only record a yearly growth rate of **2.6%** from 2002 to 2022
- **The US** remains at the **top of the R&D expenditure ranking** with a significantly sharp increase in the years after 2012

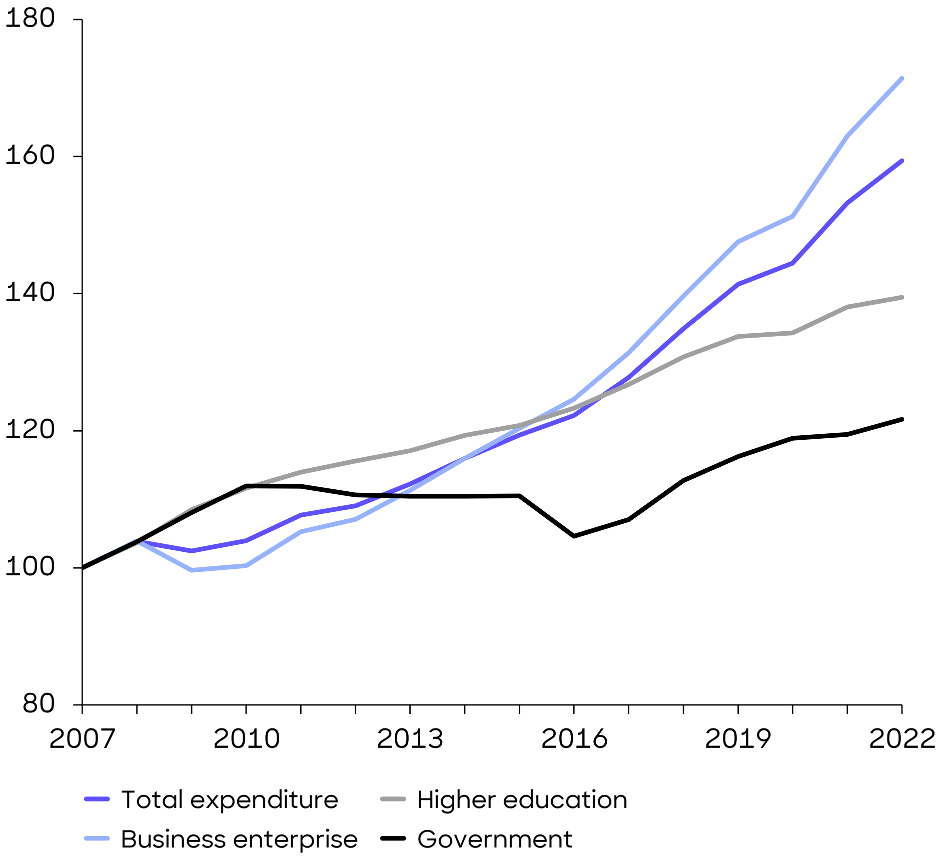
Source: OECD; Roland Berger

R&D expenditure in OECD countries is driven by the business sector, with private R&D spending outpacing public funding

Gross R&D expenditure in OECD by segment, 2022 [%]



Real gross R&D expenditure in OECD by segment, growth 2007-2022 [Index, 2007=100]



- In OECD countries, the **business sector accounts for nearly three-quarters of R&D spending,** making it the most impactful driver of innovation
- From 2007 to 2022, all sectors have increased their spending, with **business investments demonstrating the most substantial growth**
- **Government R&D spending** exhibited the **least growth.** A significant factor contributing to this trend is the **high level of government debt in OECD countries,** restricting the capacity of governments to raise their R&D expenditure

1) Higher Education is composed of: all universities, colleges of technology and other institutions providing formal tertiary education programs, whatever their source of finance or legal status. All research institutes, centers, experimental stations and clinics that have their R&D activities under the direct control of, or administered by, tertiary education institutions

2) Government is defined as: all units of central/federal, regional/state and local/municipal government, including social security funds, except those units that fit the description of higher education institutions

Source: OECD; Roland Berger

5.1 Value of Innovation

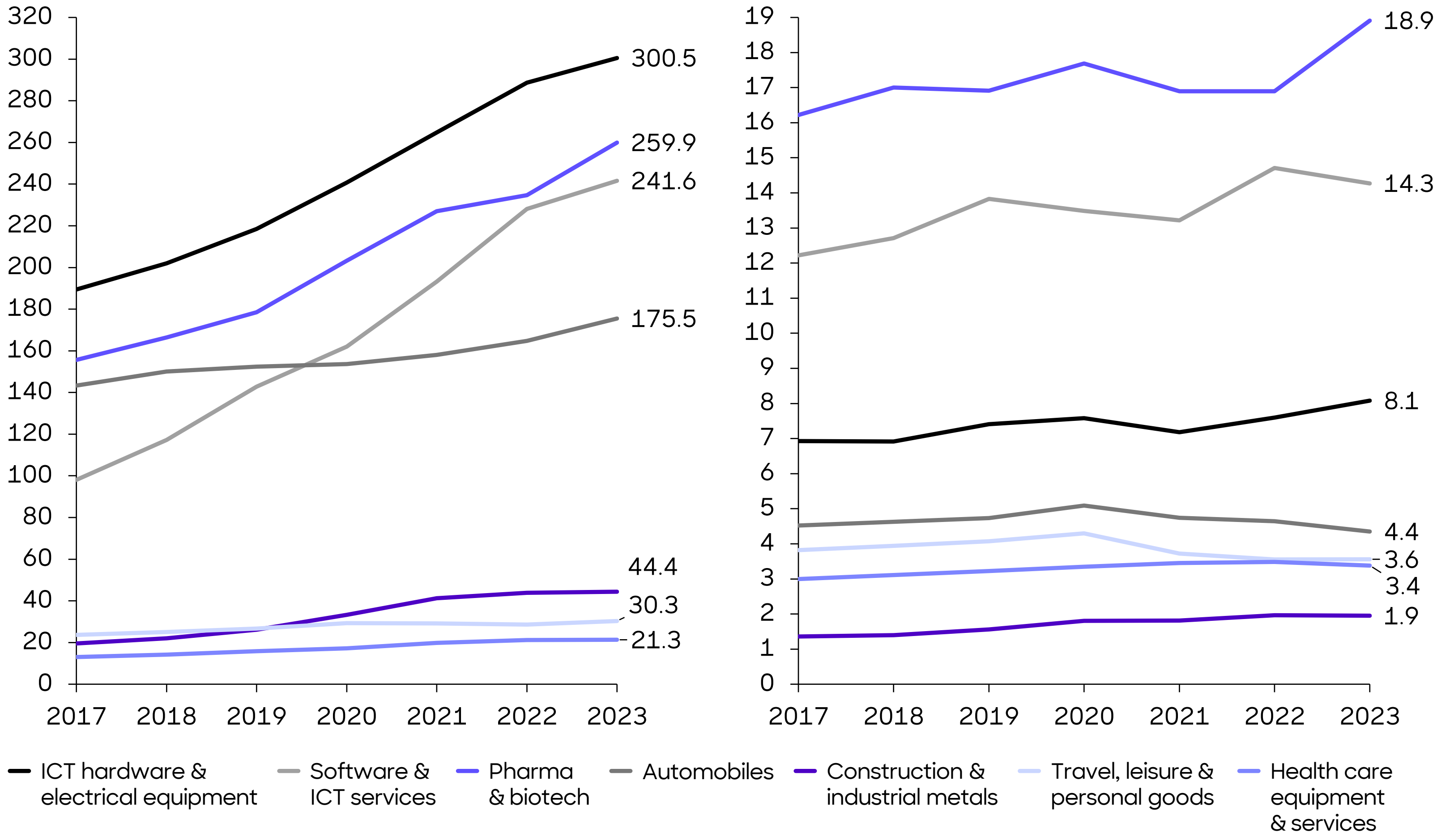
5.2 Frontier Technologies

5.3 Humans & Machines

Companies in the ICT, pharma, software and automobile sectors spend most on R&D as revenues grow – Intensity ticked upwards or stayed constant

Nominal R&D spendings by industry, 2017-2023[1)] [USD bn]

R&D spendings/revenues by industry, 2017-2023[1)] [%]



- **R&D spending** in absolute terms **has risen in almost all sectors** but particularly in those **with higher revenue inflows**
- As there is **little dynamism in spending intensity,** sectors that have been able to attract **more income,** as reflected in rising revenues, **allocate more money** (but not more of their revenues) to R&D spending
- For example, the **ICT hardware and electrical equipment sector, accounts for the highest expenditure** in absolute terms, while investing on average around 8% of its turnover in R&D
- **Innovation** is **most important** in the **pharmaceutical & biotech** and **software & ICT services sectors,** which spend the largest share of their revenues on R&D

1) Based on R&D spending of 1,700 out of the biggest 2,500 corporate R&D spenders globally

Source: WIPO; Roland Berger

Major economies identify and fund critical and emerging technologies to help them win the global innovation race

Overview of a representative selection of key technology areas, strategies, and governmental support measures in selected countries and the EU

	USA	EU	China	Germany	South Korea	Japan
Number of key technology areas	19 "critical and emerging technologies" with 2–15 "critical and emerging technology subfields" each (103 subfields in total)	10 "critical technology areas" with 4-5 technologies each (42 technologies in total)	7 "cutting-edge areas of science and technology" with 3–5 specifications each (28 in total)	12 "key technologies"	12 "strategic technologies"	20 "technologies as critical fields"
Strategies	"United States government national standards strategy for critical and emerging techno-logy," May 2023	Commission recommendation on security-relevant technology areas, October 20231	14th Five-year Plan, March 2021	Shaping the future with technological confidence," BMBF impulse paper, April 2021	"National strategic technology nurture: plan," October 2022	Economic security strategy," February 2022
Selected support measures	USD 369 bn IRA USD 230 bn for semiconductor production USD 140 bn for electric vehicles and batteries USD 20 bn for biomanufacturing	USD 294 bn for the "Green industrial deal" USD 141.5 bn for "NextGenerationEU" USD 762 m for 5G infrastructure (Horizon 2020) USD 980 m for smart networks and services	USD 369 bn IRA USD 230 bn for semiconductor production USD 140 bn for electric vehicles and batteries USD 20 bn for biomanufacturing	USD 5.4 bn by 2025 for the AI strategy USD 3.3 bn in quantum computers by 2026	USD 430 bn for semiconductors over 23 years USD 10 bn for bio-technologies by 2026 USD 73 bn for mobility /vehicles by 2026 USD 1.3 bn for robotics by 2026	Investments are to come primarily from the private sector. In addition, USD 1.05 trillion is to come from public-private partnerships over the next 10 years

Source: CESifo; Roland Berger

Technology & Innovation

5.1 Value of Innovation

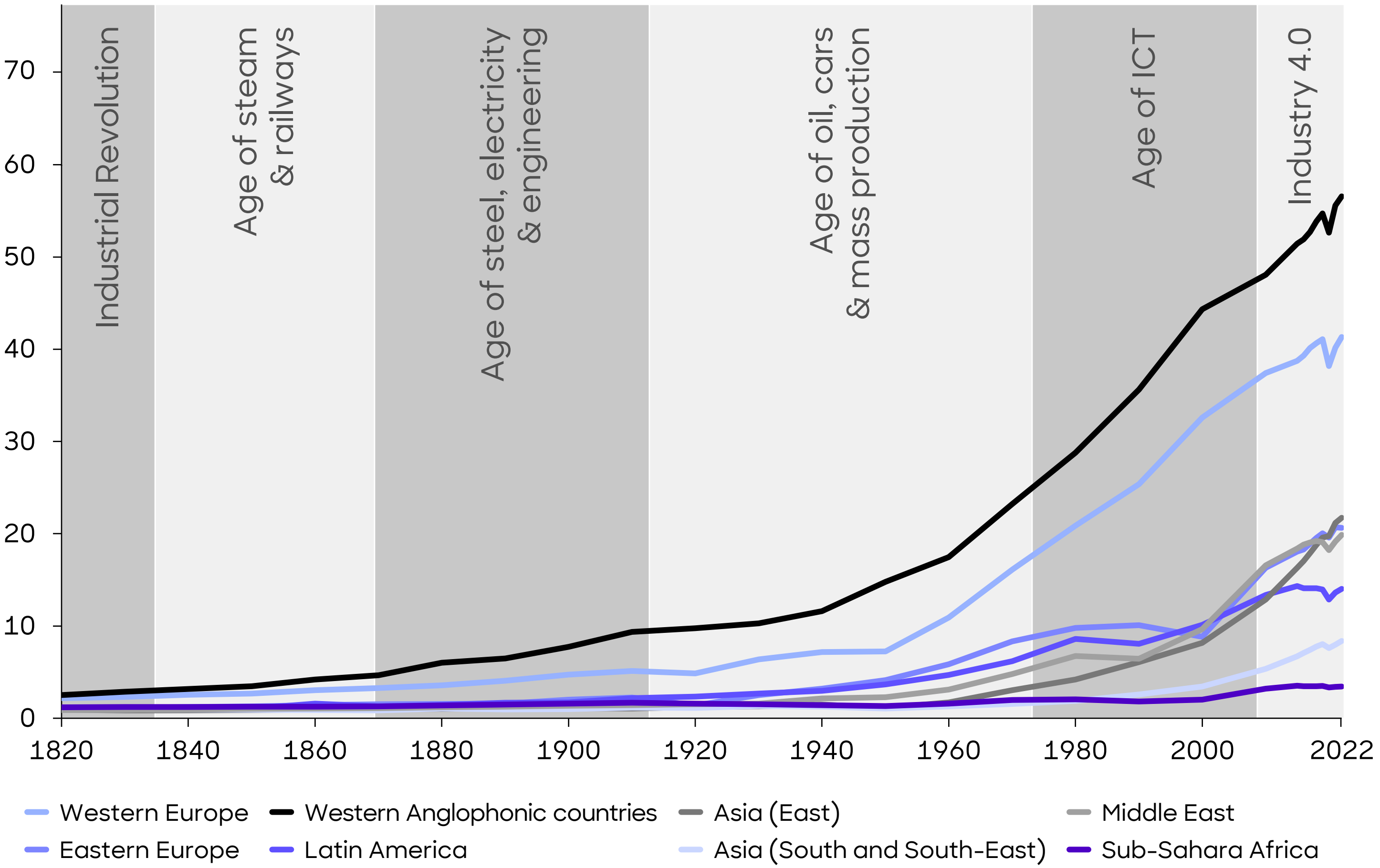
5.2 Frontier Technologies

5.3 Humans & Machines

Waves of innovation have boosted prosperity in all regions of the world thus feeding expectations for the future

Development of technological breakthroughs and real GDP per capita [2011 USD]

GDP per capita [USD '000]



- **Innovation continues to transform the global economy** ever since the Industrial Revolution. At every step, transformation has been initiated by a **technological breakthrough increasing prosperity**
- However, this **rise in prosperity** has been **uneven across regions;** the prosperity gap between Western economies and Sub-Saharan Africa is huge. But even in the latter region, the real GDP per capita has nearly doubled over the past three decades
- The historical development indicates a **positive outlook for the future.** Innovation is a constant, driven by **new ideas that are consistently translated into value**
- Given the **dual nature of innovation** – whether it is used for the greater **good** (e.g. rising prosperity, health, work environment, daily life, etc.) or for the **bad** (e.g. cybercrime) – it is crucial to decide how to handle innovation. This decision hinges on a multifaceted landscape, influenced by innovation providers and users, policymakers through regulatory frameworks, and the socio-economic and natural environment that innovations inhabit

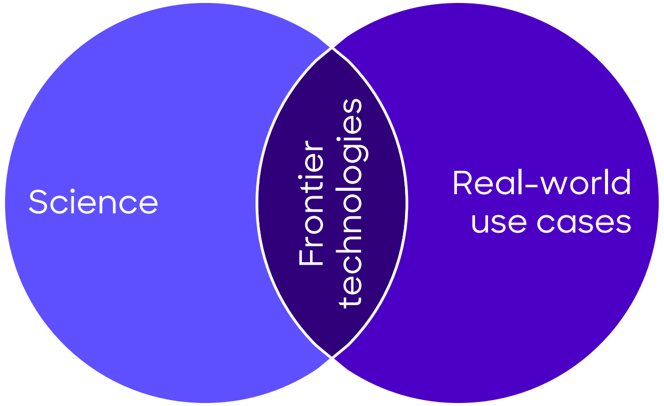
Source: UNCTAD; University of Groningen/Maddison Project Database; Roland Berger

5.1 Value of Innovation
5.2 Frontier Technologies
5.3 Humans & Machines

Frontier technologies are emerging technologies at the convergence of innovative scientific advancements and real-world applications

Frontier technologies

Frontier technologies are emerging at the nexus of groundbreaking scientific innovation and practical application, driving transformative change across industries



Ideas → **Market**

An example we all know: the invention of the Internet

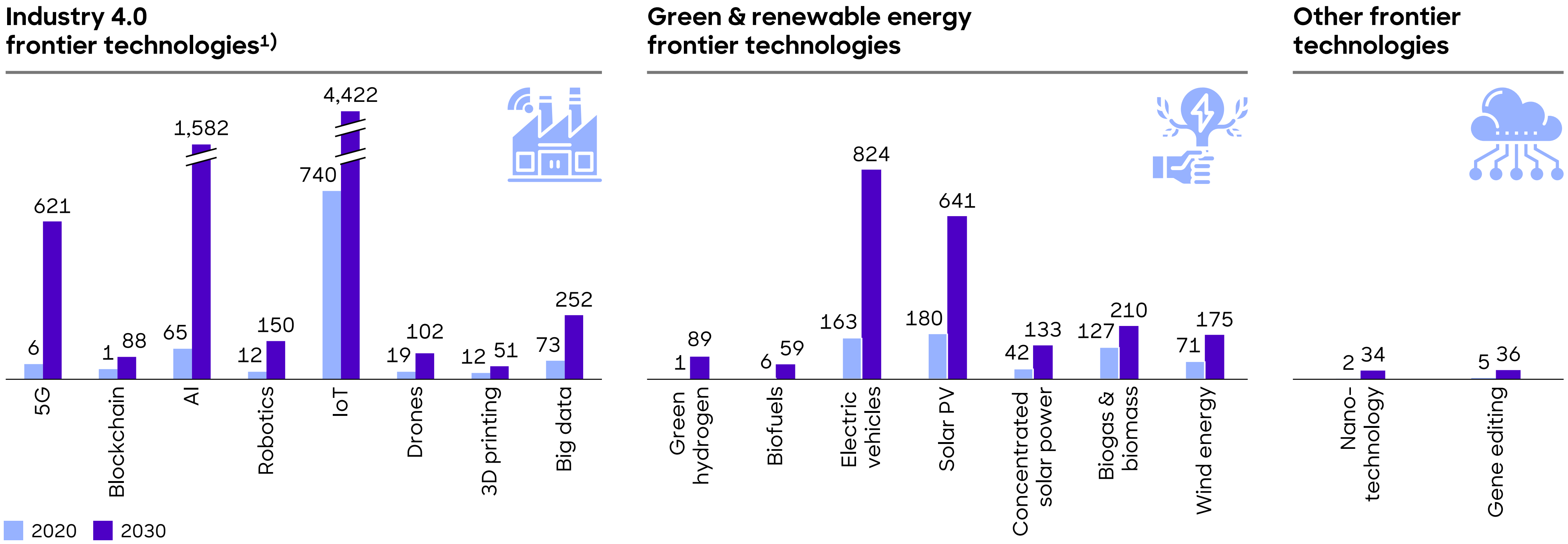
- **1958** – Invention of the modem
- **1966** – Launch of ARPAnet project
- **1974** – The term internet was coined
- **1988** – Connecting the first non-federal networks to federal networks
- **1991** – The worldwide web (WWW) was made available to the public
- **1996** – For the first time, more email than postal mail
- **2024** – Internet companies dominate the list of the most valuable companies globally

- Frontier technologies refer to **innovative, cutting-edge technologies** that leverage recent scientific breakthroughs to address complex challenges or create new opportunities across various sectors
- They emerge from the **convergence of advanced research, radical innovations, and practical real-world implementation.** Often driven by rapid developments in fields like artificial intelligence, clean energy, and biotechnology, they **shape future industries and societal changes**
- Frontier technologies drive **transformative change,** boosting productivity, sustainability, and propose solutions for global issues. They unlock new markets, improve efficiency, and are **crucial for economic growth, industrial advancement** (e.g. Industry 4.0), and environmental sustainability (e.g. Green Tech)
- These technologies are pivotal in **tackling** urgent **global challenges**, such as climate change, resource scarcity, and healthcare needs by enabling more efficient and sustainable solutions

Source: Spencer Task Institute; Roland Berger

Today's frontier technologies are expected to experience considerable growth, maturing to a market value of USD 9.5 trillion by 2030

Global market size estimates of selected frontier technologies, 2020 and 2030 [USD bn]



- In its latest Technology and Innovation Report, UNCTAD defines **17 new and rapidly developing technologies that take advantage of digitalization and connectivity**
- **These frontier technologies** can be classified into **three broad categories:** Industry 4.0, green & renewable energy, and others
- In some cases, these **categories intersect.** For example, drones are not classified as green frontier technology; however, using delivery drones for small package deliveries allows for a reduction in GHG emissions since the energy consumption per load is lower compared to other means of delivery

1) Some of the mentioned (or closely related) technologies are explained in more detail in the following sub-trend. AI and robotics will be discussed further in chapter 5.3 Humans & Machines

Source UNCTAD; Roland Berger

Given their infrastructure advantages, developed economies clearly lead in terms of frontier technology readiness

Top 15 countries' readiness to use frontier technologies [by overall rank]

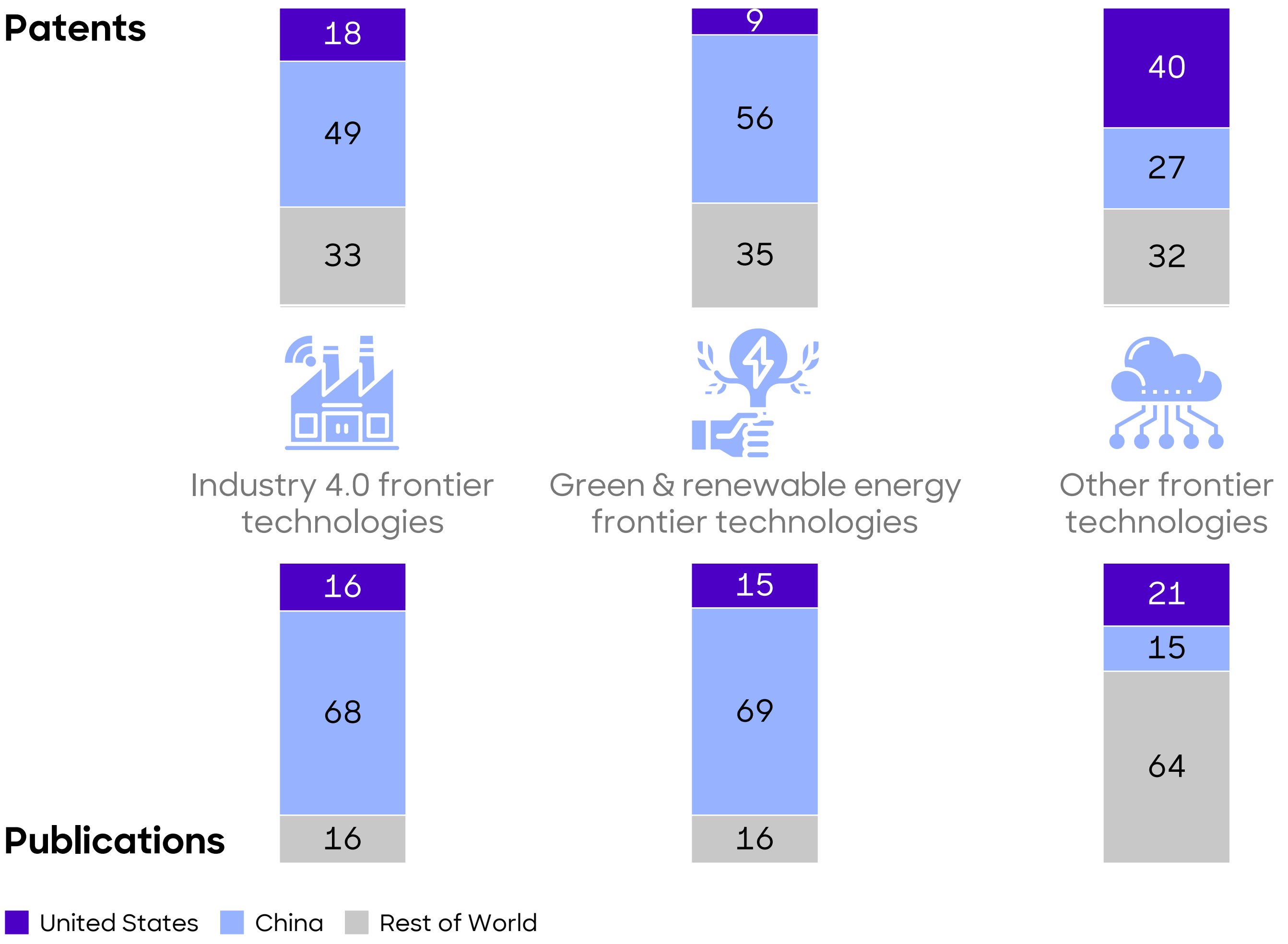
Country	Overall rank	"Building blocks" ICT	Skills	R&D	Industry	Finance
US	1	11	18	2	16	2
Sweden	2	6	2	16	11	18
Singapore	3	7	8	17	4	17
Switzerland	4	21	13	12	5	5
Netherlands	5	4	9	15	10	31
South Korea	6	15	26	3	9	7
Germany	7	24	17	5	12	40
Finland	8	22	5	21	20	30
Hong Kong	9	9	23	29	2	1
Belgium	10	13	4	23	19	48
Canada	11	5	21	9	29	20
Australia	12	33	1	11	57	13
Norway	13	3	6	27	50	6
Ireland	14	26	11	22	1	105
France	15	18	24	8	17	21

- UNCTAD assesses countries' preparedness for frontier technologies. It presents a "readiness index" ranking **166 countries based on five necessary "building blocks":** ICT deployment, skills, research and development (R&D) activity, industry activity, and access to finance.
- **Developed economies** clearly **dominate** the ranking, given their infrastructural advantages over developing economies. The index shows that countries in Latin America, the Caribbean, and Sub-Saharan Africa are the least ready to use, adopt, or adapt to frontier technologies and are at risk of missing current technological opportunities
- Only a **few developing countries** have the **necessary capacities** to take advantage of frontier technologies, which rely on digitalization and connectivity
- **China,** the **most-ready developing country, ranks 35,** followed by Brazil (40), India (46), and South Africa (56). China's lower-than-expected position is due primarily to urban-rural disparities in internet coverage and broadband speed

Source: UNCTAD; Roland Berger

China and the US are dominating the global landscape of frontier technology patents and publications

Global country share of patents and publications, by frontier technology, 2000-2021 [%]

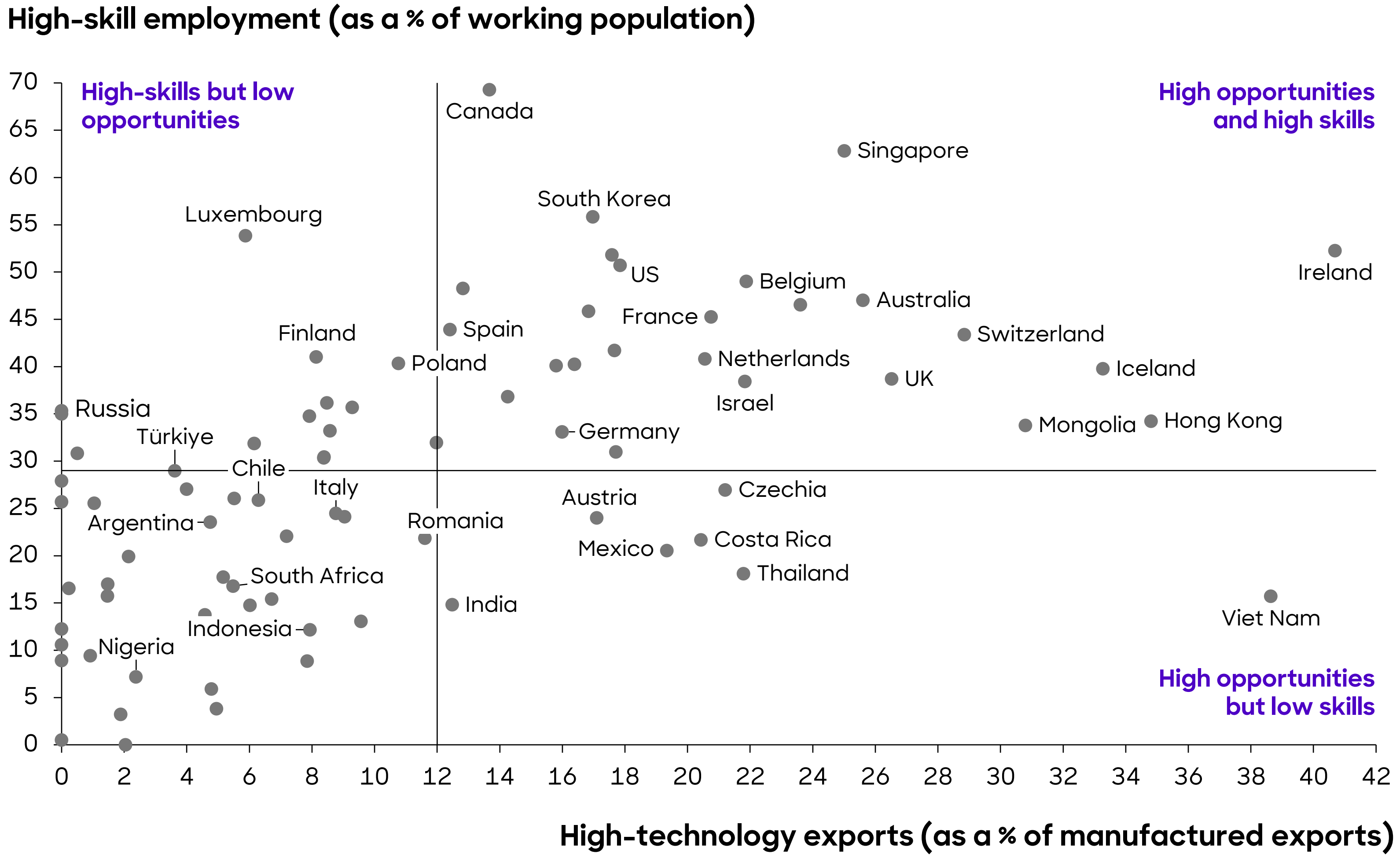


- Crucial **indicators** in measuring and comparing national **R&D efforts** include the **number of patents and publications of frontier technologies**
- Among **investors and scientists,** frontier technologies have **generated increasing interest** over the past two decades – the related **number of patents and publications** have **skyrocketed.** Patents in areas of biogas/biomass, AI, electric vehicles, and IoT account for the largest amount of patents
- The **knowledge landscape** for new fields of technology is **dominated by China and the US,** together holding two thirds of global frontier technology patents and an even higher share of publications
- However, it is vital to note that the **quality of patents is equally important.** This can be measured by the international scope of patents, the grant ratio (filed patents/granted patents) as well as the commercialization rate of patents. Under such criteria, China's performance is lower than that of major developed countries

Source: UNCTAD; Centre for International Governance Innovation; Roland Berger

Economies with higher levels of skills and stronger manufacturing industries are more likely to capture the economic gains associated with Industry 4.0

Readiness to benefit from the diffusion of Industry 4.0

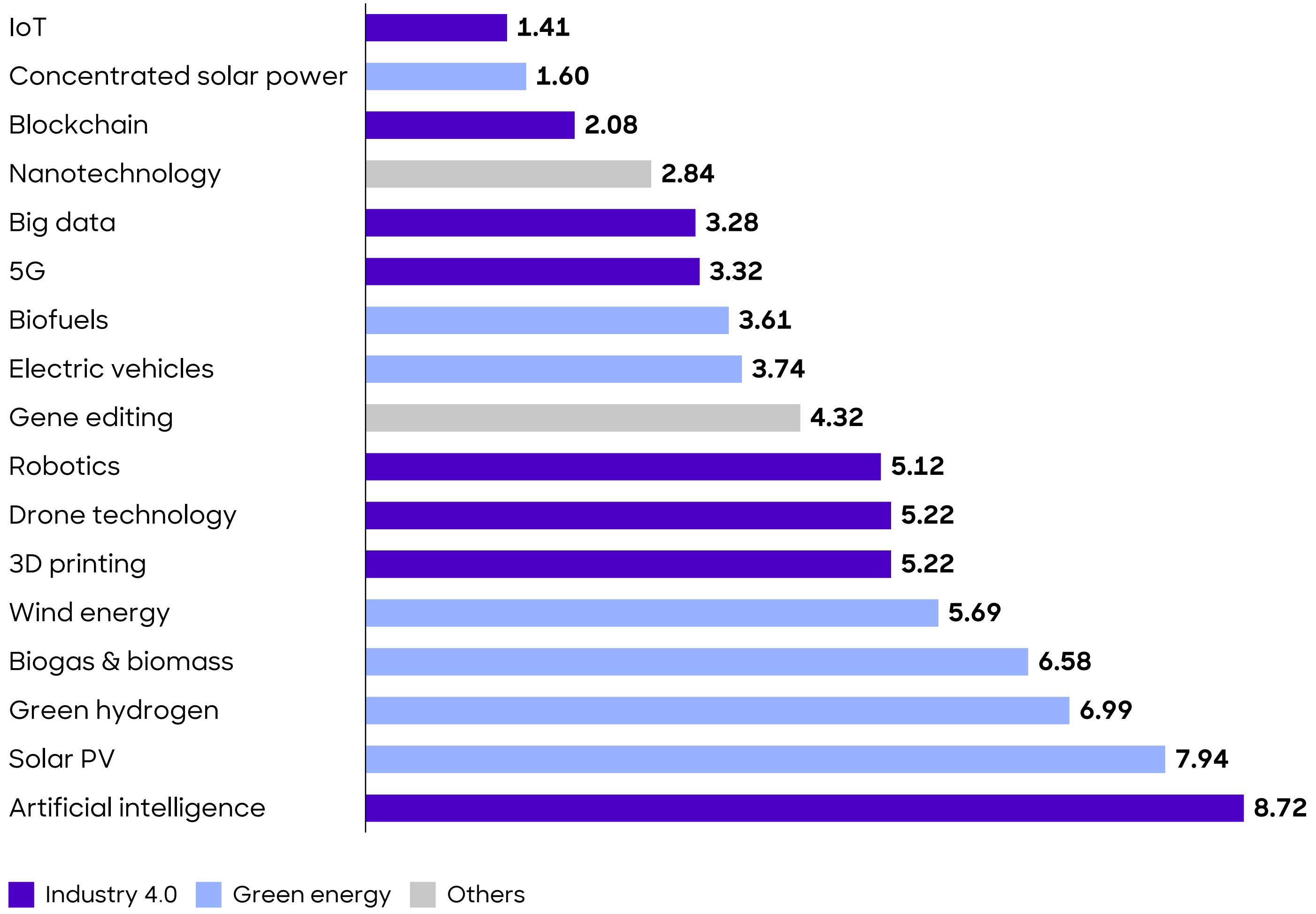


- Diffusion of Industry 4.0 technologies refers to the **adoption and integration of advanced digital technologies** into industrial and economic systems
- The countries best placed to benefit from diffusion in Industry 4.0 are those with **higher levels of skills and stronger manufacturing industries** – attributes, that can mostly be found in the group of **industrialized economies**
- Key factors influencing diffusion are the **availability of skilled workforce** and a strong **industrial base** providing a platform for adopting advanced technologies
- Additionally, a **robust digital infrastructure, high levels of R&D investment** as well as a **technology-friendly policy environment** help to bolster the readiness for Industry 4.0 diffusion

Source: World Bank; ILO; UNCTAD; Roland Berger

Considering that most of today's AI patents reference patents filed many years ago, AI stands out as one of the most mature technologies

Patent maturity of frontier technologies[1)] [years]



- While all **frontier technologies** identified by UNCTAD hold significant importance for the future, their **levels of maturity vary considerably,** as reflected in the patterns of patent filings
- Based on the timing of initial patent filings and the duration over which these patents have been subsequently cited, **AI emerges as the most mature technology**
- Most patents in the **AI** domain were filed in 2014, with an average citation date tracing back to 2005 - indicating a **time gap of approximately 9 years**
- Although this may appear counter-intuitive, **today's AI innovations,** such as those driving autonomous vehicles or the metaverse, **are closely linked to foundational patents for technologies like search engines and digital maps.** Many of the principles established in 2005 remain relevant and influential for today's patents
- In contrast, **IoT demonstrates relative immaturity,** with an average patent filing year of 2017 and an average citation year of 2016. This indicates that the foundational designs driving IoT innovation are being updated nearly annually

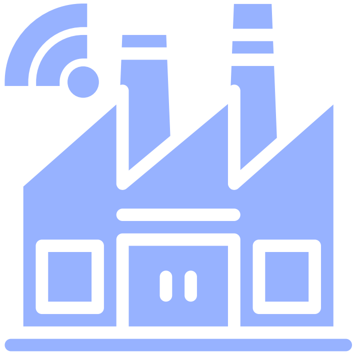
1) For each technology, the number in the bar graph indicates the patent maturity, which is the difference between the weighted average patent application year and the weighted average year of the 20 most cited patents between 2000 and 2021

Source: UNCTAD; Roland Berger

The following section provides an in-depth analysis of selected frontier technologies

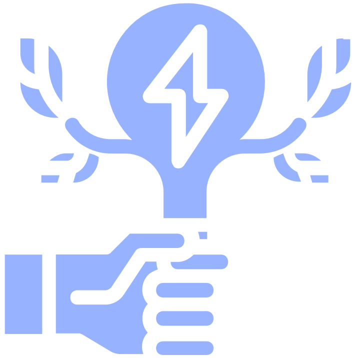
Frontier technologies represent a convergence of advancements across multiple domains, each marking a pivotal shift in global technological capability and driving transformative change

Overview of the frontier technologies presented in the following section



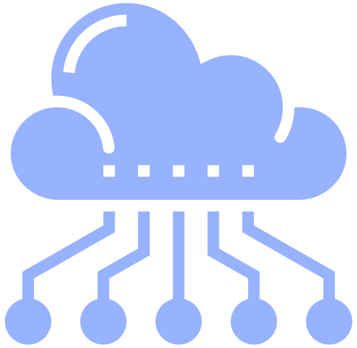
Industry 4.0 technologies

- Drones
- Communication technologies
- Internet of Things
- Quantum computing
- Blockchain



Green & energy technologies

- Efficiency improvements in renewables
- Space-based solar power
- Small-modular nuclear reactors



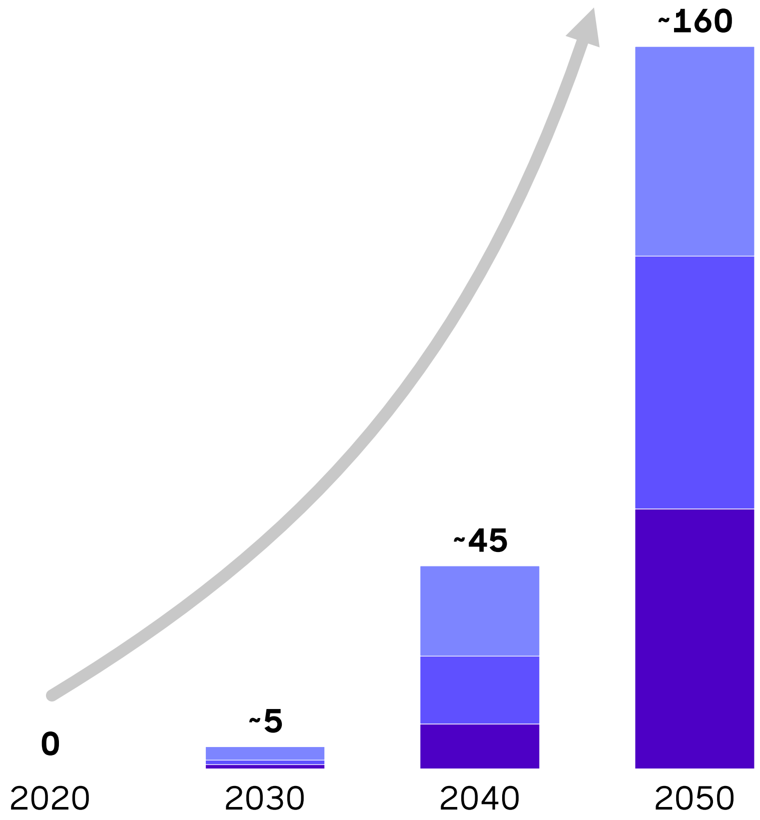
Other technologies

- Nanotechnology
- Biotechnology
- Gene therapy

Source: Roland Berger

In the future, ground transportation – already stretched to its limits in many urban areas – could be alleviated using new means of urban air mobility

Estimates of operating UAM passenger drones ['000]



City Taxi 36%

On-demand flights between any available landing station (15-50 km)

Airport Shuttle 35%

Scheduled flights on defined routes between airports and surrounding landing stations (15-50 km)

Inter City 29%

Scheduled flights on defined routes (50-250 km)

18,800 **Total distance**

flown by passenger drones [million km]

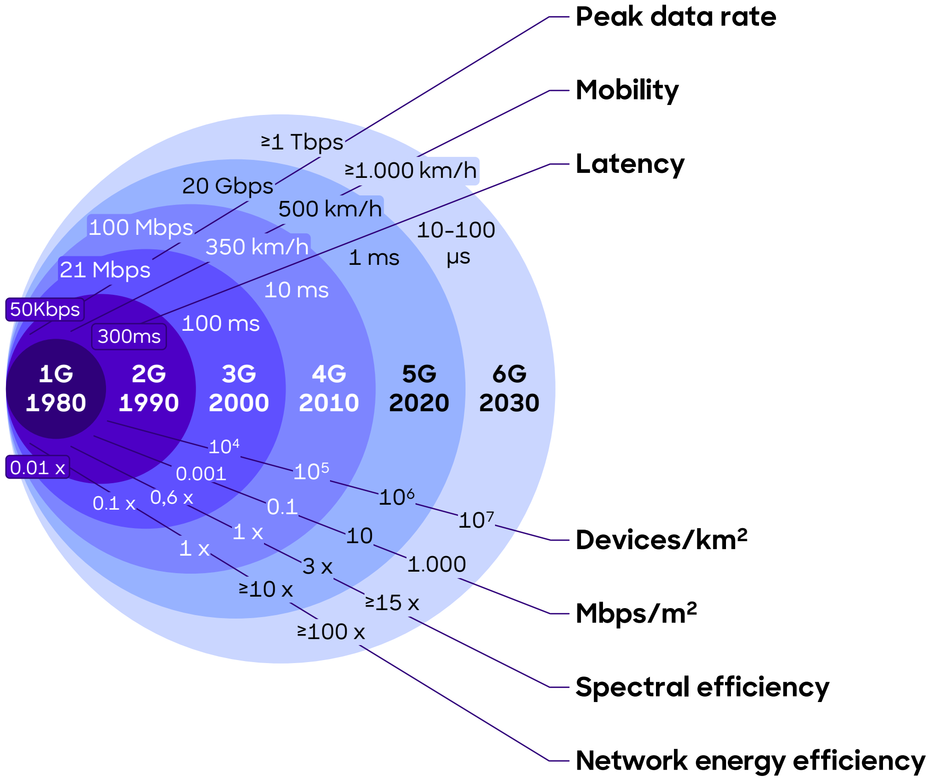
- Today, many urban agglomerations are stretched to the limit in terms of **ground transportation;** here, **urban air mobility** (**UAM**) could provide a much-needed **alternative**
- Since 1950, the world's **urban population** has **ballooned** from around 750 million to over 4 billion. By **2050,** urban areas will be home to a further 2.5 billion people, with more than **two-thirds of the total world population living in cities.** Urban transport infrastructure is struggling to adapt, taking a toll on commuters, the environment, and our economies
- In **London, drivers lost an average of 101 hours** in 2024 due to **congestion; traffic jams** in the **United States** cost the **country USD 74 billion** in time lost in 2024 – costs, that **can be avoided** in the future by new means of urban air mobility
- Around the globe, **aerospace giants** such as Boeing and Airbus as well as **well-funded startups** are working on the necessary UAM technology to create this new mode of transport
- Test flights for **prototypes** are already underway and the vision of **flying taxis** is expected to become a reality **within a decade**
- But for all the excitement, there are **also concerns:** as the development of UAM drones increases, **regulation is sure to follow,** which **imposes constraints** on providers. **Public acceptance** also still must be won

Source: Roland Berger

New communications technologies are being developed faster, supporting fundamental innovations in the long term – Future 6G rollout a next step

6G commercialization is within reach supporting data-hungry applications

Timeline of wireless communication networks and their differences across selected KPIs



Selected use cases benefitting most from 6G technology

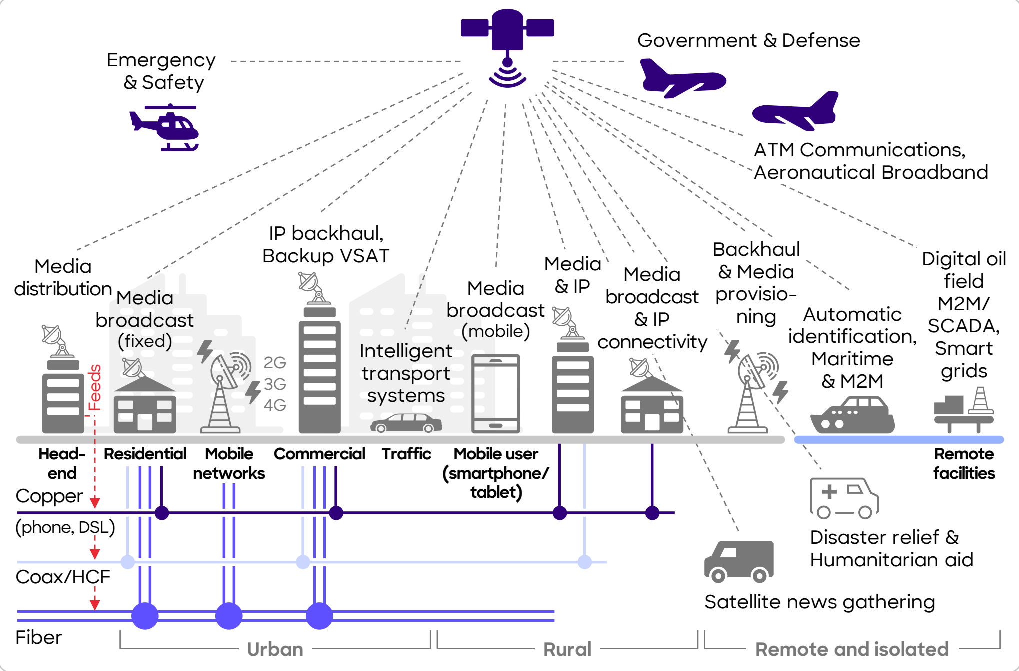
- Remote healthcare
- Smart environments
- Industrial automation
- Precision agriculture
- Instant volumetric sensing
- LTA drones[1)]
- Space connectivity
- Fully autonomous vehicles
- Smart infrastructure

- In the past, **commercialization of communication technologies has been slow:** research on the 3G standard started in 1990 while its commercial phase will only come to an end in the mid-2020s
- **Frontier communication technologies** are important since their enduring qualities support fundamental innovation. **Advancing comparatively faster, 6G technology** is already under research and will be commercialized from 2030 onwards
- Driven by the capability of reliable and low-latency communication via 5G, there are **trends for creating stand-alone networks in automated industries.** Under **6G,** this trend will continue for **applications of more special purpose networks** and smaller sub-networks, e.g. in networks of drone swarms
- The higher data rate technology **paves the way for more innovations: instant volumetric sensing** (scanning and virtualizing 3D objects instantly), requires 6G data transfer capabilities. Equally, **fully autonomous vehicles** or **smart interconnected infrastructure** are further data-hungry areas where 6G is essential

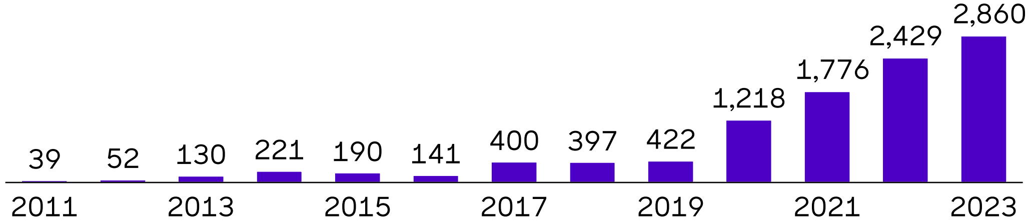
1) LTA: Lighter than air
Source: HCIS; 6G World; IEEE; Spatial Information Industry; Roland Berger

Satellite internet is growing in importance, providing a crucial complement to existing networks, especially for remote areas and facilities

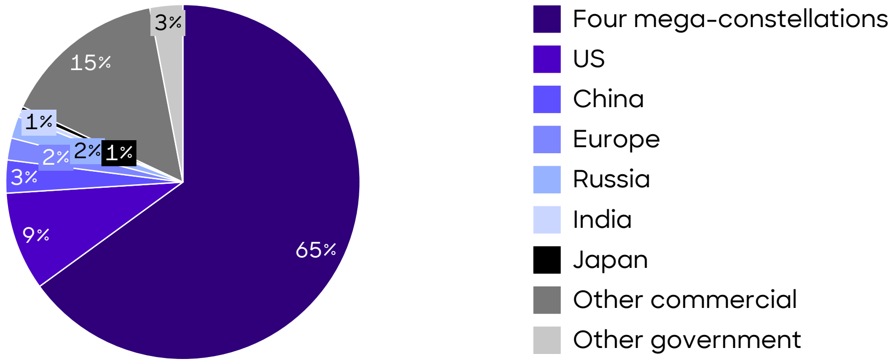
Architecture of a satellite-complemented internet infrastructure



Annual launches of small satellites, globally, 2011-2023 [#]



Market share of all satellites, 2033[1)] [%]



- **Satellite-based internet has experienced rapid growth** in recent years – not least due to Starlink's rapidly growing satellite constellations. Advancements in LEO satellite technology as well as **reduced deployment costs** have enabled **faster, lower-latency internet connections** with seamless **global coverage,** connecting even remote regions and revolutionizing the internet
- The **miniaturization of satellites** and the development of **reusable launch systems** have dramatically **lowered deployment costs,** making satellite internet more accessible globally. As a result, **satellite internet acts as a crucial supplement to existing infrastructure,** delivering connectivity to **remote locations** or **challenging terrains,** such as remote islands or mountainous areas, where traditional networks are hard or costly to implement; it can also provide **essential communication during natural disasters** when terrestrial networks may be compromised

1) The four mega-constellations – Starlink, Kuiper, G60, and GuoWang – are projected to account for nearly two-thirds of all satellites by 2033. Currently, only Starlink is operational. Values for countries represent government-operated satellite constellations

Source: DGTintra; Bryce Space & Technology; NovaSpace; Roland Berger

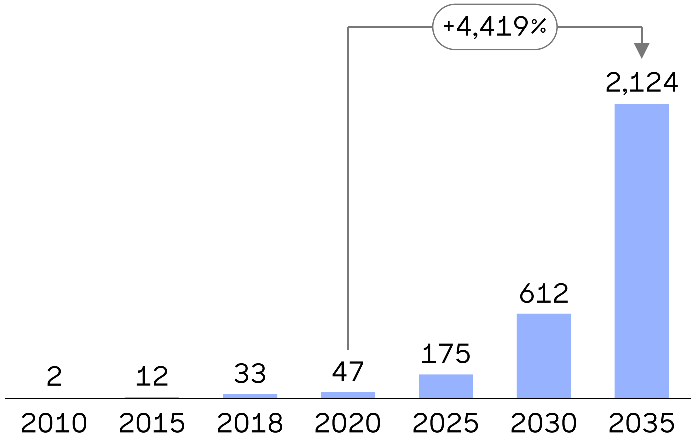
5.1 Value of Innovation

5.2 Frontier Technologies

5.3 Humans & Machines

Vast increases in data creation and Internet use mirror IoT's trend regarding more interconnected and smarter physical objects and processes

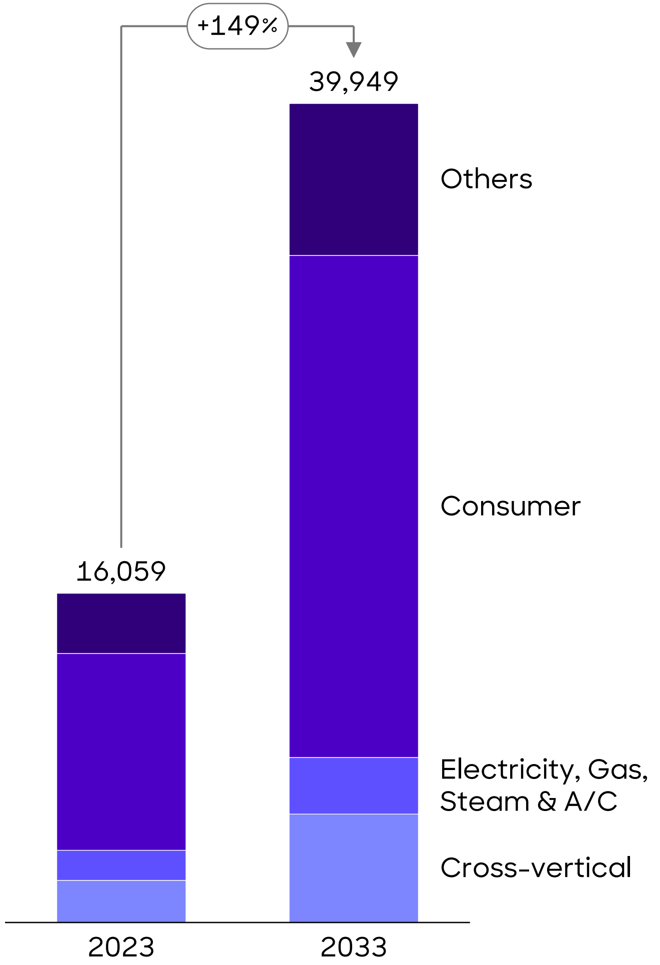
Amount of data created, worldwide, 2010-2035 [zettabytes[1)]]



What happens in 60 seconds on the Internet[2)]

- 43 years of streaming content is watched
- USD 12 million spent online
- 42 million messages sent via WhatsApp
- 6,060 resumes submitted on LinkedIn
- 5.9 million searches on Google

Connected devices worldwide, 2023 and 2033 [m]

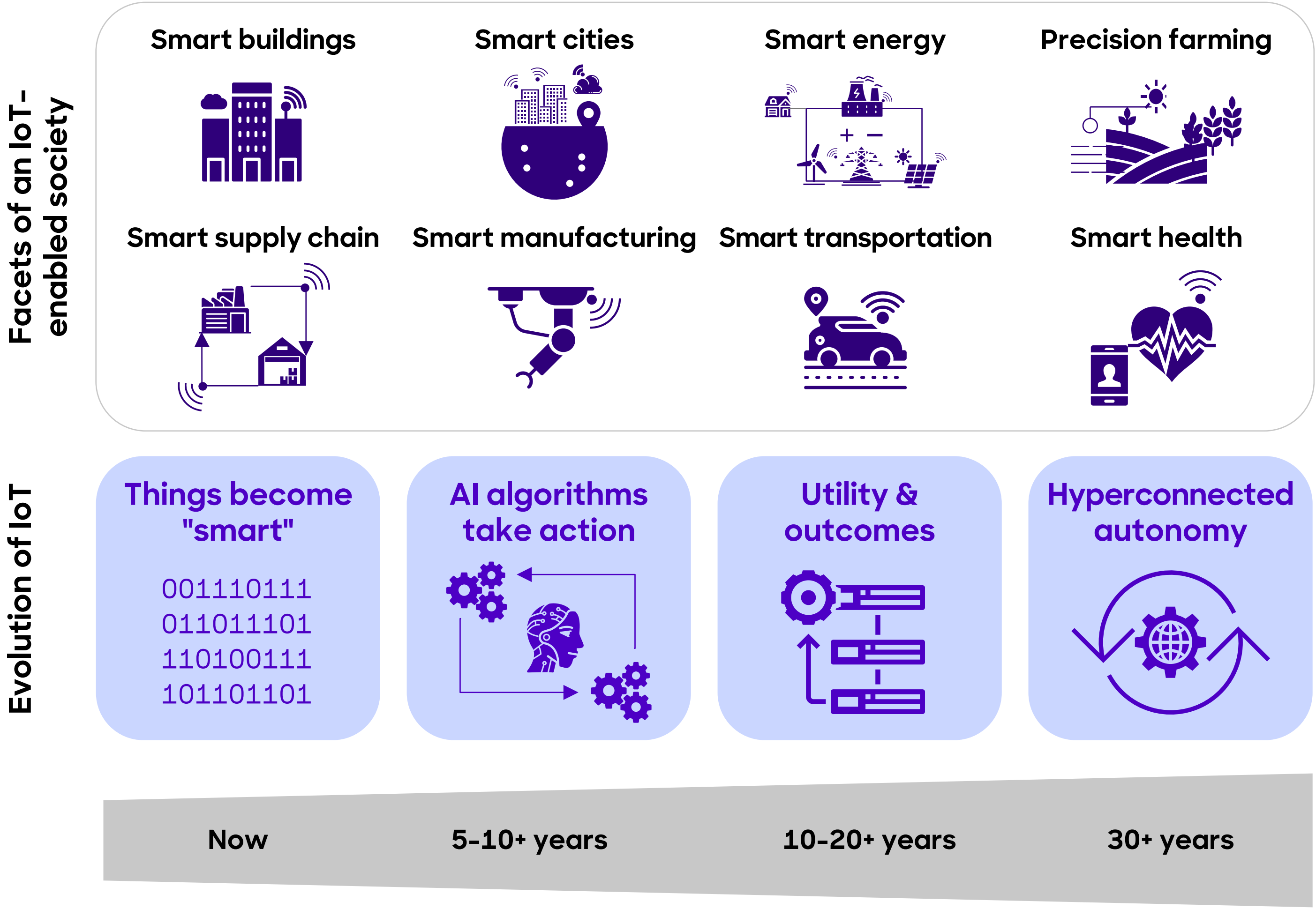


- **Ever-increasing amounts of data** generated via rising use of the Internet also **helps to enable the IoT (Internet of Things), a network of physical objects** equipped with digital sensors, software and other technologies; all objects are interconnected via a server able to transfer data
- **IoT connected devices and servers** often have **security vulnerabilities** that make them easy targets for **attacks;** they also **lack scalability** due to centralized server architectures. Such **characteristics have held back IoT's full potential to date. Blockchain's** distributed ledger technology (DLT) has the potential to address these issues: its distributed ledger creates **trust between participants** while its **decentralized approach** allows for better **future scalability**
- The **Internet of Bio-NanoThings** (**IoBNT**) is a network of **natural and artificial nano-biological functional devices** seamlessly integrated into internet infrastructure. IoBNT is created to **control non-conventional domains,** e.g. the human body, enabling disruptive new applications in the **future**

1) 1 zettabyte = 1 billion terrabytes; 2) 2023 data or newer
Source: Transforma Insights; Go-Globe; Statista; Roland Berger

The Internet of Things encompasses numerous facets of everyday life - And we are only at the beginning of its development

Facets of an IoT-enabled society and their evolution



- **Internet of Things (IoT) devices** are increasingly embedded in **everyday activities and devices,** from home automation to farming, connected vehicles, or smart wearables
- The **number of IoT-connected devices** is **projected to** grow significantly, driven by advancements in connectivity (5G, edge computing) and the decreasing cost of sensors
- Despite current adoption, **IoT technology is still in its infancy,** with vast **untapped potential** for innovation, scalability, and new use cases
- The **combination of AI and IoT** at the edge will **enable predictive analytics, autonomous decision-making,** and **personalized user experiences,** driving efficiency and innovation across industries
- **AI-powered IoT** will **reduce latency, enhance real-time processing,** and **improve the scalability** of connected devices.
- In its **future** evolution, **IoT is expected to evolve into hyperconnected systems,** where AI-driven devices operate autonomously to manage cities, industries, and transportation with minimal human intervention

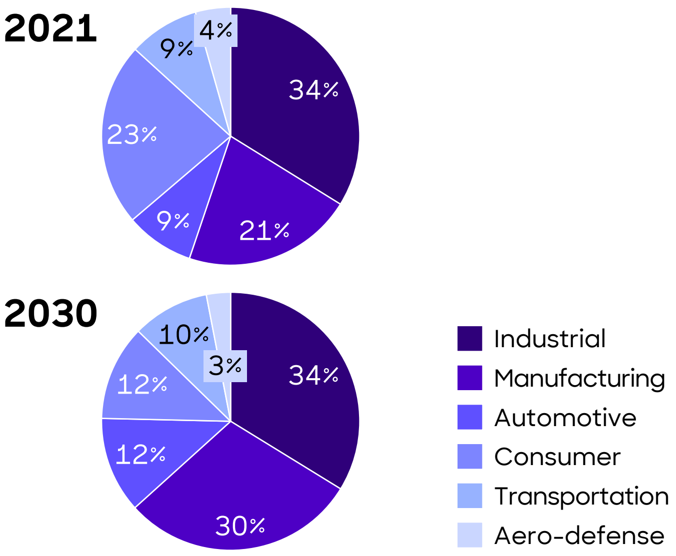
Source: National Institute of Standards and Technology; Roland Berger

IoT is an evolving set of disparate technologies at various levels of maturity - some are more mainstream and mature, while others are still immature

Maturity states of key technologies underlying the Internet of Things

Mature	Nearing maturity	Coming up	Years out	Far on horizon
• CPUs, MCUs, GPUs • Edge gateways • Cloud computing • Cellular IoT • Security chips	• ASICs • Intelligent sensors • Edge AI • Streaming analytics • eSIM • 5G • Supervised ML	• Edge AI Chips • Cloud-connected sensors • AR technology • Edge data centers • IoT marketplaces • IoT security platforms • Low/no-code platforms • Satellite IoT • Digital twins	• QRNG chips • Neurosynaptic chips • ML-optimized gateways • Automated ML • Data ecosystems • Open RAN • Li-Fi • TSN • SAS	• Biodegradable sensors • Quantum computing • Brain-machine interfaces • 6G

Distribution of IoT market shares, by sector, 2021 and 2030 [%]



- **IoT encompasses a mix of technologies at different maturity levels,** with some well-established and others still emerging. Its evolution is driven by advancements in **underlying technologies.** Today's **smart devices** use sensors, processors, and wireless connectivity to gather data, enabling AI and machine learning (ML) to generate insights, predict outcomes, and automate processes
- As **IoT becomes integral to enterprise operations,** it **fosters new products, ecosystems and "as-a-service" solutions.** Future intelligent IoT deployments will drive autonomous systems, operational efficiency, and innovation, reshaping industries and enabling growth. While some technologies, e.g. **digital twins, are already in use,** others, such as automated machine learning or quantum computing, are further on the horizon in terms of enterprise applications of IoT?
- Currently, **consumer applications** like wearables or smart home appliances play a major role in the IoT market. Their share, however, is expected to decline as the **significance of IoT in manufacturing is expected to grow substantially.** Interconnected production facilities hold the potential to greatly enhance productivity

Source: National Institute of Standards and Technology; Roland Berger

Technology & Innovation

5.1
Value of Innovation

5.2
Frontier Technologies

5.3
Humans & Machines

As the cornerstone for many future technologies, quantum computing will revolutionize hardware by radically increasing computing power

Qubits beat bits: A single qubit is enough to represent numbers of almost any size

Technical difference between qubits and bits

Superposition state

1
0
qubit

Quantum computer

1 qubit
Probability of being in state 1 set to:
24.3%
which, in decimal notation, is
0.243
multiplied by 1,000:
243

1 qubit
Probability of being in state 1 set to:
10.37982%
which, in decimal notation, is
0.1037982
multiplied by 10,000,000:
1,037,982
Even larger numbers need **more precise measurements/ manipulations**
(just like moving from 0.234 to 0.1037982)

Larger numbers

Binary state

0 1
bit

Classical computer

8 bit binary encoding of decimal number **243**

2^7 … 2^0
1 1 1 1 0 0 1 1

12 bit binary encoding of decimal number **3,980**

2^{11} … 2^0
1 1 1 1 1 0 0 0 1 1 0 0

16 bit binary encoding of decimal number **56,814**

2^{15} … 2^0
1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0

20 bit binary encoding of decimal number **1,037,982**

2^{19} … 2^0
1 1 1 1 1 1 0 1 0 1 1 0 1 0 0 1 1 1 1 0

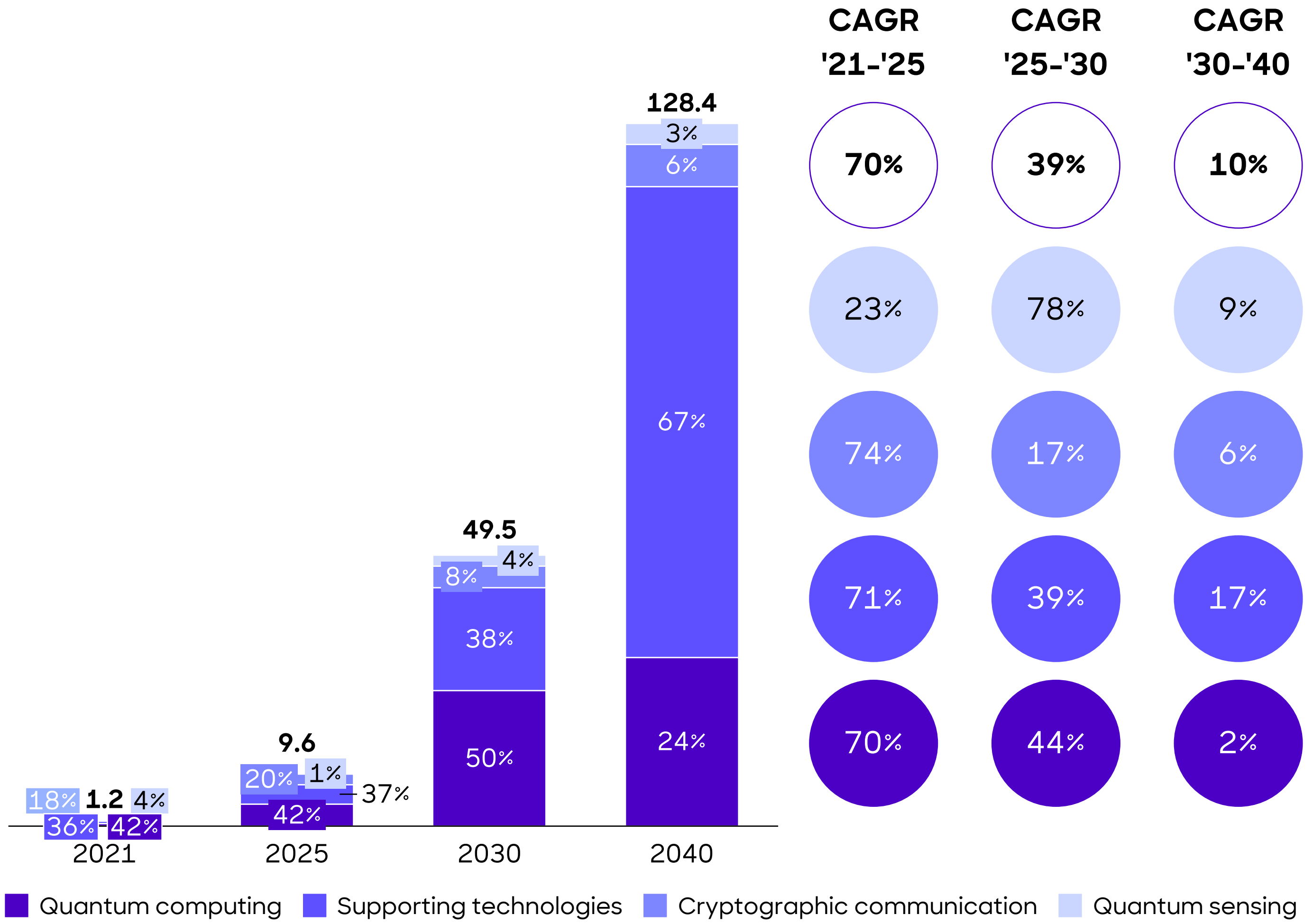
Even larger numbers need **even more bits**

- **Quantum computers substantially differ** from regular computers. In contrast to conventional computers that work **with bits stating only two discrete, stable states** (0 and 1), **quantum computers work with a superposition of states:** a **qubit**, the quantum version of a bit, has **infinite possible states** between 0 and 1
- Bearing **superpositions** in mind, a single qubit is described by **two probabilities** of finding it in one possible state (1) or another (0). State probabilities can be prepared, changed, and measured. Once a **measurement** has been performed, even **quantum particles** can **only be in one state**
- Quantum computing's **key advantages** are twofold: it allows the representation of a **huge number of values** and **computations with all values to be performed simultaneously.** Theoretically, with just 1,000 qubits, we would have the power to **control more values than there are atoms in the universe** – a challenging thought

Source: Roland Berger

Quantum technologies are advancing rapidly, with recent breakthroughs highlighting its transformative potential

Outlook for quantum market segment growth to 2040 [USD bn]



- Quantum technologies, long confined to theoretical potential, are now demonstrating **practical benefits.** With a market volume of USD 1 billion in 2021, projections estimate a **fifty-fold growth by 2030** and a market value of USD 128 billion by 2040
- Most of this **growth** will stem from quantum computing and its **supporting technologies**, including cooling equipment, vacuum pumps, and advanced optical systems
- In December 2024, Google unveiled its **quantum chip,** Willow, capable of solving complex problems in under five minutes – equivalent to 10 septillion years on a classical supercomputer. This **breakthrough** marks a major advance in practical quantum computing by **exponentially reducing errors** as qubit numbers scale, overcoming a three-decade long challenge
- This **milestone** suggests a future where quantum computers could **transform industries** by **enabling advancements in drug discovery, artificial intelligence, and data encryption.** However, experts caution that while these developments are promising, **real-world applications may still be years away**

Source: Roland Berger

Moore's law predicted the computing power of today's computers – Quantum computing reveals future spheres of computational power

Number of physical qubits	<1,000	1,000 – 100,000	100,000+
Sectors with potential interest	Quantum computing companies; Academia; Research institutions	Finance	Pharmaceutical; Energy; Agriculture; Security
Projected development of computing power	2023: 1,225 qubits	→	Future
Potential applications	• Calculations of small chemicals • Test quality of quantum hardware • Test theories about black holes • Quantum assisted optimization	• Enhance machine learning • Enhance optimization problems • Test quality of quantum hardware • Finance simulations	• Simulate critical fertilizer components • Chemistry for energy or pharmaceutical applications • Break some forms of encryption • Simulate crystals, metals or superconductivity • Grover's search algorithm[1)]

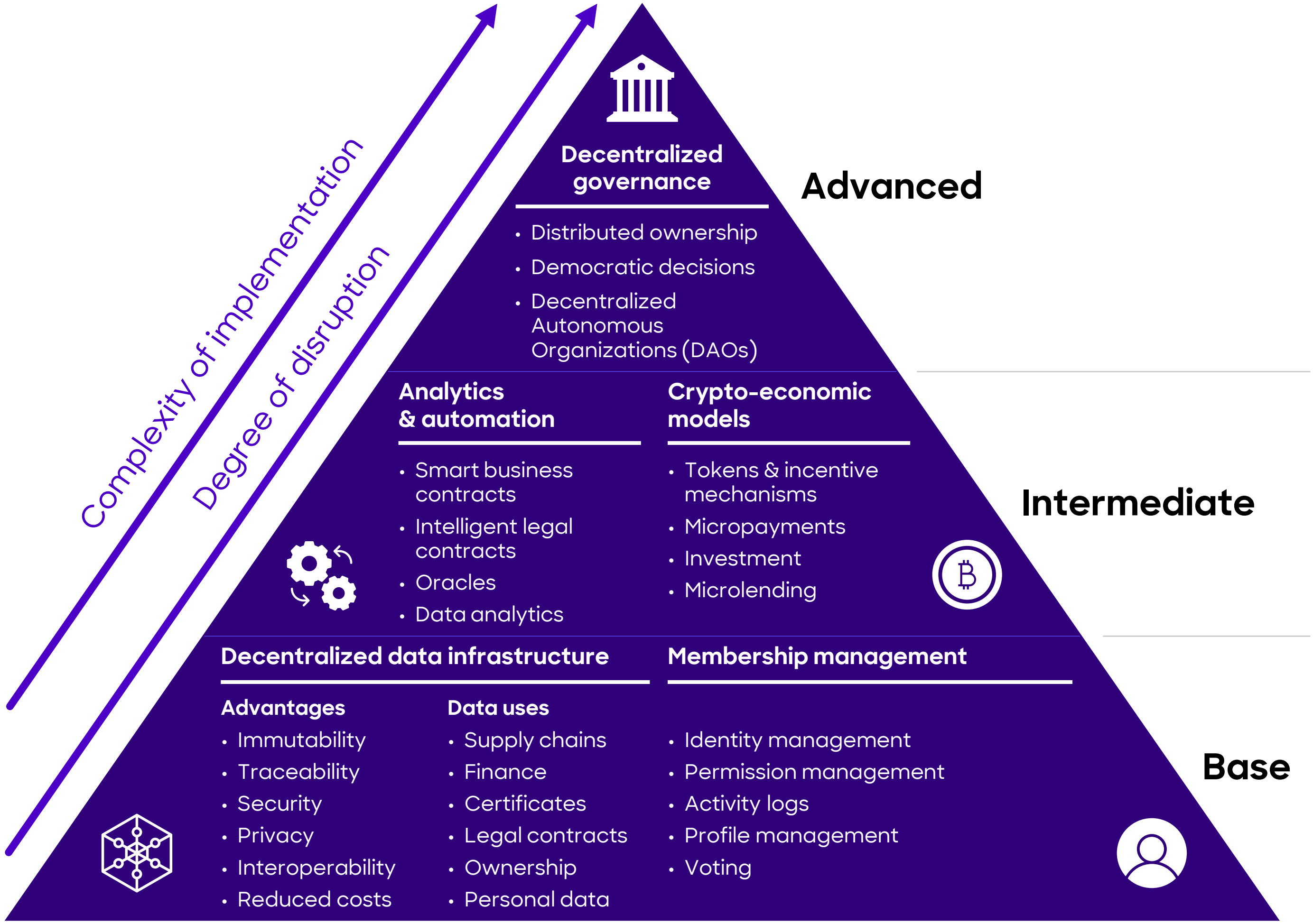
- In the future, **quantum computing** could **transform a broad range of sectors** such as finance, pharma, energy, and security
- In **2024,** Atom Computing revealed a quantum computer with a computing power of **1,225 qubits,** more than **double the capacity of IBM's Osprey machine, which has 433 qubits**
- IBM announced a computing power of **100,000 qubits by 2033,** showcasing an exceptionally **fast scale-up** in this technology
- However, there could be some **limitations regarding assumed applications.** It is unclear whether computers with lower qubits will be useful for end users or can create an advantage in optimization tasks
- Moreover, there might be **limitations regarding the impact** of quantum computing in machine learning, optimizations or cryptography

1) Grover's search algorithm can speed up an unstructured search problem quadratically and therefore demonstrate the superior speed of quantum computers

Source: Atom Computing, IBM; Gao; Helmholtz; arXiv; TechCrunch; IBM; Roland Berger

As another core digital technology, blockchain, impacts processes by means of its unique decentralized transactional characteristics

Blockchain value proposition pyramid

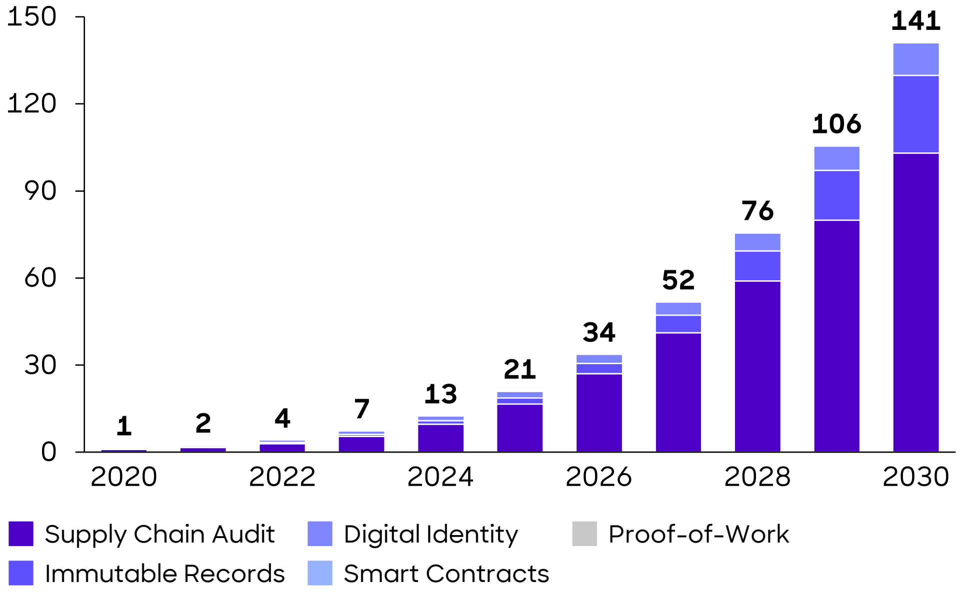


- **Blockchain** is a **decentralized digital ledger** that securely stores records across a network of computers in a way that is **transparent, immutable, and resistant to tampering**
- Blockchain technology offers **new value propositions** that extend beyond decentralized storage, including **innovative crypto-economic and investment models, as well as new forms of decentralized participative governance.** These could pave the way for the evolution of **next-generation digital platforms** and **multi-stakeholder business interactions**
- One of the **most advanced components** of this value proposition is the rise of **Decentralized Autonomous Organizations (DAOs)**, which **leverage blockchain to create self-governing entities without the need for centralized management,** enabling more democratic decision-making processes in organizations
- While some of these value propositions can be **seamlessly integrated into existing digital platforms,** more disruptive aspects, such as business automation and new economic and governance models, present greater **challenges.** However, they have the potential to drive not only technological innovation but also a transformation of current social, economic, and governance structures

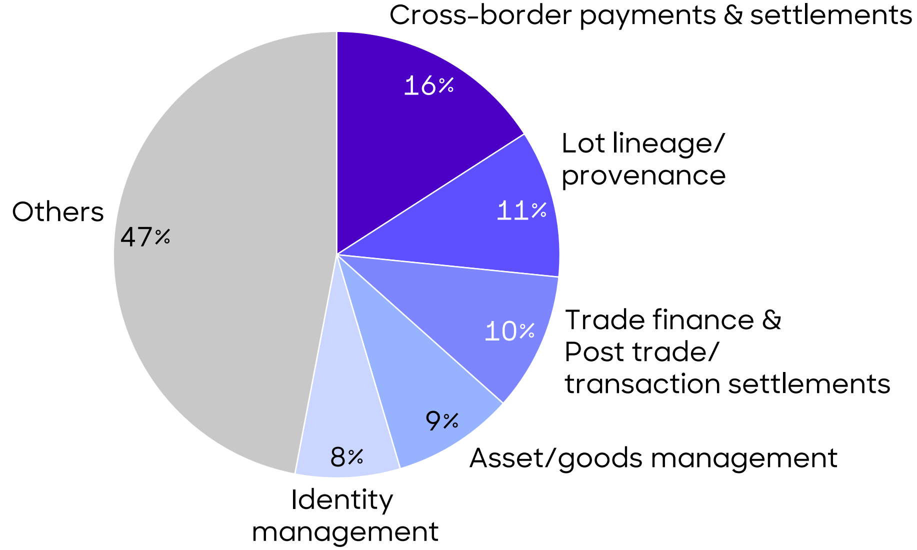
Source: Zutshi, Grilo, Nodehi (2021); Investopedia; Roland Berger

Blockchain technology is driving transformative growth across industries, with its market projected to exceed USD 140 billion by 2030

Size of the global distributed ledger market, by use case, 2020-2030 [USD bn]



Global blockchain market share, 2021, by use case [%]



- **Blockchain,** the most widely known form of **decentralized ledger technology (DLT),** enables secure, transparent, and immutable recording of transactions across distributed networks, eliminating the need for centralized authorities
- The **DLT market** has grown rapidly, driven by its applications in finance, supply chains, and beyond. By **2030,** it is projected to exceed **USD 140 billion** as adoption continues across various sectors
- **Blockchain underpins cryptocurrencies like Bitcoin,** powers smart contracts and decentralized finance (DeFi), ensures traceability in supply chains, and offers secure solutions for anti-counterfeiting
- **Across various industries,** blockchain is driving significant advancements by **improving efficiency, ensuring transparency, and enhancing security.** Its decentralized nature and ability to create tamper-proof records are unlocking innovative solutions and reshaping traditional processes

Source: Transforma Insights; IDC; Roland Berger

5.1 Value of Innovation

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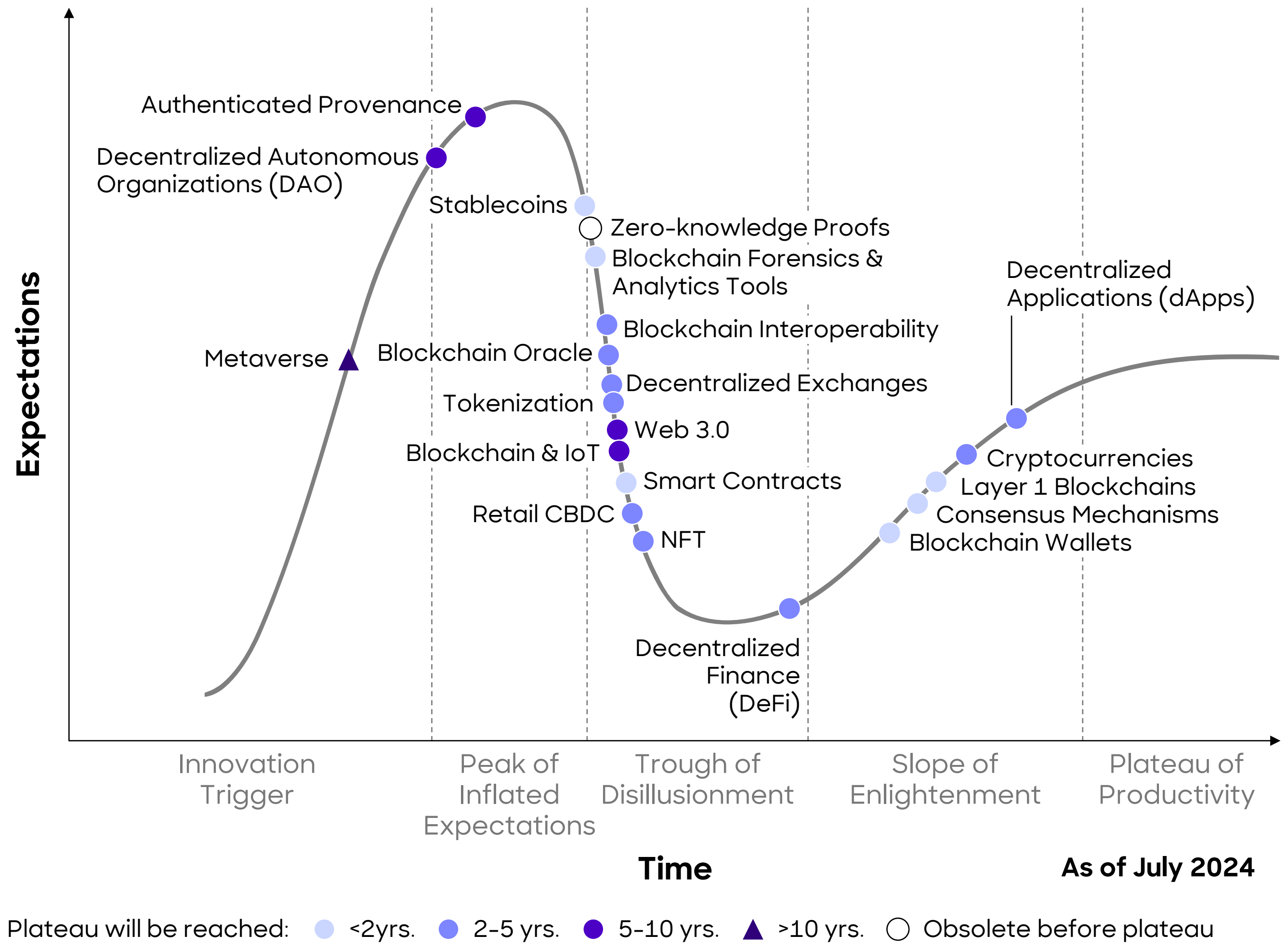
Most blockchain applications are likely to achieve widespread adoption within the next decade, with dApps and cryptocurrencies already gaining traction

The Gartner Hype Cycle™ for Web 3.0 and Blockchain, 2024

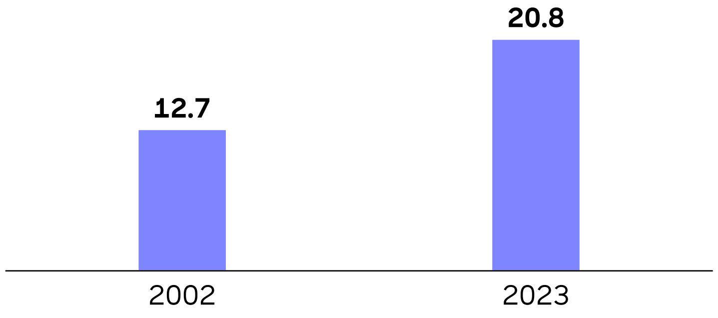


- Gartner's **Hype Cycle** for **blockchain** and **Web 3.0** applications assigns **different key stages** to the life cycle of said technologies, charting **expectations** regarding their plateau of productivity – a state of maturity in terms of mainstream penetration and market applicability
- As **blockchain technology will further penetrate** markets and applications, activities will become **more decentralized,** thus **increasing trading efficiency** by substituting a central intermediary with a pre-defined blockchain-based protocol
- **Decentralized finance** (DeFi) is an example where blockchain is used in finance. It is a **service that offers peer-to-peer decentralized technology** built on Ethereum
- By **leveraging blockchain** technology to create trusted, transparent systems without relying on centralized authorities, **Web 3.0 represents the next evolution of the internet**
- Characterized by decentralization, data ownership, and peer-to-peer interactions, **Web 3.0 eliminates reliance on intermediaries,** fostering trust through immutable and transparent blockchain networks

Source: Gartner; Etherium; 101blockchain; Roland Berger

Although the efficiency and capacity of renewable energy sources have increased, their capacity factor still lags behind conventional sources

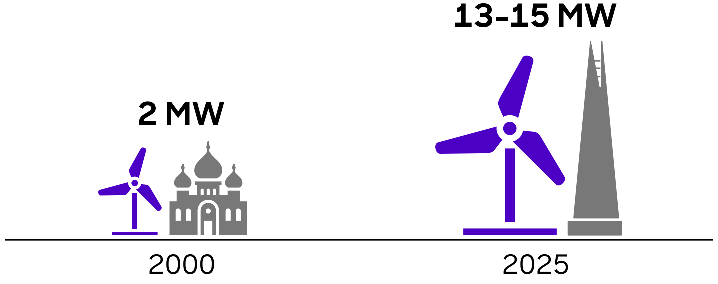
Solar PV module efficiency, residential systems, 2002 and 2023 [%]



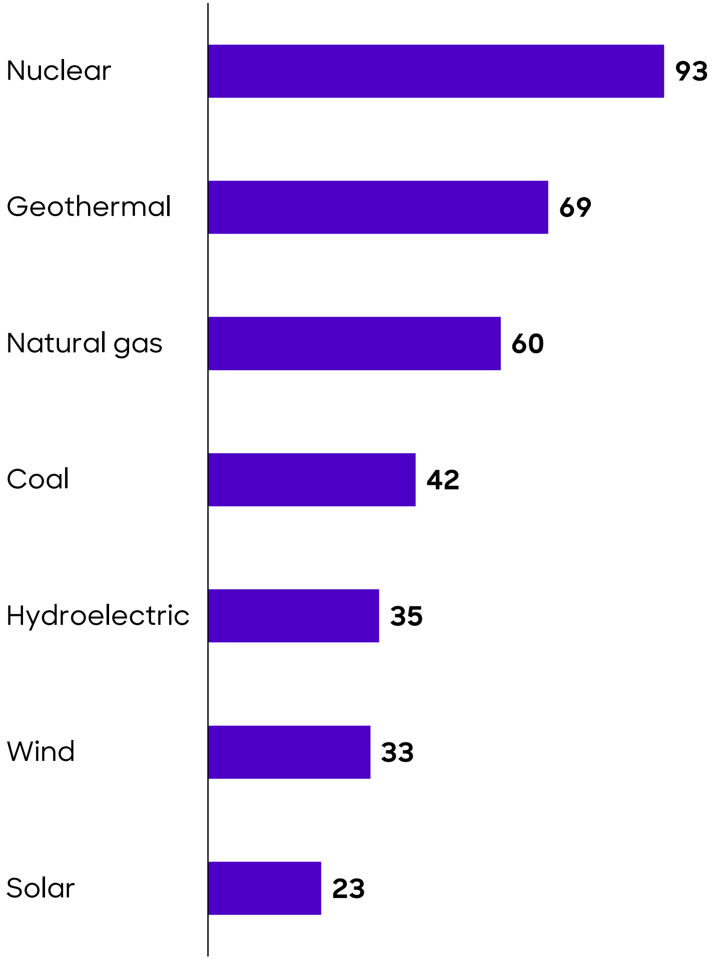
Rated capacity of wind turbines, 2000 and 2025 [MW]

With expanding rotor blades, wind turbines in the 2000s reached a height of more than 100m, comparable to St. Paul's Cathedral in London

It is expected that 2025 will usher in turbines as tall as 310m, comparable to "The Shard" in London



Capacity factor by energy source, 2023 [%]



- **Advancements in solar technology** such as the development of **multi-junction cells,** bifacial panels as well as improvements in material science, have significantly enhanced module efficiency over the years, enabling higher energy output from smaller installations
- Also, **wind turbines** have seen a **dramatic increase in their rated capacity,** driven by innovations in turbine design, taller towers, longer blades, and improved aerodynamics, allowing for higher energy generation at lower wind speeds
- Despite these technological advancements, **wind and solar PV** continue to **trail conventional energy sources** like nuclear and natural gas **in terms of their capacity factor,** highlighting variability challenges
- **Ongoing improvements in energy storage and grid integration** are addressing intermittency, making wind and solar PV more competitive with traditional energy sources

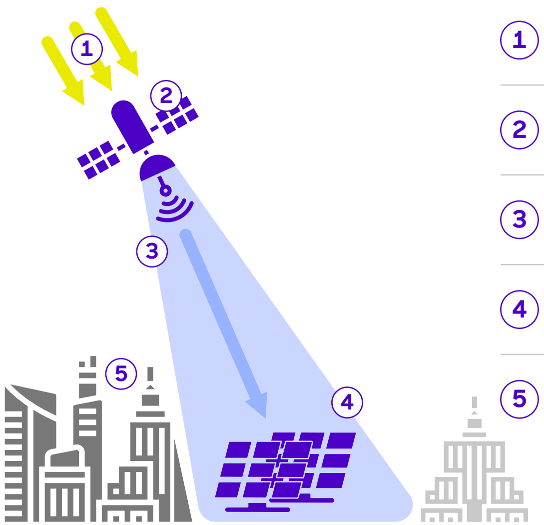
1) The capacity factor measures how often a plant is running at maximum power. A plant with a capacity factor of 100% means it's producing power all of the time

Source: Berkeley Lab; Lumify Energy; EIA

Space-based solar power has the potential to address the world's growing demand for clean energy – Yet significant challenges remain

Schematic illustration on space-based solar power

Schematic illustration on space-based solar power



1. **Incident solar radiation**
2. **Solar energy capture and regulation**
3. **Power beaming**
4. **Beam capture and conversion**
5. **Transmission and distribution**

Progress and milestones

2020
The US Naval Research Laboratory conducted the first successful test of solar power generation in space

2023
CalTech achieved a milestone by successfully beaming power back to Earth from a space-based solar array, demonstrating the feasibility of wireless power transmission

2030
China aims to generate one megawatt of energy from its SBSP systems by this year as part of its broader energy strategy

2035
China plans to have a commercially viable SBSP system operational

2040
UK aims for the first operational solar power station in space following initial trials starting around this time

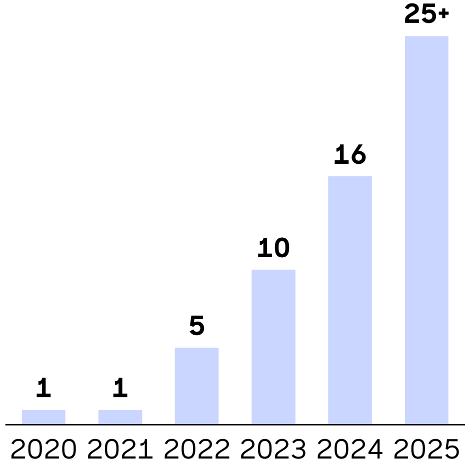
2050
NASA and other agencies envision that SBSP systems could be fully operational, providing significant contributions to global energy needs while supporting net-zero emissions goals

- **Space-based solar power (SBSP)** involves **collecting solar energy in space** and **wirelessly transmitting it to Earth.** While costly, SBSP offers a clean energy source with the potential to meet or even exceed global energy demand.
- SBSP technology uses **solar panels in space, combined with reflectors or inflatable mirrors** to direct solar radiation onto the panels. Energy is then transmitted to Earth via microwave or laser, and received by a rectenna
- Unlike terrestrial solar power, SBSP provides continuous energy as **satellites in geostationary orbit** are unaffected by weather or night cycles; the higher solar radiation intensity in space enables greater energy capture. SBSP arrays are expected to generate **2,000 GW of power constantly,** much more than today's terrestrial solar farms that rely on sunlight to generate power
- Scaling SBSP presents **considerable challenges,** including high **development costs,** uncertain **economic viability,** and **energy transmission efficiency.** Additionally, the risk of collisions with space debris and other satellites complicates system deployment and maintenance

Source: ESA, NASA, Extrapolate, US DoE; Roland Berger

As the demand for decarbonizing energy generation grows, there is growing interest in a new generation of smaller, more modular nuclear reactors

Cumulative number of newcomer countries interested in small modular reactors (SMRs)



Key benefits of SMRs over large nuclear plants

Advantages of SMR

Costs

With lower capital investment requirements due to their compact size, comparable per-unit costs enabled by modularization, design simplification, and standardization, as well as regulatory harmonization, SMRs have the **potential to achieve lower per-unit electricity costs** than large nuclear reactors

Time

While large reactors are often custom-designed for specific locations requiring site-specific solutions, thus extending construction timelines, the modular design of SMRs enables serial production off-site with lower on-site labor, thus benefitting from **economies of scale:** SMRs enable **faster deployment** compared to large nuclear plants

Siting

Given their small size, **SMRs can be sited in locations that are not suitable for larger nuclear power plants,** including remote or disused areas, to support the grid and complement intermittent renewables. While median-sized nuclear plants require 832 acres and provide 1.2 MW/acre, proposed SMRs only require 10 acres and provide about 47MW/acre

Safety

SMRs feature simpler designs, operate at **lower power and pressure,** and utilize **passive cooling systems, making them safer** than traditional reactors. With reduced refueling needs, they also minimize the transportation and handling of nuclear fuel, decreasing the risk of accidents. Some SMRs are designed to run for up to 30 years without requiring refueling

- SMRs are **small nuclear reactors with a maximum output of up to 300 megawatts electric** (MWe), capable of producing 7.2 million kWh per day. In contrast, large nuclear power plants have outputs exceeding 1,000 MWe, generating around 24 million kWh per day
- Globally, **over 80 SMR designs are in various stages of development across 18 countries.** While nations like the US, UK, Canada, Japan, and South Korea are actively pursuing their own designs, **Russia and China have already connected their first SMRs** to the grid in 2019 and 2021, respectively
- SMRs have the potential to play a **key role in decarbonizing the global energy mix,** contributing to **grid stability** amid rising renewable energy integration and growing electricity demand. They are also well-suited for **installation on decommissioned coal power plant sites,** replacing emissions-intensive generation with clean energy. Alongside renewables like wind, solar, and hydrogen, SMRs are poised to **complement the decarbonized energy systems mix of the future**

Source: World Nuclear Association; IAEA; EU Commission; OECD NEA; Roland Berger

Nanotechnology is uniquely placed to revolutionize material science and innovation – By 2050, applications could affect every industry and purpose

Nanotechnology will evolve from today's already commonplace uses to extraordinary future applications

Past — Future

2000s Projected development of nanotechnologies **2050+**

Potential applications

Passive nanostructures

- This includes **nano-materials, -structures or -tubes**
- **Graphene,** for example, is a form of carbon, **derived from graphite,** consisting of a single layer of atoms arranged in a two-dimensional honeycomb-lattice nanostructure. Mechanically, it is 100x stronger and 6x lighter than steel, and displays many other unique optical and electronic properties

Active nanostructures

- **Nanomaterials performing** functions and **tasks** in materials or objects
- **Nanomedicine**, for example, has the potential to cure diseases such as cancer: **nanorobots** are being developed to navigate in human blood vessels. Those robots can detect viruses or destroy cancer cells, as artificial immune cells cannot be manipulated by cancer

Nanosystems

- **Self-assembly of nano-factories** that works together with other nanoparticles and machines
- In 2018, an MIT engineer created a **nanomaterial** that can grow, strengthen, and repair itself using CO_2 from the air. Since then, self-healing concrete and ceramics have already been developed, as well as renewable polymers

Molecular nanosystems

- **Full control of nanosystems** able to create structures to complex, atomic specifications including applications for every industry and purpose
- **Molecular devices** leading to understanding and control over the basic building blocks of everything

- **Nanotechnology covers** a wide range of different fields from **material science to robotics** and **nanobiotechnology,** but refers to areas of science and engineering where dimensions in nanometer scale are utilized in the design, production, and application of materials **for structures, devices, products, and systems**
- Already widely present in many consumer products and industrial applications today, **nanotechnology is expected to impact many more sectors in the future:** for example, it could be used in the **health** sector to monitor and treat diseases; equally, it could be used in **agriculture** and **food** sectors to create more sustainable, higher quality products

Source: Medium; Graphenea; Valuer; Mecs-press; European Commission; Roland Berger

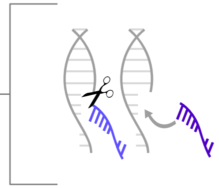
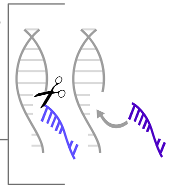
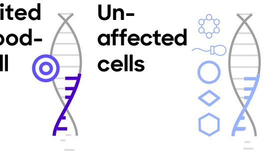
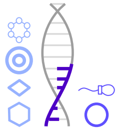
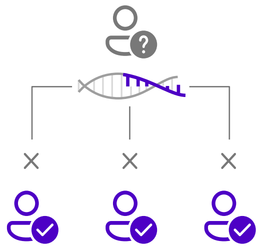
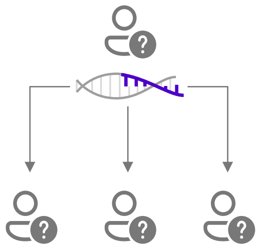
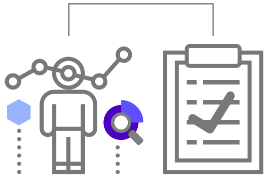
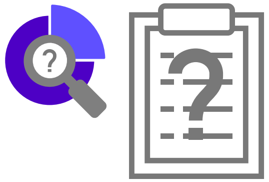
Biotechnological innovations enable many beneficial applications but entail ethical and societal risks – Research is ongoing, yielding breakthroughs …

Application	Definition	Benefits	Challenges
Digital health/ Personalized medicine	Tailored medical treatment using AI to combine data from genetic sequencing, diagnostics, and biomonitoring	Misdiagnoses plummet and healthcare outcomes improve	Access disparities due to costs or location; personal health data misuse or manipulation
On demand medicine production	Cell- and gene-based therapies, combined with improvements in drug design and production, for faster disease response	Rapid, more effective medical treatments	Disputes over R&D prioritization in developed vs. developing countries
Bioprinting and xenotransplantation	Additive manufacturing to "print" biological parts for medical testing or tissue replacement, grow human-compatible organs in animals for transplantation	Reduce delays and rejections of organ transplants & repairs	Access disparities due to high up-front costs
Computer-human interfaces	Machine augmentation of human cognitive processes	Novel treatments for neurological disorders; enhanced cognition and expanded perception	Tension between augmented and non-augmented individuals; new cyber/bio vulnerabilities
Bio-manufacturing	Bio-design and production of enhanced or highly specified materials, medicines, and food	Improved speed and reliability in design and making novel materials, medicines	Increased potential for misuse and workforce restructuring
Environmental restauration	Large-scale ecological intervention, through biotechnology, reforestation or ocean engineering, creates, manipulates, or rescues damaged environments	Barren or depleted lands turn productive; mitigation of manmade and natural threats	Unintended, potentially global environmental or public health consequences
DNA-based data storage	DNA used to encode and store data	Practically unlimited capacity for long-term data storage	Increased potential for long-term social monitoring

Source: National Intelligence Council; Roland Berger

... such as the Nobel Prize-winning gene editing process CRISPR – Concerns remain mainly in areas of germline gene editing

Genetic editing holds many promises

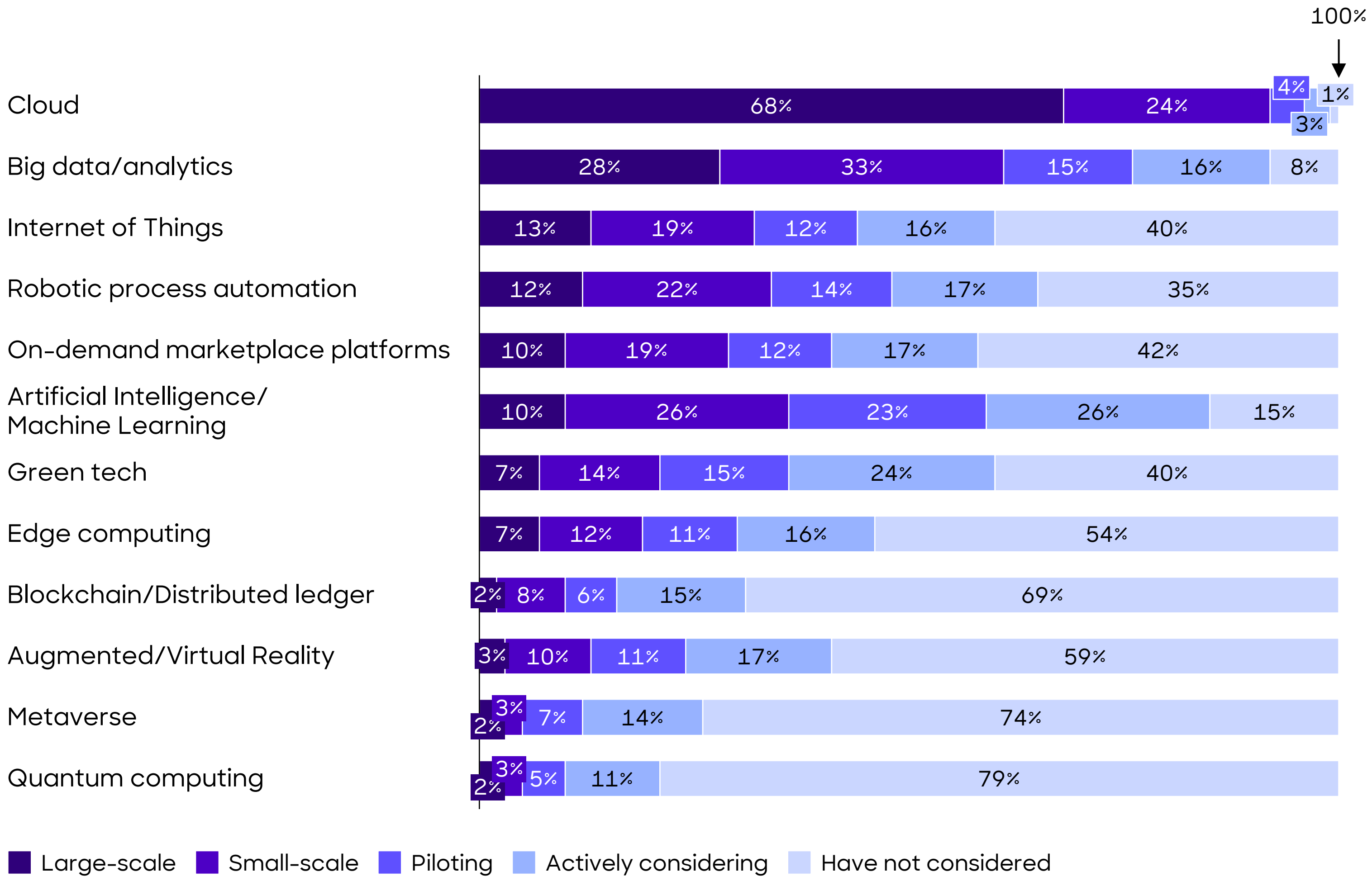
	Somatic gene editing	**Germline** gene editing
Edit	**Blood cell**  Somatic therapies target genes in specific types of cells (blood cells, for example)	**Sperm, egg, or early embryo**  Germline modifications are made so early in development that any change is copied into all of the new cells
Copy	**Edited blood-cell** **Un-affected cells**  The edited gene is contained only in the target cell type. No other types of cells are affected	**All cells edited**  The edited gene is copied in every cell, including sperm or eggs
Risks / **Next generation**	 Any changes, including potential off-target effects, are limited to the treated individual The edited gene is not passed down to future generations	 If the person has children, the edited gene is passed on to the future generations
Consensus	 Somatic cell therapies have been researched and tested for more than 20 years and are highly regulated	 Human germline editing is new. Heritability of germline changes presents new legal and societal considerations

- **CRISPR** – clustered regularly interspaced short palindromic repeats – represents **a new milestone in biotechnology** and has the potential to cure hitherto incurable diseases. This **technology,** with its origin in the immune system of bacteria, uniquely combines attributes of being highly accurate, safe, and versatile
- **CRISPR genetic editing technology** consists of two parts: Cas9, a pair of molecular scissors that cuts DNA, and a single guide RNA (sgRNA), a template that guides Cas9 to the desired section of DNA
- The use of CRISPR that focuses on somatic (cells of the body) gene editing have already undergone successful trials. In late 2023, the UK regulator approved Casgevy, a **CRISPR-based therapy for treating sickle cell disease** (SCD) and **transfusion-dependent beta thalassemia** (TDT). This marked the first-ever approval of a CRISPR-based medicine
- **Diseases** that **are caused by genetic disorders** could be **overcome by gene editing treatments** – as well as other diseases, such as cancer
- Although editing germline (reproductive) genes unlocks further possibilities in the quest to combat diseases, there are many **ethical, legal and scientific concerns** regarding human germline engineering particularly when so-called off-target (unintended) effects result from the process. At present, an international group of scientists has called for a global moratorium on genetically editing human embryos

Source: Harvard Gazette; The Nobel Prize, nbr; Science; Athens Science Observer; Roland Berger

Adoption is the key to success of frontier technologies - Many digital frontier technologies are not yet widely adopted

Survey on the adoption of emerging technologies in companies worldwide 2023 [%]



- **Adopting new technologies** helps **businesses** stay **competitive,** improve **efficiency**, enhance **customer experiences**, and drive **innovation**, leading to cost savings and better decision-making
- However, **widespread adoption** is also beneficial for the technology itself, as it **accelerates further innovation and scalability,** creating **network effects** that increase its value as more organizations make use of it
- Technologies such as **cloud** and **big data** are already **widely adopted** because they **provide immediate business value,** offering scalable infrastructure, cost-effective data storage, and data-driven insights that **improve operations**
- **Other frontier technologies,** e.g. the metaverse, blockchain, or quantum computing, **face higher adoption barriers** due to technological **complexity,** unclear business models, and limited use cases, requiring **time to mature** and prove their future value

Source: Nash Squared; Cionet; Roland Berger

Human-machine interaction is transforming work and society, offering new opportunities while posing several challenges

Human & Machines

What is Human & Machine Interaction?

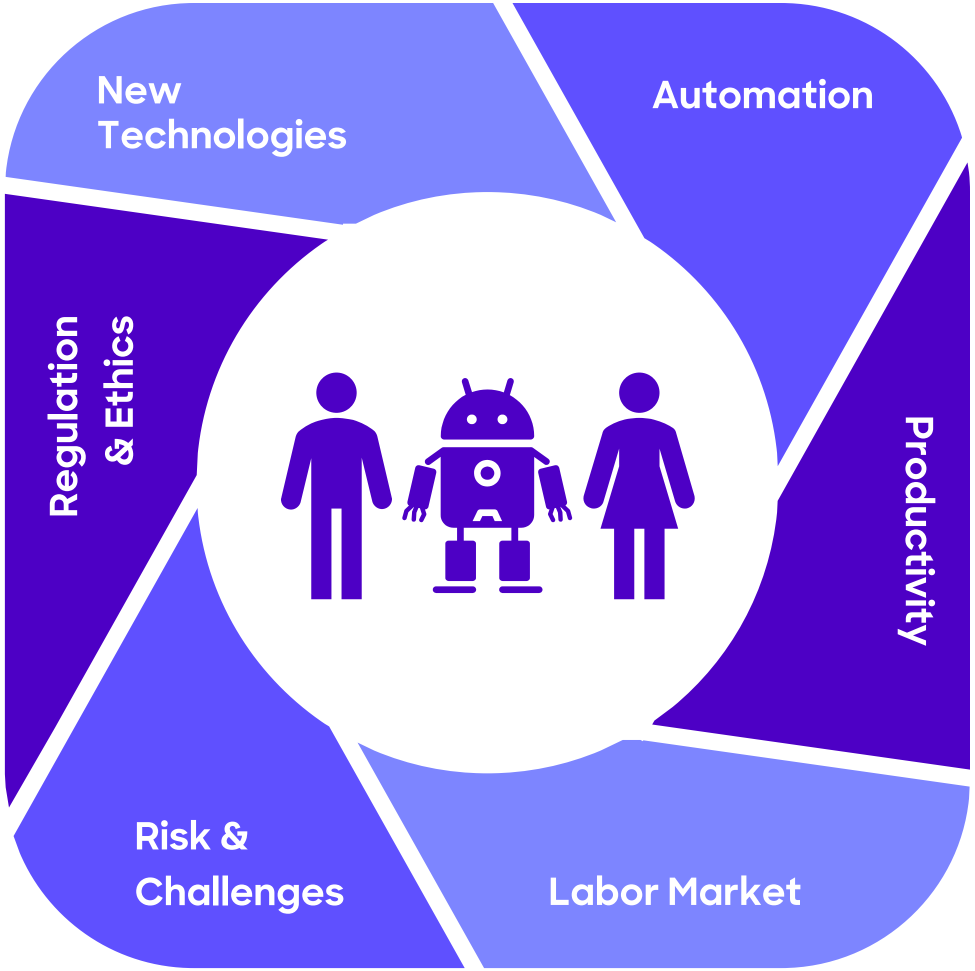
Human & Machine Interaction (HMI) describes the diverse **interaction, communication, and collaboration between humans and technological systems,** particularly automation and artificial intelligence

How does HMI take place?

Interaction can take on **many different forms:** through contact interaction (e.g. touchscreens), speech/sound interaction (e.g. voice commands), gesture-based (e.g. sensor gloves), facial expression/recognition, text input (e.g. keyboards), tactile interfaces (e.g. exoskeletons), and neural-computer interfaces (through brain activity signals) – **and increasingly through combinations thereof**

How does this interaction impact our world?

This interaction is increasingly shaping our work environments and societal structures. It offers **opportunities** for greater efficiency and innovation, but also brings **challenges,** such as regulatory issues, ethical considerations, and impacts on the labor market



Source: Karpov, A.; Roland Berger

At present, our most popular human-machine interaction – the use of smartphones – is already affecting our lives, throwing up new challenges

Selective effects of smartphone usage

Positive

59%

59% of respondents use their smartphones for video calls, making it easier to maintain personal connections

47%

47% of smartphone users use their devices for educational videos

71%

Driven by smartphones, the mobile banking rate in developing countries has risen to 71%, leading to greater financial inclusion and secure transactions

Negative

67%

Of the teachers surveyed, 67% noticed their students being negatively distracted by mobile devices

40%

Almost 40% of all consumers and 60% of 18- to 34-year-olds admit to using their phones too much

26%

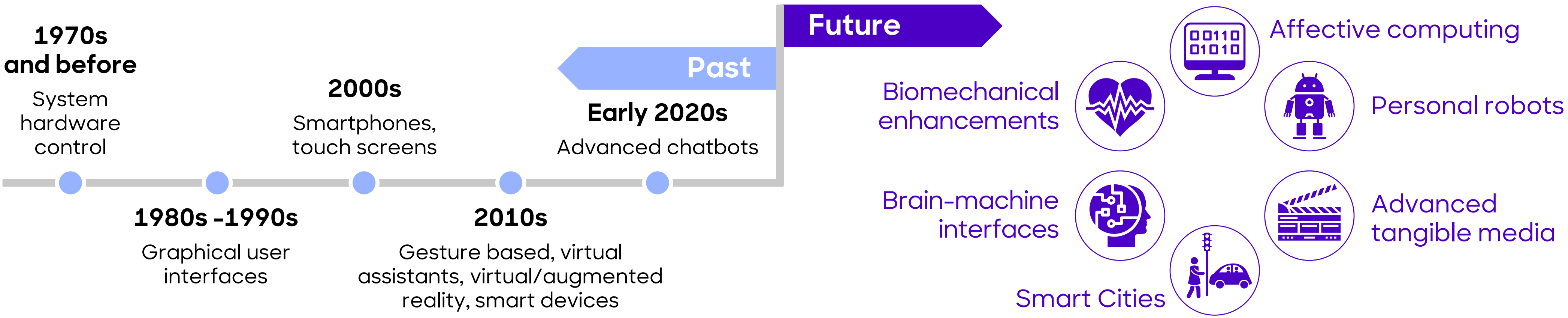
26% of accidents involving cars are caused by cell phone use while driving

- **The interaction between humans and machines,** whether through AI, automation, or smart devices, **brings many advantages,** such as making it easier to maintain personal connections and support, especially to disadvantaged individuals, but also highlights how **technologies can negatively impact our lives:** in the case of the ubiquitous smartphone, for example, a sense of being constantly distracted and feelings of being overwhelmed have been reported, particularly in the younger generation
- Adverse effects of smartphone use in combination with social media consumption have led **Australia** to become the first country globally to **ban the use of social media for under 16s** from 2025 onwards. **France** and other EU countries have already regulated the use of smartphones in schools. **Globally, one in seven countries** have introduced some form of **restriction** (laws, decrees, policies, guidelines) during the school day. Other **governments** as well as global **tech companies** are closely **following these developments**

Source: Demandsage; Fokus; TechJury; SlickText; Roland Berger

In the future, new technologies will continue to converge and affect the relationship of humans and machines – New milestones lie ahead

Development of human-machine interaction



- **Human-machine interaction (HMI)** has been an area of research and innovation **since the 1970s,** when **computers** were first in **use, mainly in business.** Then, computers were large and expensive devices that were highly complex and difficult to use. To overcome this, early HMI technology focused on increasing the usability of computers, e.g. by developing graphical user interfaces (GUIs). Since then, progress in HMI technology has accelerated to meet the **changing needs of a wider variety of users**
- **User interfaces** and **human-machine interaction have become much simpler and more accessible,** e.g. through the adoption of touch screens and virtual assistants such as Apple's Siri or AI-powered chatbots like ChatGPT. Today, humans interact with a vast number of smart devices connected to the internet such as heating or lighting systems; advances in IoT (Internet of Things) will only underscore this development for businesses
- In the **future, biomechanical enhancements,** such as exoskeletons, will augment **human physical capability, personal robots** will collaborate with people using **language or non-verbal cues, affective computing** can **respond** intelligently **to natural human emotional feedback,** and **advanced tangible media** will enable humans to **remotely interact with others using all senses** (and even with people no longer with us through means of tangible memories)
- The **direct connection of human and machine (brain-machine interface)** has left the realm of science fiction: research into bionic humans is already at an advanced stage. Trials underway also include **implanting chips into people's brains** so that machines can be controlled with their minds – the danger here lurks in reversing direction of control. Globally, up to 100,000 people are estimated to have been **"bio-hacked",** i.e. have microchips embedded into their hands or arms; the chips are used for making payments, for storing medical data or to enable access to passcode protected systems. The technology-savvy country Sweden has the largest share of such "cyborgs" (bio-hacked humans)

Source: MIT; The Economist; European Commission; BBC; Roland Berger

Interactions between humans and machines are multifaceted – Society's capacity to adapt and shape technological advances is fundamental

The human-machine relationship at different touch points

Technological inequality

Technological progress is a driver of wealth, but also carries implications of social and economic inequality

Social media & society

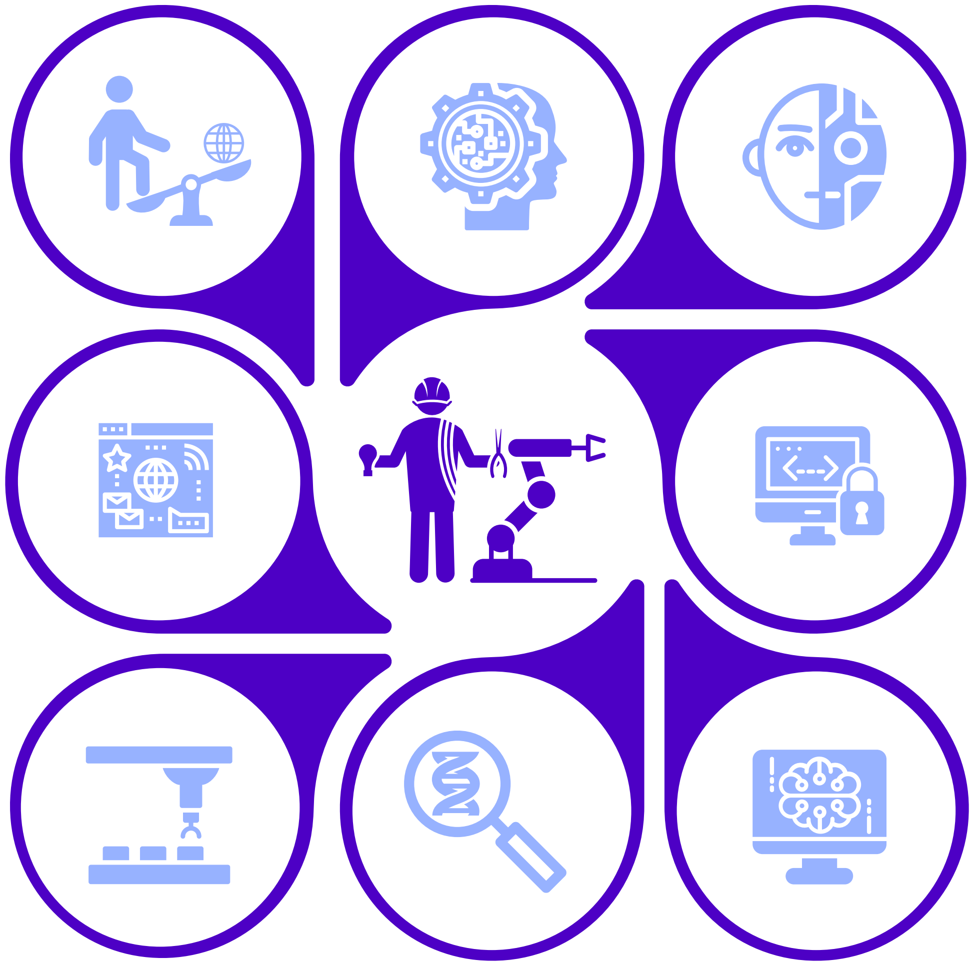
Social media has changed our lives. Emergent technologies and new digital realms, like immersive virtual spaces, continue to drive societal transformation

Fusion of humans & machines

Using thoughts to control devices: Brain-computer-interface technologies set to advance human-machine interactions – yet many issues remain

Biotechnology & humans

Advances in biotechnology are changing society by eradicating fatal diseases. Ethical concerns arise regarding gene editing and human enhancement



Technology governance

Technological advances entail aspects of uncertainty. Regulators are faced with trade-offs

Machine behavior & AI

AI is becoming smarter. Imbedding re-sponsible, moral code for smart systems is fundamental – its omission poses existential risks to future generations

Cybersecurity

Cyberattacks exploit the public and private proliferation of the internet. Malicious attacks on sensitive infrastructure and data storage facilities carries immense costs

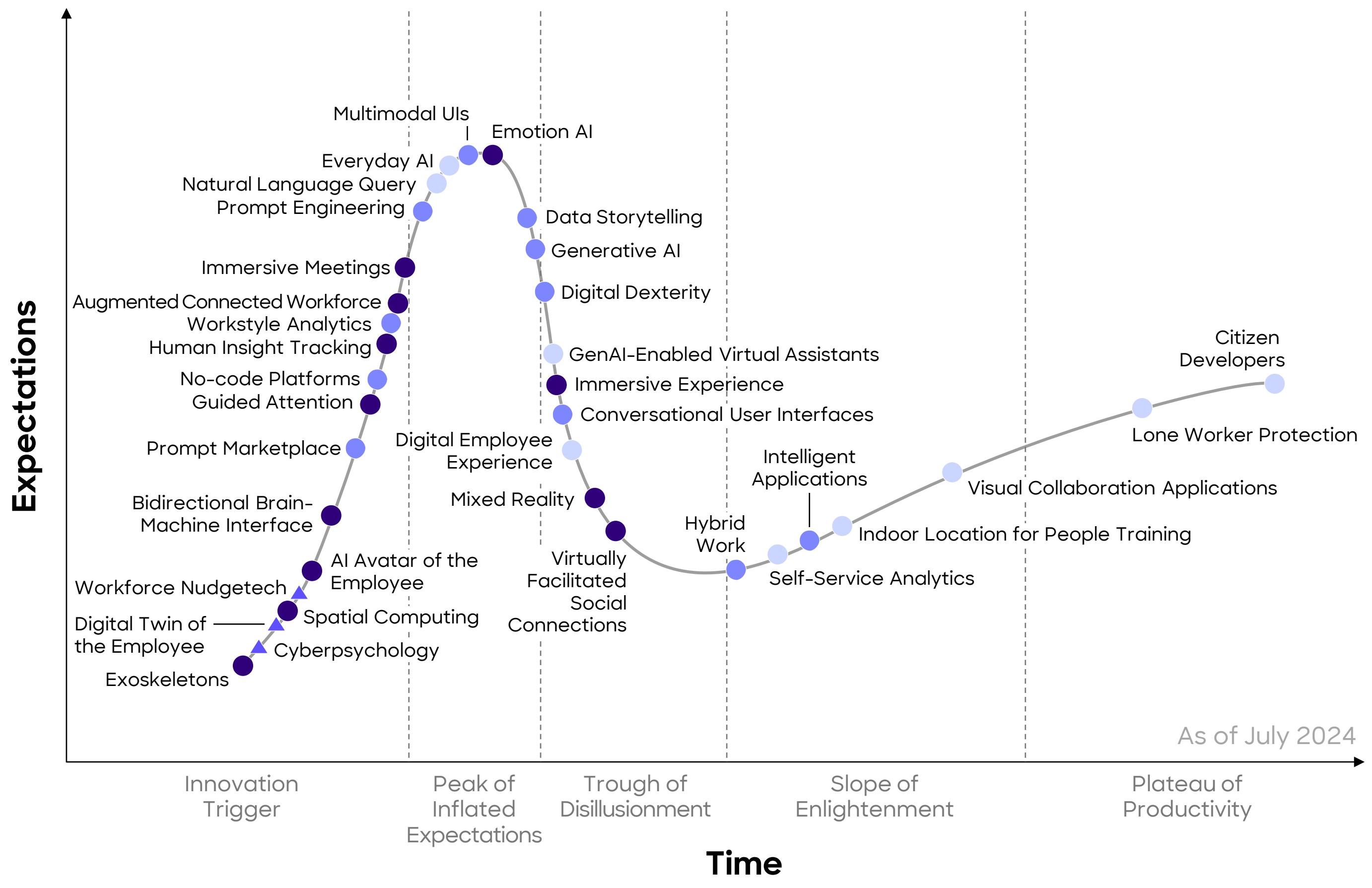
Future of work

Workplaces have undergone profound change, but the key question remains:
Will robots complement humans – or substitute them?

Source: Roland Berger

AI, digital technologies, and personalized solutions are shaping the future of work, driving efficiency and productivity

Gartner Hype Cycle™ for the future of work in 2024



Plateau will be reached: <2 yrs. 2-5 yrs. 5-10 yrs. > 10 yrs.

- The **pace of digitalization,** driven by AI, is fundamentally **reshaping the workplace.** Gartner's Hype Cycle™ gives a forward looking, comprehensive overview of key technologies influencing the future of work
- **Technologies such as generative AI, digital twins, and AI-driven avatars** are expanding workforce capabilities, enhancing collaboration between humans and technology to **boost productivity** and **efficiency**
- 51% of **digital workers** are **personalizing their work environments** through customization and automation. Key focus areas for this trend include no-code platforms and GenAI-powered virtual assistants
- Organizations with a **Digital Employee Experience** (DEX) leader will **adopt emerging technologies twice as fast** by 2028 as those without, thus creating a competitive advantage through faster tech adoption
- **Low digital workplace maturity is a barrier to productivity gains:** According to Gartner's Digital Workplace Maturity Assessment only 14% of organizations have achieved the level of digital maturity needed to empower employees to embrace new ways of working

Source: Gartner; Roland Berger

The future of work is shifting toward higher-skilled tech roles – Outmoded jobs are to be replaced by digitalization and automation

Top 10 jobs by fastest relative net growth and net decline, 2025-2030

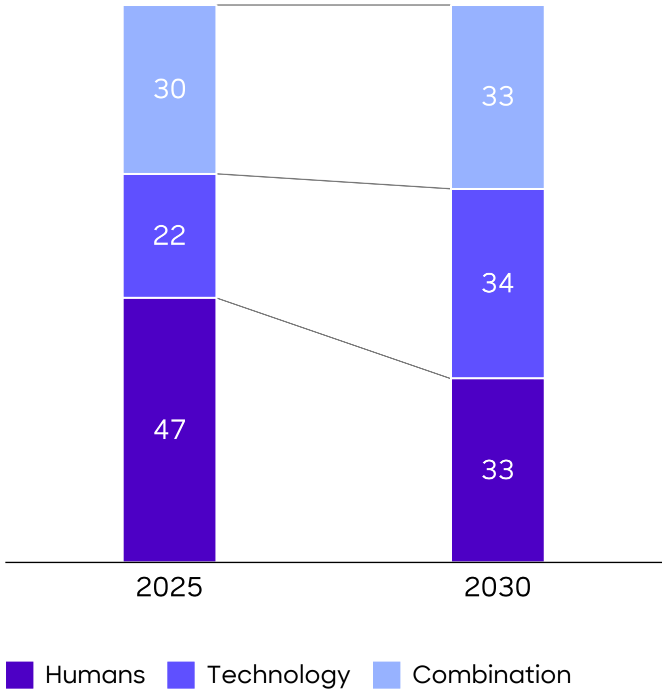
	Increasing demand	Decreasing demand
1	Big data specialists	Postal service clerks
2	FinTech engineers	Bank tellers and related clerks
3	AI & machine learning specialists	Data entry clerks
4	Software and applications developers	Cashiers and ticket clerks
5	Security management specialists	Administrative and executive secretaries
6	Data warehousing specialists	Printing and related trades workers
7	Autonomous & electric vehicle specialists	Accounting, bookkeeping and payroll clerks
8	UI & UX designers[1)]	Material-recording and stock-keeping clerks
9	Light truck or delivery services drivers	Transportation attendants and conductors
10	Internet of Things specialists	Door-to-door sales workers, news and street vendors, and related workers

- The **fastest-growing jobs** are **technology-related roles**, such as big data specialists, FinTech engineers, and AI & machine learning specialists. Roles expected to see the **steepest decline** are **primarily clerical positions**, for example in postal services and banking; this is largely **due to digitalization and automation**
- **Big data, cloud computing, AI, and digital platforms** are driving industry transformation, **creating demand for tech-focused roles.** In addition to technical expertise in AI and big data, **technological literacy, network security, and analytical thinking are highly sought-after skills.** Companies must invest in upskilling and reskilling their employees accordingly
- A **structural job churn of 22%** is expected over the next years. **Frontline jobs** such as farmworkers and delivery drivers will see the **highest absolute growth.** Care roles (nurses, social workers) and education jobs will also expand significantly. Within the 55 economies surveyed, 170 million new jobs will be created in the period from 2025 to 2030, while 92 million will be lost, resulting in a **net gain of 78 million jobs**

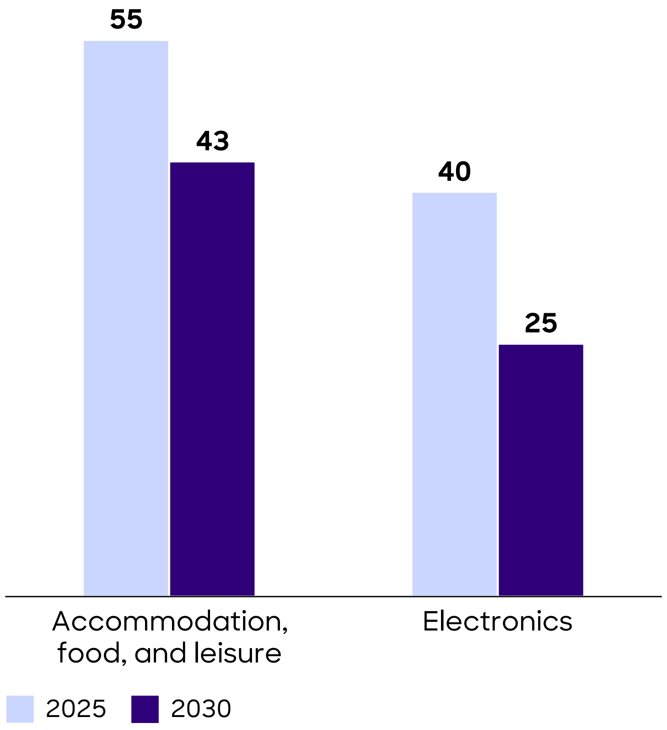
1) UI (User Interface) focuses on interface design, UX (User Experience) on the overall user experience
Source: WEF; Roland Berger

By 2030, automation will take on more tasks, reducing human-only work, while collaboration with machines continues to grow

Share of work tasks expected to be performed predominantly by humans, by technology, or by a combination of both, 2025 and 2030 [%]



Industries with highest and lowest share of work tasks expected to be performed predominantly by humans, 2025 and 2030 [%]

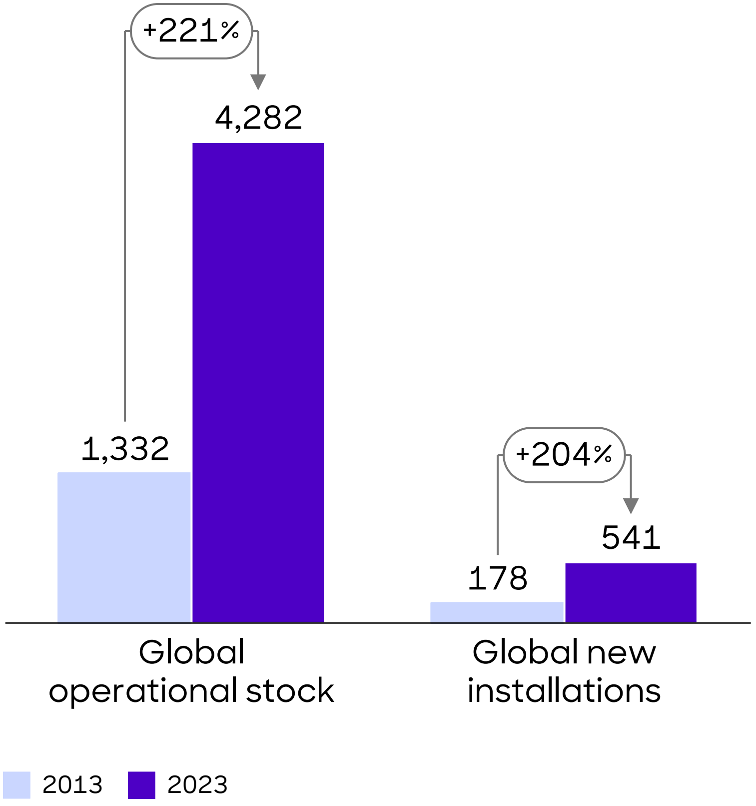


- The proportion of **work tasks performed solely by humans is expected to decrease** from 47% today to 33% by 2030, while **tasks performed by technology are projected to grow** from 22% to 34%; the remainder will be handled through **human-machine collaboration,** which is anticipated to **grow** from 30% to 33%
- Of the reduction in human-performed tasks, **82% is attributed to advancing automation,** while only 19% stem from enhanced human-machine collaboration. This emphasizes the growing role of machines in handling repetitive and process-driven tasks
- **Different industries will see varying impacts of automation and augmentation.** For instance, in sectors like electronics, **task reductions** for humans will **stem from automation only.** However, in **medical and public sectors,** nearly **half of the reductions** will be due to **increased human-machine collaboration**
- While automation enhances productivity, **concerns arise regarding** the share of economic **value created by human workers.** To address this, **policymakers and businesses must prioritize reskilling** and designing technology to complement human roles

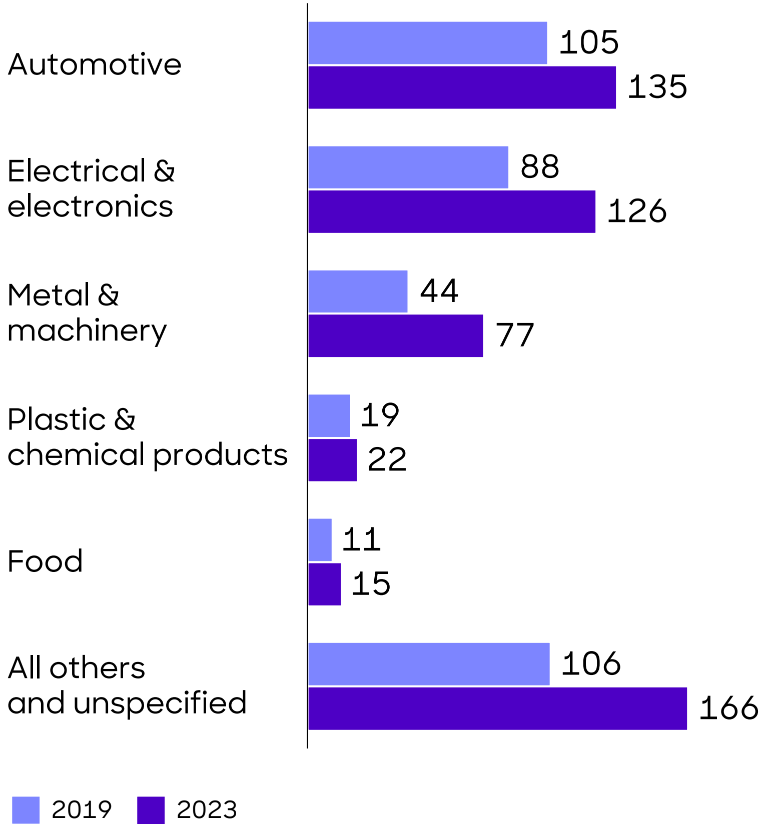
Source: WEF; Roland Berger

Over the past decade, global industrial robot stocks and installations have surged, with particularly high numbers in automotive and electronics

Global operational stock and new installations of industrial robots, 2013 and 2023 ['000]



Annual installations of industrial robots by customer industry, 2019 and 2023 ['000]

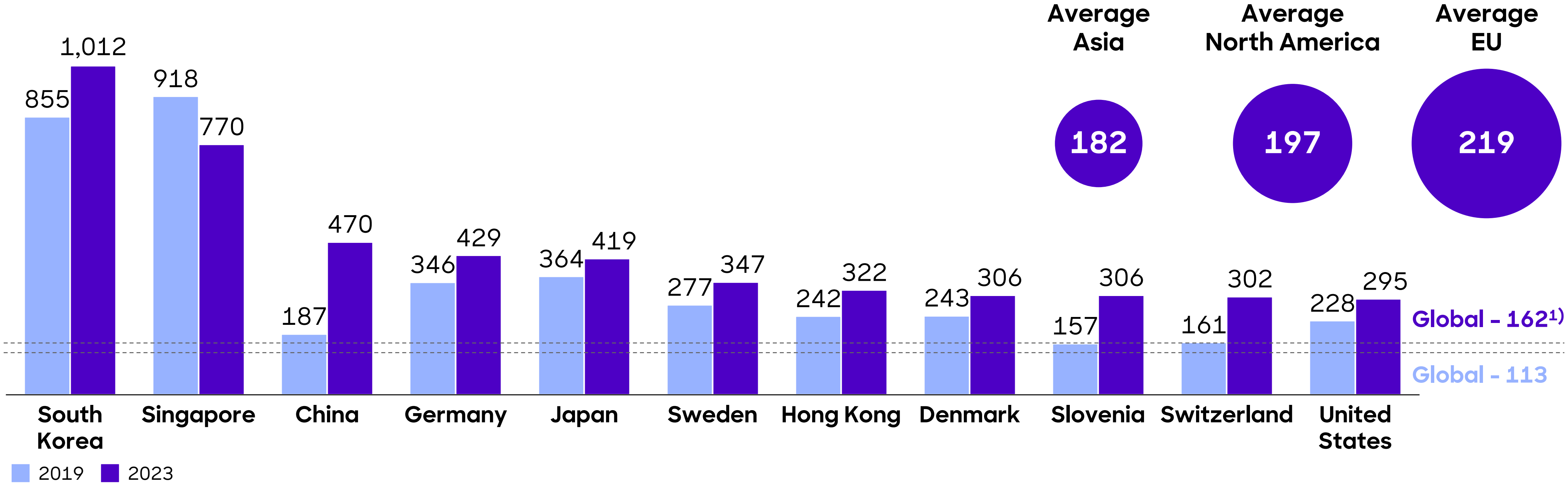


- The **number of industrial robots** has **increased by 221%** since 2013, reaching around 4.3 million units, driven by the **growing demand for efficiency and productivity** in global manufacturing
- The **long-term trend** in the number of new industrial robot installations **shows a significant increase.** New installations rose from 178,000 in 2013 to 541,000 in 2023, representing a **204% increase over the decade** and an average **annual growth rate of 20%**
- The **automotive sector leads in annual installations** of industrial robots in 2023, closely followed by electrical & electronics
- Since 2019, **installations have increased across all categories,** with particularly strong growth in the top three sectors, **reflecting a significant surge in automation demand across diverse industries**

Source: IFR; Roland Berger

Global industrial robot use is surging boosting manufacturing productivity - South Korea leads in terms of density while China shows notable growth

Countries with the highest robot density in the manufacturing industry
[robots installed per 10,000 employees]



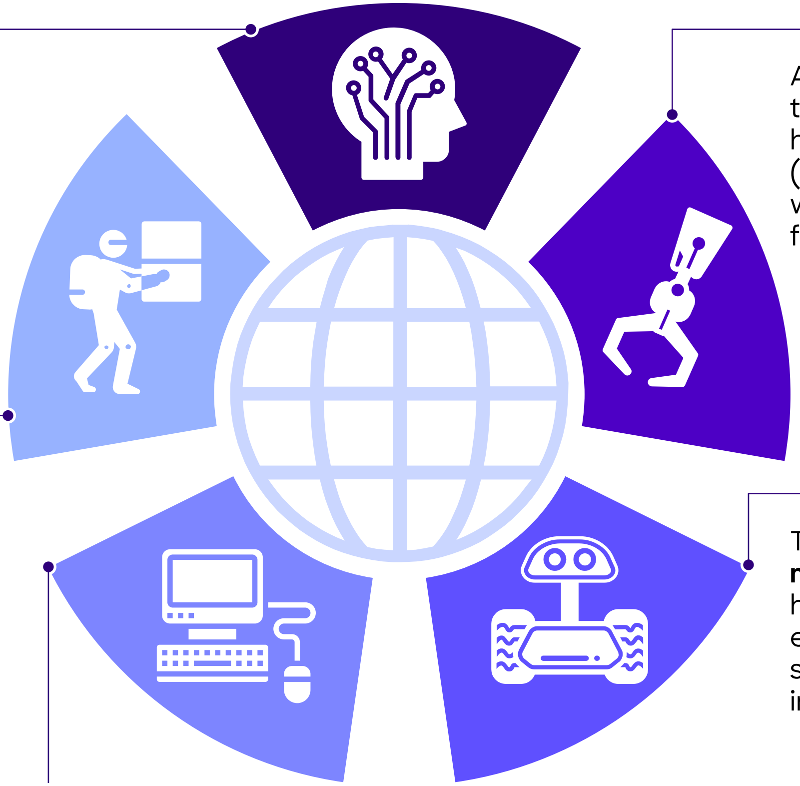
- **South Korea leads the world in robot density** with over 1,000 robots per 10,000 employees, driven by its strong electronics and automotive industries. It is followed by Singapore and China, with China recently overtaking Germany for third place and the United States ranking 11th with 295 robots
- Since 2019, South Korea has risen to the top, while **Singapore experienced a decline in robot density,** likely due to its small manufacturing workforce, where even slight increases in workforce size reduce density figures. **China,** on the other hand, **has shown the most significant growth,** more than doubling its robot density over the same period
- **Regionally, the EU leads with an average of 219 robots** per 10,000 employees, followed by North America with 197 and Asia with 182. **Globally, the average robot density has increased by over 40% in recent years,** reaching 162 robots per 10,000 employees

1) The regional averages displayed (Asia, North America, EU) are higher than the global average because they exclude regions with significantly lower robot densities, such as parts of South America and Africa, which contribute to the overall lower global average

Source: IFR; Roland Berger

Robotics and automation are becoming more efficient, more flexible and more human-centered

Top 5 global robotics trends in 2024



AI & Machine Learning[1)]

The integration of **generative AI** opens up more intuitive, natural interfaces for robot control and significantly increases efficiency. Predictive maintenance optimizes the availability of systems through advanced data analysis and enables substantial savings in operating costs

Cobots in new applications

Advances in sensor and adaptive gripping technology are taking interaction between humans and machines to a new level. **Cobots** (collaborative robots) add complex, interactive work processes to automation and react flexibly to dynamic working environments

Humanoids[1)]

With human-like design and movement patterns, **humanoid robots** offer the possibility of seamless integration into existing environments designed for human users. This technology has the potential to profoundly transform established work structures, unlocking new dimensions of automation in an industrial and social context

Mobile Manipulators

The symbiotic combination of **mobility and manipulation** capabilities automates material handling and maintenance in complex production environments. It addresses the shortage of skilled labor and increases resilience in key industries such as logistics and automotive

Digital Twin

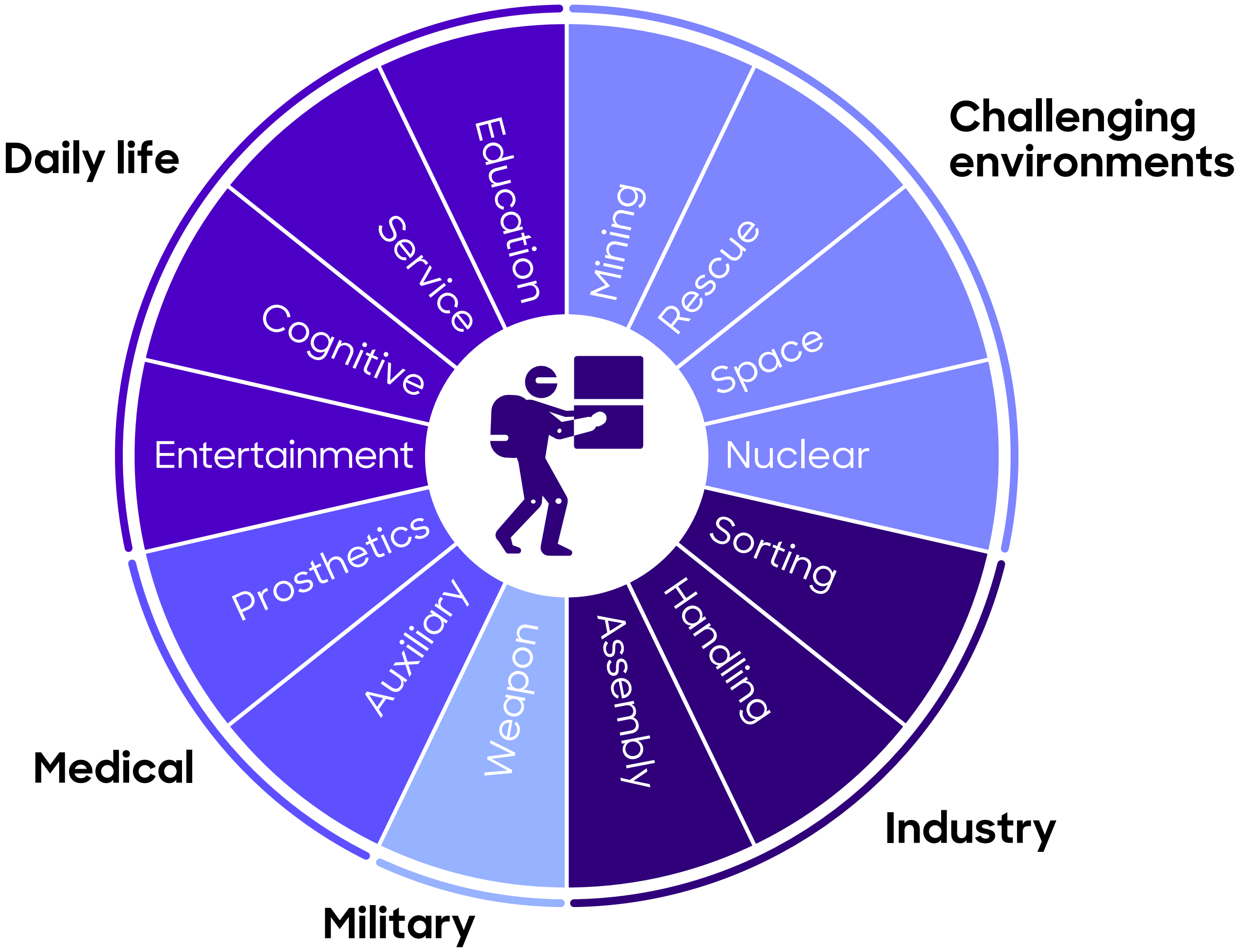
Virtual replicas of physical systems enable simulation-based optimization and precise process analysis without risks for real systems. **Digital twins** act as a bridge between the digital model and physical operation, significantly increasing both flexibility and operational efficiency

1) The trend categories "AI & Machine Learning" and "Humanoids" are explored in greater detail on subsequent slides in this chapter

Source: IFR; Roland Berger

Humanoid robots offer versatile uses and great potential for daily life and specialized tasks, driven by advances in AI, design, and sensors

Selective applications of humanoid robots



- **Applications for humanoid robots span diverse fields,** including industry and manufacturing, where they perform repetitive or hazardous tasks; in healthcare, humanoid robots can assist in patient care and elderly support
- In education, they **act as** interactive **learning tools,** while in **disaster response,** they take on search-and-rescue missions in dangerous environments. Humanoids are also **utilized in entertainment,** providing engaging experiences, and **in service sectors,** such as retail and hospitality, for customer interaction and assistance. Their **growing versatility** highlights their potential for integration into daily life and specialized tasks across multiple domains
- **Trends in humanoid robotics include advances in artificial intelligence and learning-based approaches** for greater autonomy and adaptability, the use of **lightweight materials and energy-efficient systems,** and **biomimetic designs** for natural movement
- **Enhanced human-robot interaction, diverse application areas, and global collaborations are driving progress:** advanced sensing capabilities and optimized control methods improve perception and stability, while modular designs and cost-efficient technologies, e.g. 3D printing, increase flexibility and scalability

Source: IEEE/CAA; Roland Berger

AI in robotics enhances capabilities, boosts efficiency, and improves safety, driving transformative progress across industries

Selected benefits of AI in robotics

Enhanced capabilities

Complex task execution

Improved learning and adaptation

Increased efficiency and productivity

Automation of repetitive tasks

Reduced errors and improved accuracy

Improved safety

Operation in hazardous environments

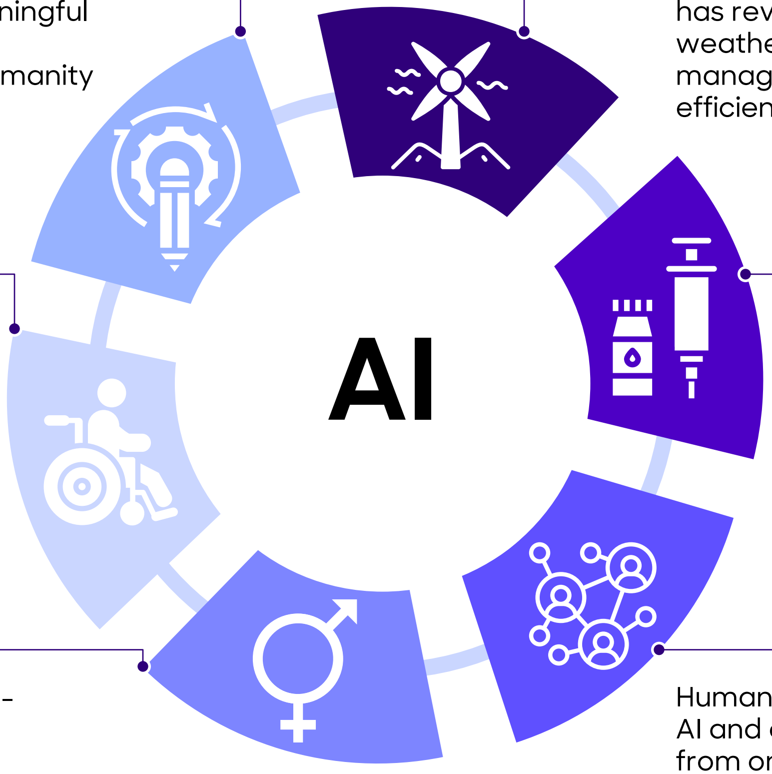
Enhanced human-robot-collaboration

- **AI enhances robotics by enabling autonomy, adaptability, and efficiency,** using technologies such as **computer vision** for **object detection,** navigation, and precise manipulation; **machine learning** for **decision-making and predictive analysis;** and **Natural Language Processing for natural language interaction,** voice control, and sentiment analysis. This ensures seamless human-machine collaboration and supports advanced robotic functions
- **Different types of AI** are used in robotics to suit specific needs: **weak AI handles simple predefined tasks** like voice assistants (e.g., Siri/Alexa), **strong AI powers autonomous systems,** such as self-driving cars and humanoid robots, while **specialized AI is tailored to industrial applications,** e.g. painting, assembly, or precision manufacturing
- **Generative AI simplifies robot programming** by enabling the **use of natural language,** reducing the need for specialized programming skills, and **making automation more accessible to businesses of all sizes**
- **Predictive maintenance** powered by machine learning **reduces costly production** downtime and process optimization driven by AI improves efficiency and supports better data-driven decision making
- The **integration of AI and robotics** is **revolutionizing industries** such as manufacturing, healthcare, and logistics by enhancing efficiency, adaptability, and autonomy, with AI-powered robots reshaping the technological landscape

Source: GeeksforGeeks; IFR; Roland Berger

AI drives innovation, enhances lives, and combats global challenges such as discrimination and crime

How AI is helping humanity (selection)



Boosting productivity

AI automates repetitive tasks and analyzes data, freeing individuals to focus on creative and meaningful work. By streamlining workflows and optimizing processes, AI enhances efficiency, benefiting humanity through improved output and reduced effort

Optimizing renewable energy generation

AI, combined with IoT, cloud computing, and big data, has revolutionized renewable energy. AI integrates weather data and sensors to optimize, predict, and manage energy consumption, enhancing dispatch efficiency and reducing the need for operating reserves

Helping people with disabilities

Artificial intelligence enables greater independence for people with disabilities. Voice-assisted AI, especially for the visually impaired, facilitates communication and describes surroundings, helping to overcome daily challenges

Developing new drugs

AI is revolutionizing drug discovery by analyzing vast data to identify potential molecules. Pharmaceutical companies use predictive analytics and iterative optimization to select the best candidates for manufacturing

Reporting sexual harassment

AI provides innovative tools for reporting gender-based violence and abuse. AI monitors internal communications for inappropriate content and supports victims through platforms that document incidents, including time and location details

Combatting human trafficking

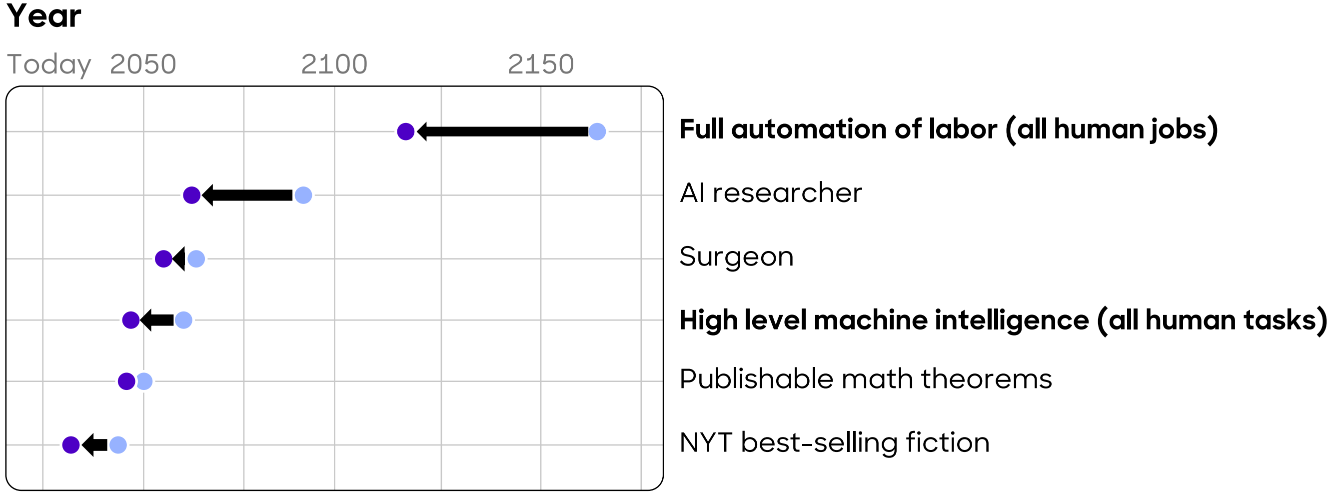
Human trafficking is a criminal act and a global threat. AI and computer vision tools analyze images and data from online ads to identify potential victims and alert authorities, thus helping to prevent illegal activity

Source: Forbes; Roland Berger

Fuelled by recent technological advances, AI experts have revised down their estimated timelines for human-level AI by several decades

Comparison of Expert Surveys on AI Progress, 2022 and 2023

When will unaided machines be able to accomplish every task better and more cheaply than human workers?



Survey 2023 Survey 2022


Expected time to human-level performance dropped **1-5 decades** since the 2022 survey


Median respondents put **5%** or more on advanced AI leading to human extinction

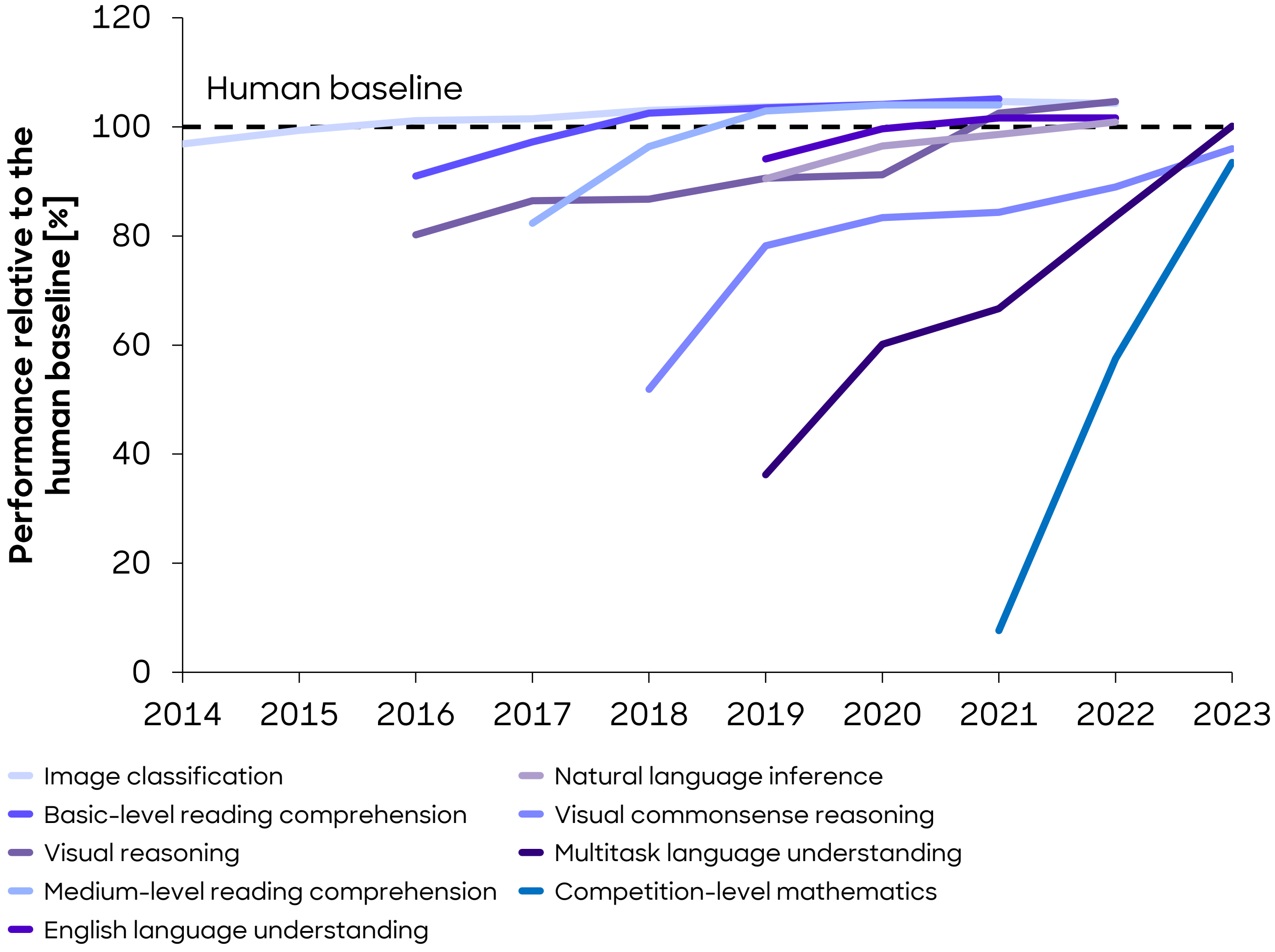

70% of participants would like to see research aimed at minimizing risks of AI systems be prioritized more highly

- While stating an exact date for the existence of **human-level AI** (i.e. AI that can accomplish every task better and more cheaply than human workers) is nearly impossible, a survey of experts in this field has tracked and analyzed their views regarding AI for the century ahead
- With the most recent advances in computing power and AI, **experts have readjusted their estimates** in the last few years; now, 90% (2018: 81%) of experts anticipate the existence of human-level AI within the next 100 years – and **50% expect it even before 2061**
- AI experts **stress especially the tremendous risks of ungoverned and rogue AI.** In this survey, they have evaluated disastrous long-run effects (such as human extinction) with a 5% probability

Sources: AI Impacts; Roland Berger

AI surpasses humans in many areas but remains challenged in complex tasks and reliability

AI Index technical performance benchmarks vs. human performance, selective indicators, 2014-2023 [%]

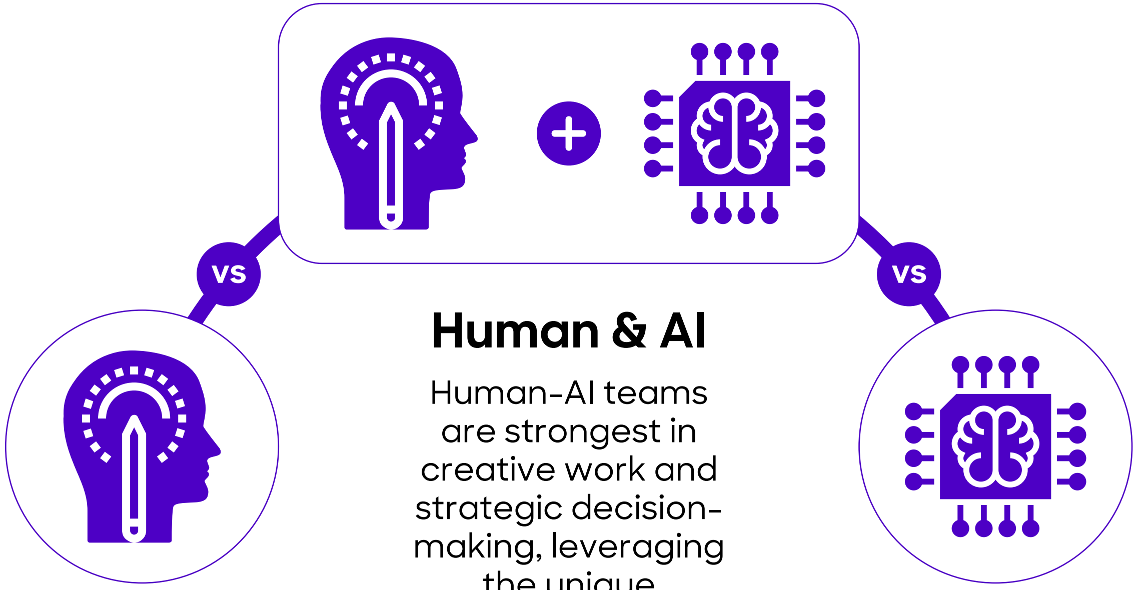


- By 2023, **AI** had reached **performance levels** that **outperform humans in various tasks** such as image recognition (achieved in 2015), basic reading comprehension (2017), visual reasoning (2020), and natural language inference (2021)
- Despite this, **certain areas remain in which AI trails human abilities;** these include more intricate **cognitive tasks,** such as **visual commonsense reasoning** and **solving advanced-level mathematical problems at a competitive standard.** Even though AI has not yet reached the human baseline in competition-level mathematics, it surpasses most people, as this baseline represents specialized mathematical knowledge
- AI has become **increasingly versatile** in generating **written content** across numerous professions, demonstrating its **broad applicability** and **rapid development**
- However**, challenges of maintaining factual accuracy** persist; large language models (LLMs) occasionally **produce "hallucinations",** where false or misleading information is presented as fact, highlighting the ongoing need for improvement in reliability
- Despite notable advances in newer models such as GPT-4, which have made significant strides in truthfulness**,** ensuring **consistent accuracy remains a critical challenge** for AI development

Source: Stanford University; Roland Berger

Humans and AI complement each other, with AI handling data-intensive tasks and humans focusing on creative work and strategic decision-making

Humans and AI: Better in partnership – or alone?



Human & AI

Human-AI teams are strongest in creative work and strategic decision-making, leveraging the unique strengths of both

Human

Humans excel in creativity, moral reasoning, emotional tasks, and contextual interpretation

AI

AI is superior in routine tasks, data analysis, pattern recognition, and accurate predictions

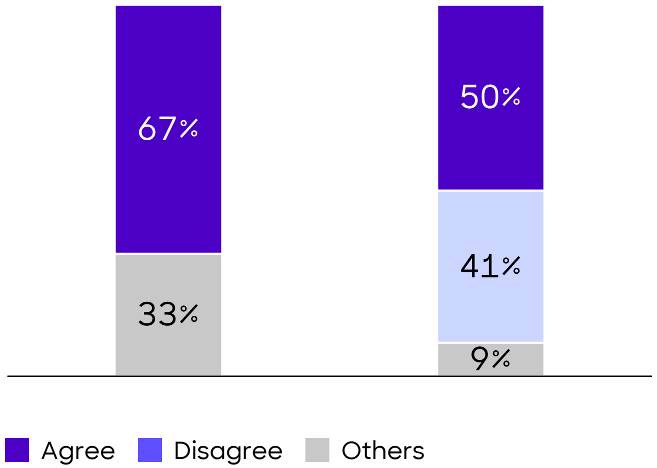
- **Human-AI teams perform better on average than humans working alone** but fall short compared to AI systems operating independently, especially in tasks like detecting deep fakes, demand forecasting, or medical diagnoses
- **Humans excel in areas requiring creativity, contextual understanding, nuanced judgment, and ethical reasoning.** They are uniquely skilled at interpreting social or cultural cues, adapting to ambiguity, and addressing emotional or psychological dimensions. However, **AI systems are increasingly demonstrating creative potential** in areas such as art, design, and storytelling – **challenging traditional assumptions about human superiority in creative tasks**
- **Human-AI collaboration in creative tasks can show clear advantages,** such as generating texts, images, or videos. Humans provide innovative direction, while AI enhances efficiency through detailed execution of repetitive processes
- **Organizations should evaluate whether human-AI systems outperform humans or AI working independently.** AI offers significant potential in creative fields, which can be strategically leveraged through clear guidelines and structured processes
- **The focus should shift from replacing humans with AI to fostering innovative collaboration.** By designing interactions that combine the unique strengths of both, organizations can unlock greater effectiveness and value

Source: MIT; Roland Berger

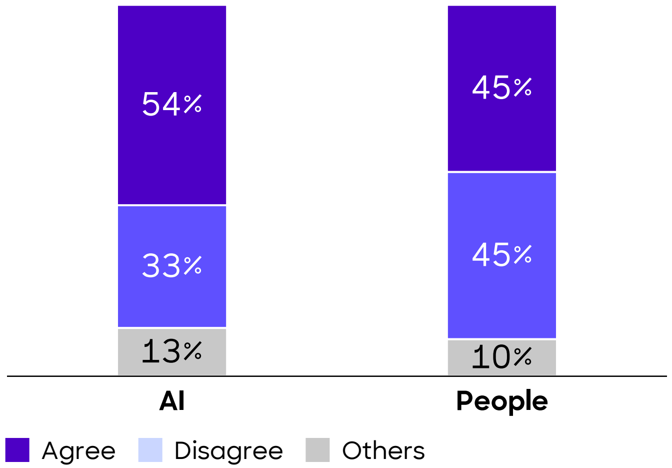
The majority of people feel well informed about AI, but have concerns about its impact on society and the economy

Results from a global survey about AI, 2024 [%]

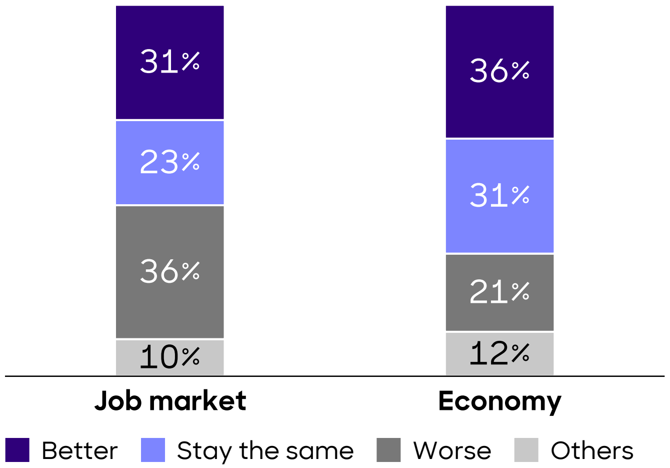
I have a good understanding of what AI is1) | **Products and services using AI make me nervous**



I trust … not to discriminate or show bias towards any group of people



The increased use of AI will make the … better, worse, or stay the same in the next 3-5 years?



- Across 32 countries, **67% of people report having a somewhat or very good understanding of AI,** with higher awareness among Gen Z (72%) and Millennials (71%) compared to Baby Boomers (58%). While 50% feel nervous about AI and 53% feel excited, **excitement is especially high in Asian countries** (China, Indonesia, Thailand, South Korea), whereas **English-speaking and European nations show more skepticism** and are more divided on AI's potential benefits versus its drawbacks
- In 29 of the 32 surveyed nations, **the majority of respondents believe that humans are more prone to discrimination than AI,** with Ireland as the only exception where more people trust human impartiality over AI
- Globally, **36% expect AI to benefit the economy** in the next 3-5 years, with **optimism highest in China** (72%) and **lowest in Canada** (18%). **Asian countries** are generally **more positive,** while **Western nations are more skeptical.** Views on **AI's impact on jobs also vary:** 31% see improvements, 36% expect declines, with Mexico and Thailand particularly optimistic, while European countries remain more cautious

1) Refers to the year 2023 and "Agree" includes "very" and "somewhat"
Source: Ipsos; Roland Berger

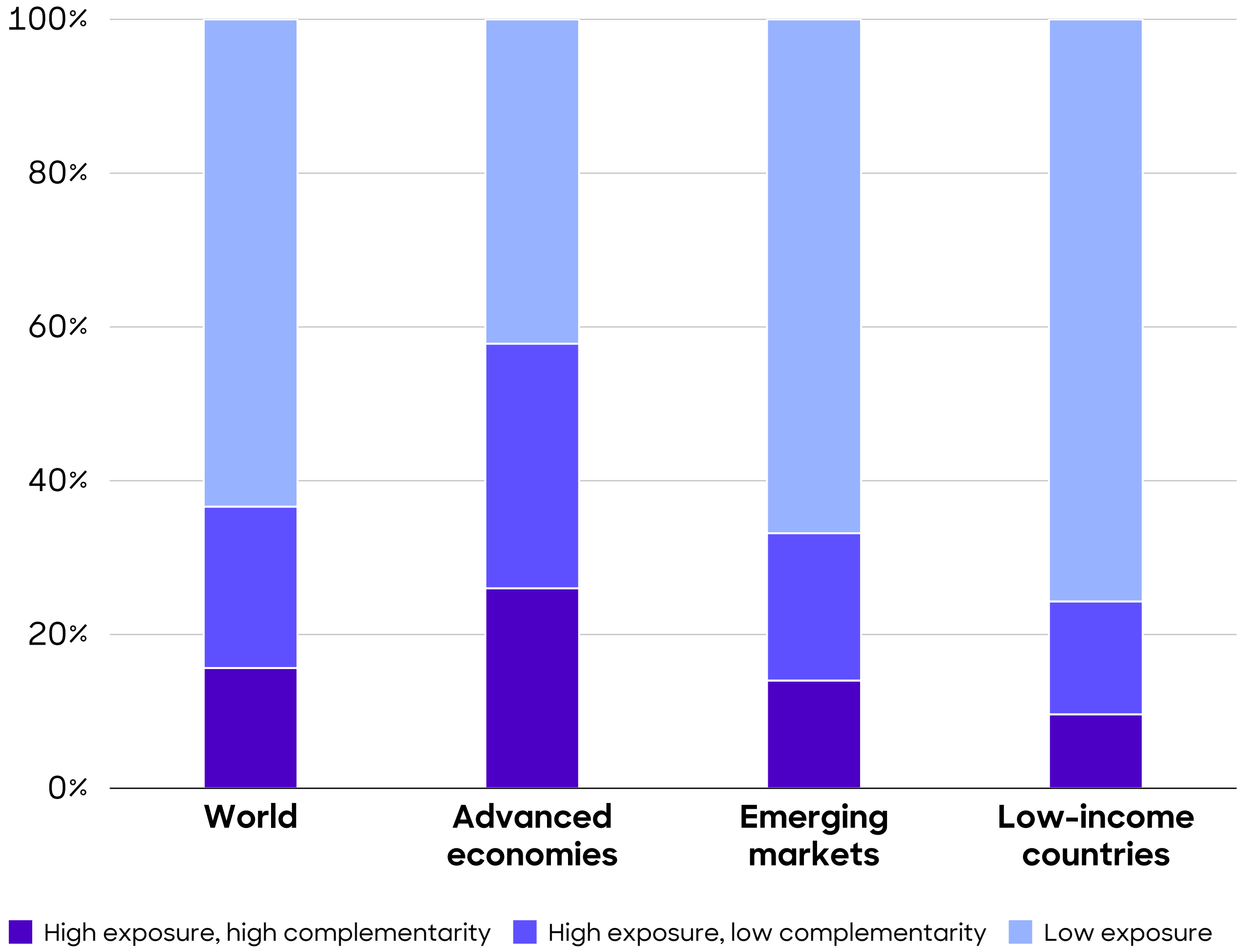

5.1
Value of Innovation


5.2
Frontier Technologies


5.3
Humans & Machines

AI impacts countries unevenly, as advanced economies face disruption and opportunities, while poorer countries see less impact and limited benefits

Employment shares by AI exposure and complementarity



- **Global impact of AI** shows that around **40% of jobs worldwide** could be **influenced by AI,** with a significant portion of tasks either replaced or complemented by AI technologies
- **Advanced economies** envisage that about **60% of jobs** are **potentially affected,** reflecting the wider adoption and use of AI technologies in these countries
- **Emerging markets** see a moderate level of impact, with **less than 40%** of jobs affected; this can be attributed to the more limited access to AI infrastructure and applications
- **Low-income countries** have the **lowest impact at 26% ,** which is due to a lack of digitization and minimal use of AI technologies – a situation that could further exacerbate economic disadvantages
- **Inequalities are highlighted** by the potential to exacerbate **global disparities,** as **advanced economies** experience **more significant impacts** but are also better equipped, while **low-income countries face fewer effects** but also see fewer opportunities to leverage AI
- Opportunities and risks show that AI could bring **significant productivity gains in advanced economies,** but there is a danger in **less developed countries** of workers being **excluded from technological developments**

Sources: IMF; Roland Berger

Targeted measures such as good governance, transparency, and security standards mitigate AI risks and promote responsible use

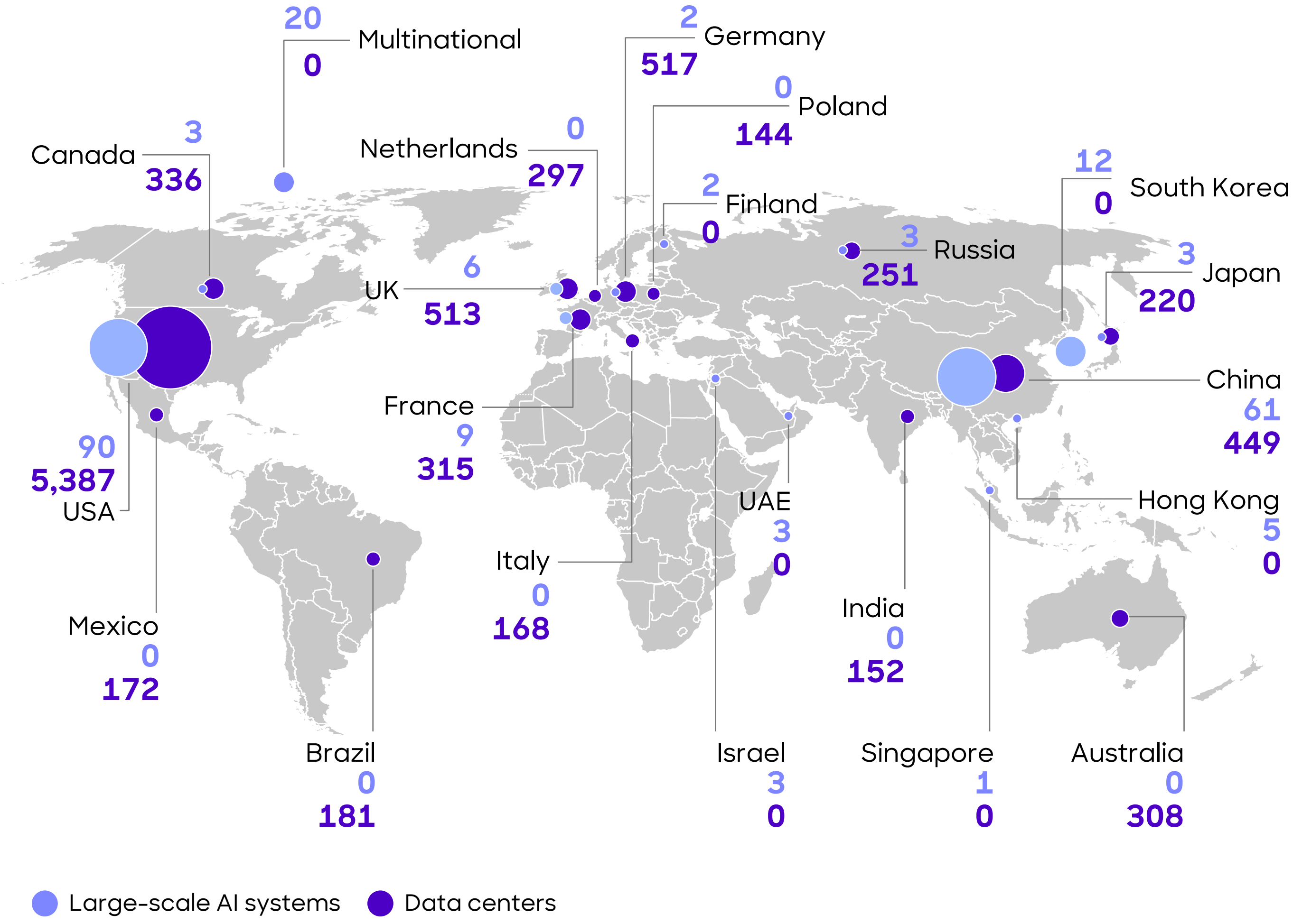
10 AI risks and how to effectively manage them

Risk		Solution
1 Bias	AI systems can inherit biases from training data, leading to unfair outcomes	Implement AI governance, use representative datasets, build diverse teams, and apply fairness metrics
2 Cybersecurity Threats	AI can be exploited for cyberattacks like phishing or identity theft	Develop AI security strategies, identify vulnerabilities, secure training data, and conduct adversarial testing
3 Privacy Concerns	AI may collect and process personal data without user consent	Inform users transparently, obtain consent, and use synthetic data where possible
4 Environmental Impact	Training large AI models is highly energy-intensive, leading to high CO_2 emissions	Optimize models for energy efficiency and use energy-efficient hardware
5 Lack of Transparency	"Black-box" AI systems make decisions difficult to interpret	Develop explainable AI models and provide decision rationales
6 Accountability Gaps	Unclear responsibility for AI system decisions	Establish clear accountability frameworks and monitoring mechanisms
7 Job Displacement	Automation by AI could lead to job losses	Invest in reskilling programs and promote roles that leverage human skills
8 Ethical Concerns	Applications like surveillance raise ethical issues	Create ethical guidelines and involve ethicists in AI development
9 Safety Risks	AI malfunctions could cause harm, e.g., in autonomous vehicles	Conduct extensive testing and implement safety protocols
10 Overdependence on AI	Excessive reliance on AI may erode human skills	Encourage human-AI collaboration and ensure humans retain critical roles

Source: IBM; Roland Berger

AI infrastructure is unequally distributed, with high costs and energy demands restricting global accessibility and sustainability

Distribution of large-scale AI systems and data centers and, 2024[1)]



- The **global digital economy is projected to grow to 26% of GDP** (USD 37 trillion) **by 2040** – driven by over 10,000 data centers currently in operation worldwide. However, this **infrastructure** is **concentrated in wealthy nations,** which control over 90%, while regions like Latin America and Africa hold less than 2%
- Key hubs include Northern Virginia, Silicon Valley, London, Frankfurt, Beijing, and Singapore. The **growing demand for massive computational power, driven by AI,** is further centralizing the data center infrastructure in established global hubs
- **Training advanced AI systems has become prohibitively expensive,** rising from thousands of dollars in 2016 to millions by 2023. These **costs limit participation in cutting-edge research** to nations with established digital ecosystems, reinforcing the dominance of wealthy countries and **widening the global digital divide**
- **Already today, data centers consume 2-4% of energy in large economies**; this is projected to reach **8% by 2030** in the US alone. In Ireland, data centers already account for over 20% of electricity use. This **demand is driven by the energy-intensive nature of AI systems,** posing significant challenges for energy sustainability. Given this sizeable impact, the question arises whether **future regulatory measures may be needed** to ensure a sustainable and responsible use of AI

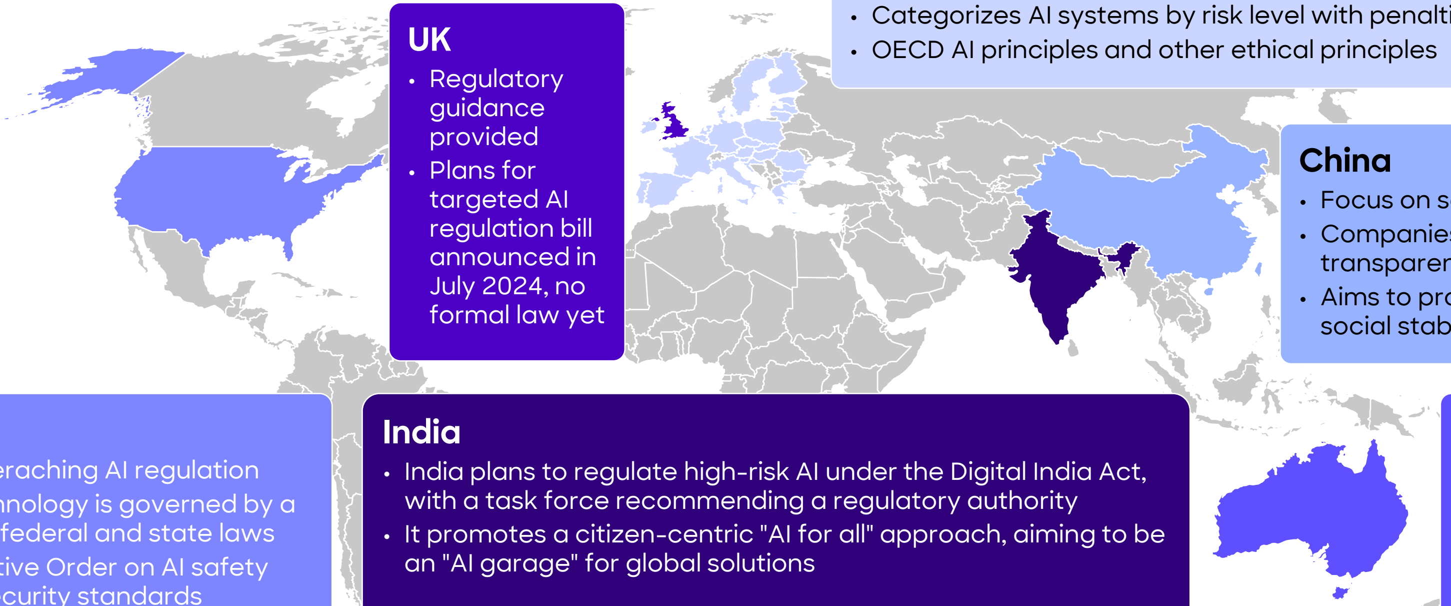
1) The map highlights countries with "large-scale" AI systems, defined as those using over 10^{23} floating-point operations for training

Source: Barclays; WEF; KKR; Roland Berger



AI regulations are a global hot topic – Frameworks and legislation aim to minimize risks and ensure safety and ethical standards going forward

AI regulation in selected countries



EU
- The EU's AI Act is the world's first comprehensive AI law
- Categorizes AI systems by risk level with penalties for non-compliance
- OECD AI principles and other ethical principles

UK
- Regulatory guidance provided
- Plans for targeted AI regulation bill announced in July 2024, no formal law yet

China
- Focus on security, ethics, and state control of AI
- Companies must register algorithms, ensure transparency, and protect data
- Aims to promote innovation while maintaining social stability and national security

USA
- No overaching AI regulation
- AI technology is governed by a mix of federal and state laws
- Executive Order on AI safety and security standards

India
- India plans to regulate high-risk AI under the Digital India Act, with a task force recommending a regulatory authority
- It promotes a citizen-centric "AI for all" approach, aiming to be an "AI garage" for global solutions

Australia
- Voluntary AI Safety Standard issued in 2024 focusing on transparency, accountability, and testing
- Legislative framework for high-risk AI under discussion to regulate critical applications and ensure safety

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- Over the past five years, **AI regulatory laws and frameworks have grown significantly,** aiming to protect individuals from potential AI risks while ensuring its safe integration into critical sectors such as healthcare, finance, and security
- **The OECD adopted ethical principles for AI in 2019,** which serve as the foundation for national regulations in many countries, while **G7 initiatives aim to harmonize AI rules and standards** with a focus on ethical AI usage. Moreover, **different countries pursue diverse regulatory strategies:** the EU emphasizes ethics and risk assessment, whereas the US adopts technology-neutral approaches
- **For the foreseeable future, companies around the world need to adapt to different AI regulatory environments,** especially if they operate internationally. This requires a careful and timely assessment of the respective legal requirements in the various markets

Source: Hamilton Locke; IAPP; Roland Berger

Corporate actions – Let's talk about challenges and opportunities arising from megatrends regarding technology & innovation (1/2)

5.1 Value of Innovation

5.2 Frontier Technologies

5.3 Humans & Machines

Conclusion and corporate impacts

Impact: Human capital is essential to master the innovation challenge – Education and culture are critical levers

Actions

- Human capital is the key lever to achieving a competitive edge in the innovation race. Companies should prioritize investments in workforce upskilling, ensuring the provision of lifelong learning opportunities within the organization, and making these training programs mandatory. Initiatives should focus on frontier technologies and methods and tools for innovation
- Equally important is fostering an innovation mindset throughout the workforce. Companies need to instill a culture of innovation in all departments, not just in R&D. Top management should lead by example. New hires should also be selected based on their commitment and ability to innovate. A diverse workforce can increase the potential to generate a wide range of ideas as the basis for innovation

Impact: A successful innovation model requires a sustainable innovation strategy, along with the right methods, sufficient investment, and a functioning ecosystem

Actions

- Companies should develop a long-term strategy that emphasizes the continuous development of innovations in products, services, and/or processes. This strategy should include the use of frontier technologies. This involves identifying relevant technologies and employing effective methods for generating ideas and testing prototypes
- Innovations require significant, longer-term investments. Companies must be prepared to allocate sufficient financial resources to R&D. Disinvesting is also a critical aspect when an innovation path becomes unfeasible. In short, active portfolio management is essential for maximizing returns on innovation investments
- Companies should consider leveraging external resources: an effective innovation ecosystem is instrumental in facilitating the exchange of knowledge and the development of novel solutions. Establishing and maintaining effective partnerships with suppliers, customers, start-ups, research institutions, and, when appropriate, even competitors can be instrumental in this regard

Learn how Roland Berger can help you to create corporate impact

Workforce transformation

Innovation Indicator 2024

Source: Roland Berger


5.1 Value of Innovation


5.2 Frontier Technologies


5.3 Humans & Machines

Corporate actions – Let's talk about challenges and opportunities arising from megatrends regarding technology & innovation (2/2)

Conclusion and corporate impacts

Impact: AI is here to stay – Companies must embrace and leverage artificial intelligence

Actions

- Companies need to embrace artificial intelligence as a transformative force. Integrating AI into core business strategies will enhance adaptability, innovation, and competitiveness in an increasingly AI-driven world
- Alongside, companies should foster human-AI collaboration. Implement training programs to ensure effective collaboration between employees and AI-powered systems, maximizing their potential while minimizing resistance to change
- It is vital that companies ensure regulatory compliance in this evolving field. When expanding into new markets, it is essential to address existing but also increasingly emerging AI regulations and data protection laws

Impact: AI and robotics drive efficiency and productivity – These technologies also reshape the workforce

Actions

- Companies need to assess their value chain to identify high-impact opportunities for generative AI, using tools such as the Roland Berger AI Readiness Radar to benchmark adoption against competitors
- Furthermore, companies should set clear strategic goals, define productivity benchmarks, and structure unstructured data to ensure AI effectiveness. Organizations can optimize existing AI models or develop custom models as needed
- Companies can also implement a targeted AI use case, evaluate and refine its performance, and scale it gradually across the organization while maintaining strict data security and privacy standards
- To mitigate job displacement, companies must support the transformation of their workforce. Investing in reskilling and upskilling initiatives is key to transitioning employees into new, value-added roles that leverage human creativity and forward-thinking decision making

Learn how Roland Berger can help you to create corporate impact

Think:Act Magazine: It's time to rethink AI

The new productivity booster: How companies can harness the potential of generative AI

Source: Roland Berger

Main sources

Megatrend - Technology & Innovation

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Source: Roland Berger

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