Megatrend 5
Technology & Innovation

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 expert sources and assessments.** Estimates reflect the normal case, i.e. a stable development of the global economy

> 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 there are such drastic global events as the Corona pandemic taking place?

Clearly yes! The Corona pandemic has far-reaching consequences and affects us deeply, all within a very short time – but in itself the pandemic does not set aside the megatrends here analyzed. Such is the inherent nature of megatrends: Climate change, the aging of society or the ongoing evolution of technology do not lose their overriding direction or importance. To cope with such challenges – and to master resulting opportunities – our awareness and understanding of these megatrends is paramount in order to develop sustainable answers

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

1 People & Society

- Population
- Migration
- Values
- Education

2 Health & Care

- Pandemics & Other Wildcards
- Diseases & Treatments
- Caregiving

3 Environment & Resources

- Climate Change & Pollution
- Resources & Raw Materials
- Ecosystems at Risk

4 Economics & Business

- Globalization Revisited
- Power Shifts
- Sectoral Transformation
- Debt Challenge

5 Technology & Innovation

- **Value of Innovations**
- **Frontier Technologies**
- **Humans & Machines**

6 Politics & Governance

- Future of Democracy
- Governance & Geopolitics
- Global Risks

Technology & Innovation

1
Value of Innovation

2
Frontier Technologies

3
Humans & Machines

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

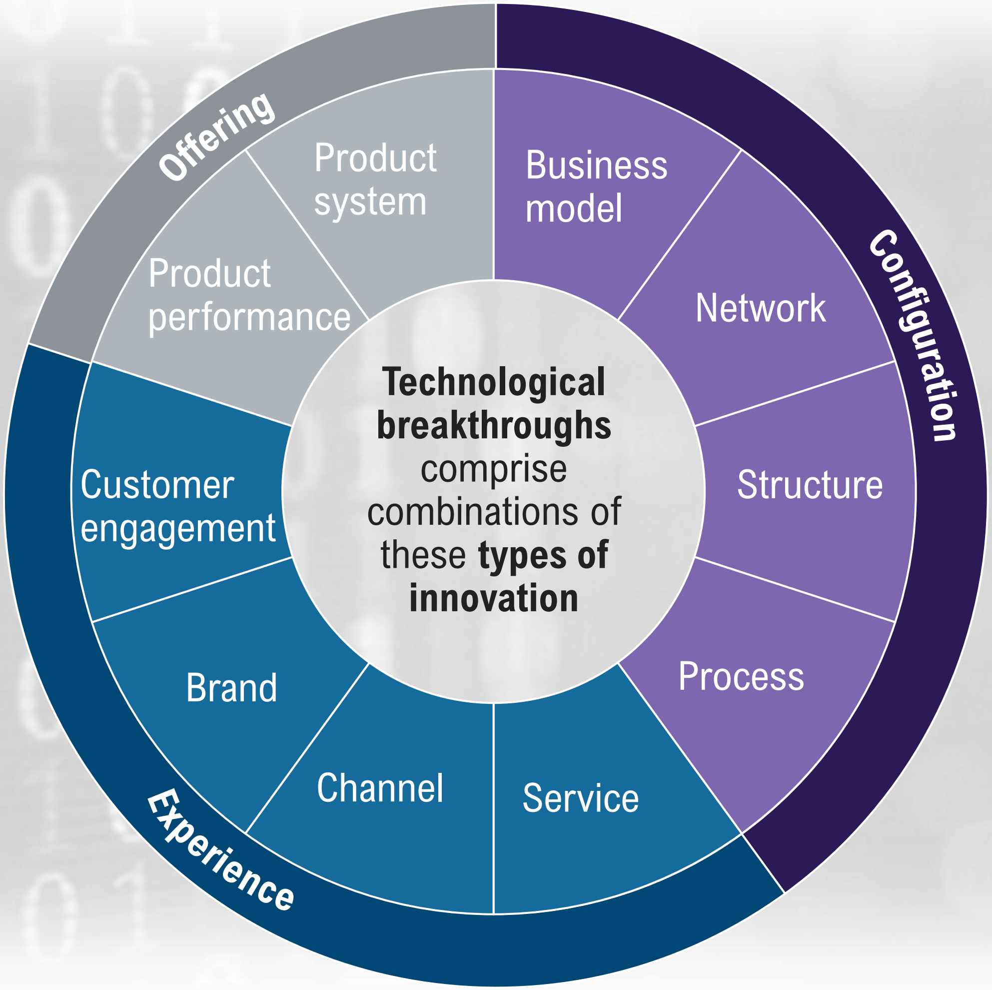
Frontier Technologies

3

Humans & Machines

Innovation combines value adding inventions with successful market penetration and are categorized into different types

Types of innovation



> Innovation is the process of **turning new ideas into value,** in the form of new products, services, or processes

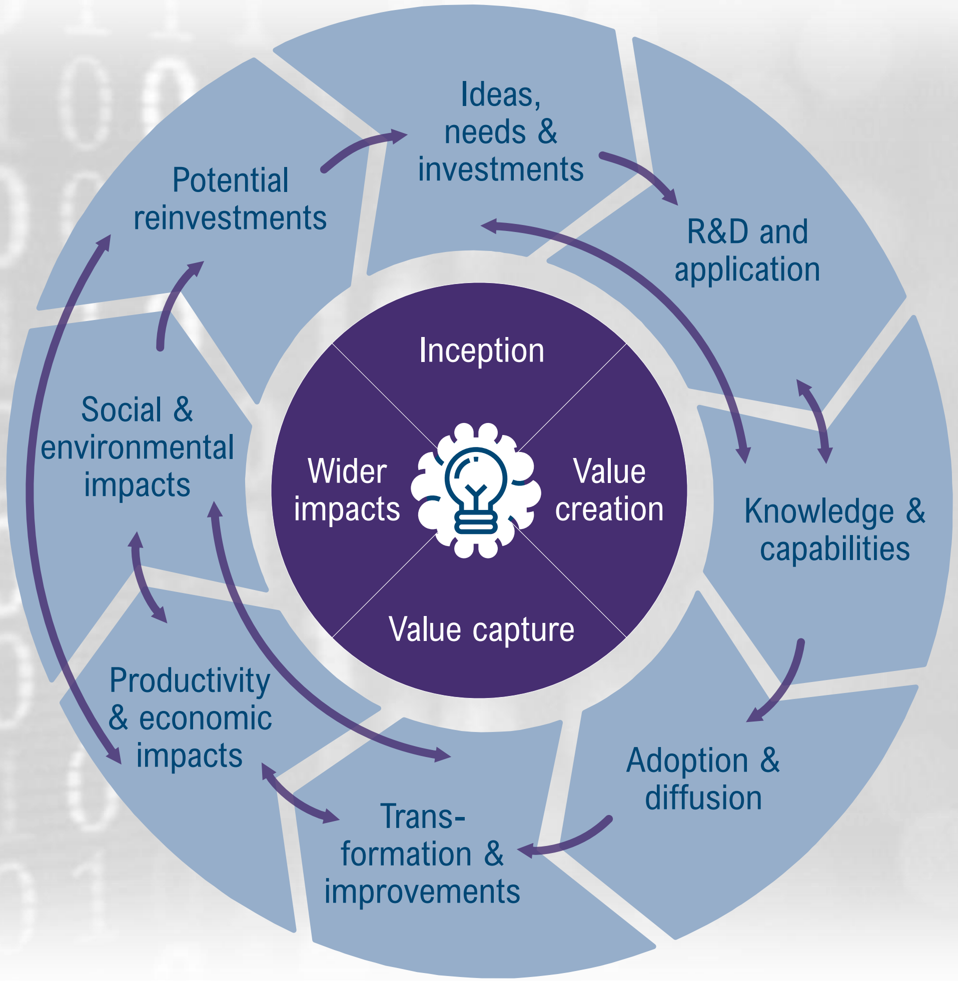
> It is deceptively complex and goes beyond mere creative inventiveness; **innovation** includes essential, practical steps to **facilitate adoption and market penetration**

> 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 innovations in other areas
- Innovations in **user experience** affect customers directly, such as public appearance or reputation of a company. Innovations in service, channels, branding and customer engagement fall under this category of innovations

Sources: WEF; Roland Berger

Technology and innovation are deeply entangled with economy and society – Successful technology asserts itself passing through the innovation cycle

The innovation cycle



- Innovation is to be understood as a **dynamic process** that touches on several **economic** as well as **societal** aspects
- Innovation is driven by different factors and can therefore be considered from **different perspectives**: From a firm-based view, innovation promises competitive advantage, higher profits, and an enhanced reputation. Such **incentives stimulate ideas and investment** aimed at maximizing a rewarding outcome
- Any innovation in the form of a new technology will only **gain widespread acceptance, adoption and diffusion when adding significant value for a range of customers** and across society. Positive feedback incentivizes future research and (re)investments in order to develop technologies further
- On a macroeconomic scale, **innovative industries** bring about **higher productivities and prosperity**. A country's intrinsic ability to innovate is due to complex, interwoven factors – it is a sign of **national competitive advantage**

Sources: Csiro; Roland Berger

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

Global Innovation Index (GII) rankings overall and by pillar, 2021[1)]

Country	GII (overall)	Institutions	Human capital and research	Infra-structure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creative outputs
Switzerland	1	13	6	2	6	4	1	2
Sweden	2	9	2	3	11	1	2	5
US	3	12	11	23	2	2	3	12
UK	4	15	10	10	4	21	10	4
South Korea	5	28	1	12	18	7	8	8
Netherlands	6	6	14	16	31	5	7	7
Finland	7	2	4	11	19	6	5	16
Singapore	8	1	9	15	5	3	13	17
Denmark	9	8	5	5	7	11	14	13
Germany	10	17	3	21	20	12	9	11

> To capture and **compare a country's ability to innovate**, a **broad spectrum of essential enabling factors** such as institutions, infrastructure, markets, knowledge base, etc. needs to be considered

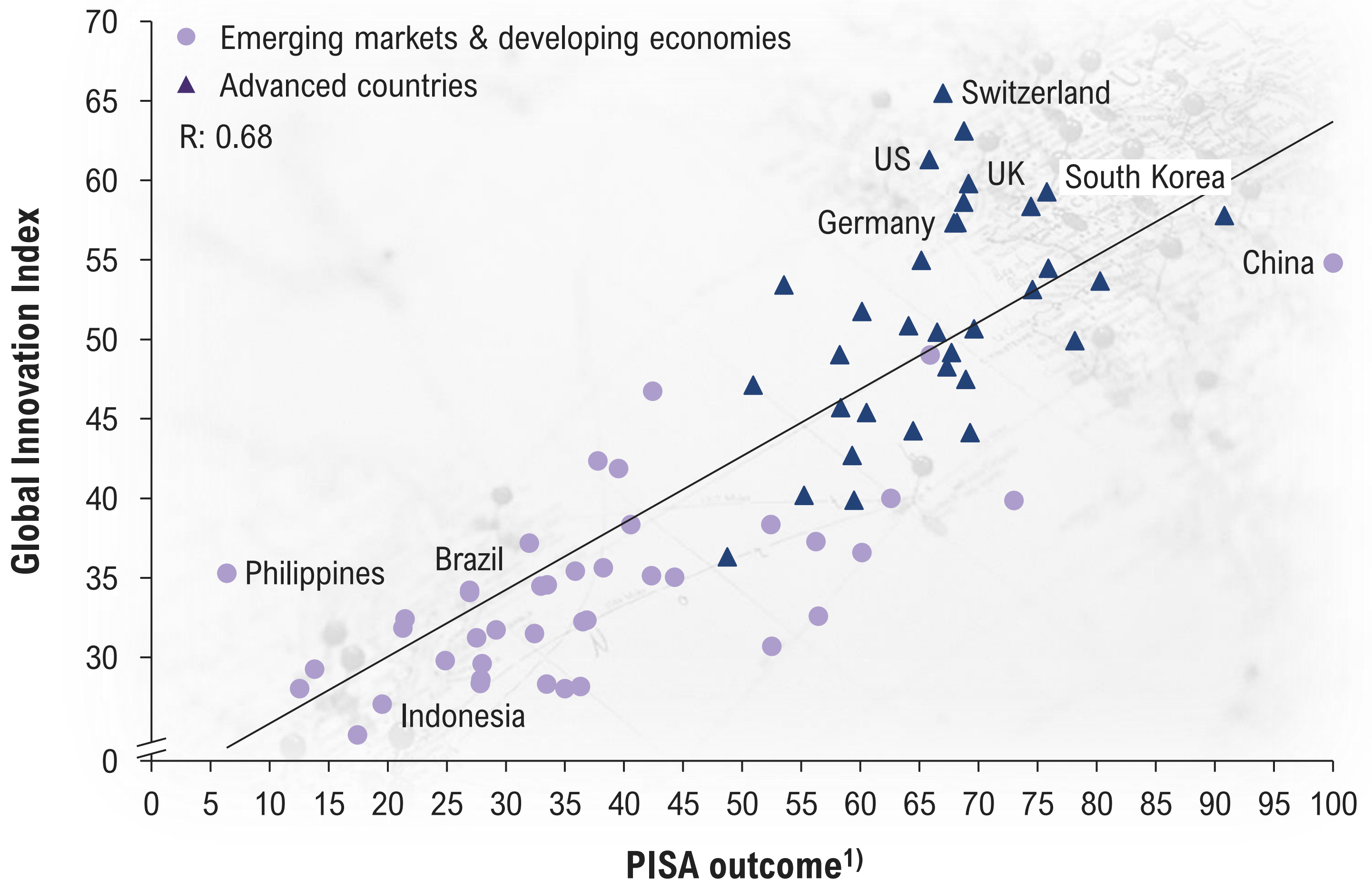
> When comparing countries, **advanced economies are leaders of innovation**. They provide best possible conditions for firms to invest in new technologies as well as considerable markets for new innovations to diffuse

1) The pillars of the GII are measured in the following categories: Institutions: Political environment, Regulatory environment, Business environment; Human capital and 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 and technology output: Knowledge creation, Knowledge impact, Knowledge diffusion; Creative outputs: Intangible assets, Creative goods and services, Online creativity

Sources: WIPO; Roland Berger

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

Global Innovation Index 2021 plotted against average PISA outcome 2018 (China = 100)



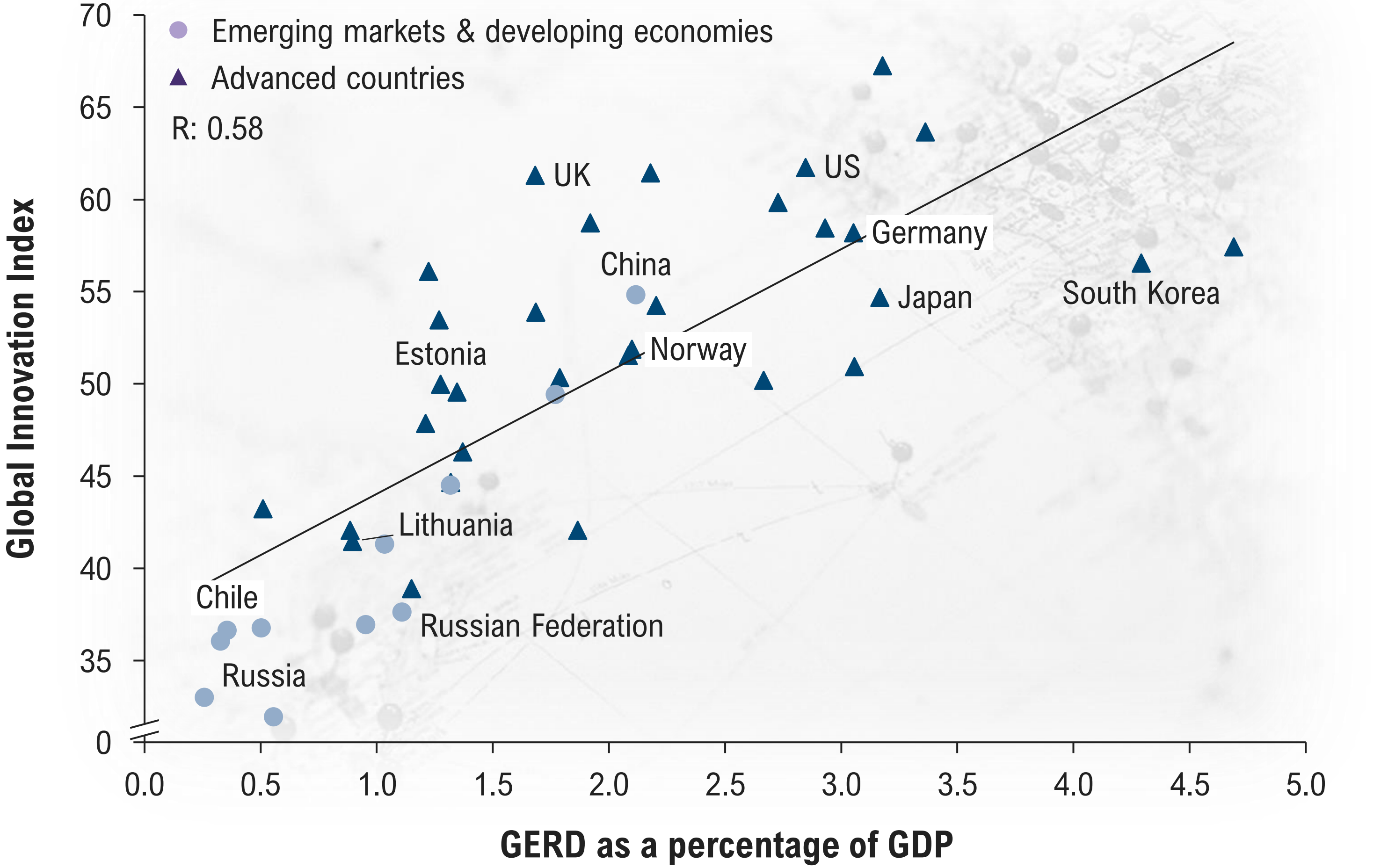
- Innovation has several driving factors, an important one is its **educational base** – a country's educational provision
- For innovation to occur, **high quality human capital is required** that is capable of **thinking beyond the limitations of existing technologies**, transforming ideas creatively into reality
- Economic growth models imply that countries with **better educational systems** experience **better abilities to innovate**
- Empirically, countries that obtained a **higher outcome** value in the **2018 PISA** study have, on average, a **higher** value in the **Global Innovation Index**
- Hence, improving a nation's **future innovation capabilities** starts in the classroom, **requiring best possible educational resources** and 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 China's outcome (China = 100) in 2018 and were edited as such by WIPO

Sources: WIPO; Roland Berger

… as well as investment in R&D – A quintessential factor for best-in-class innovation, expenditure levels signal trust in future promise

Global Innovation Index 2021 plotted against Gross Expenditure in R&D (GERD) 2019

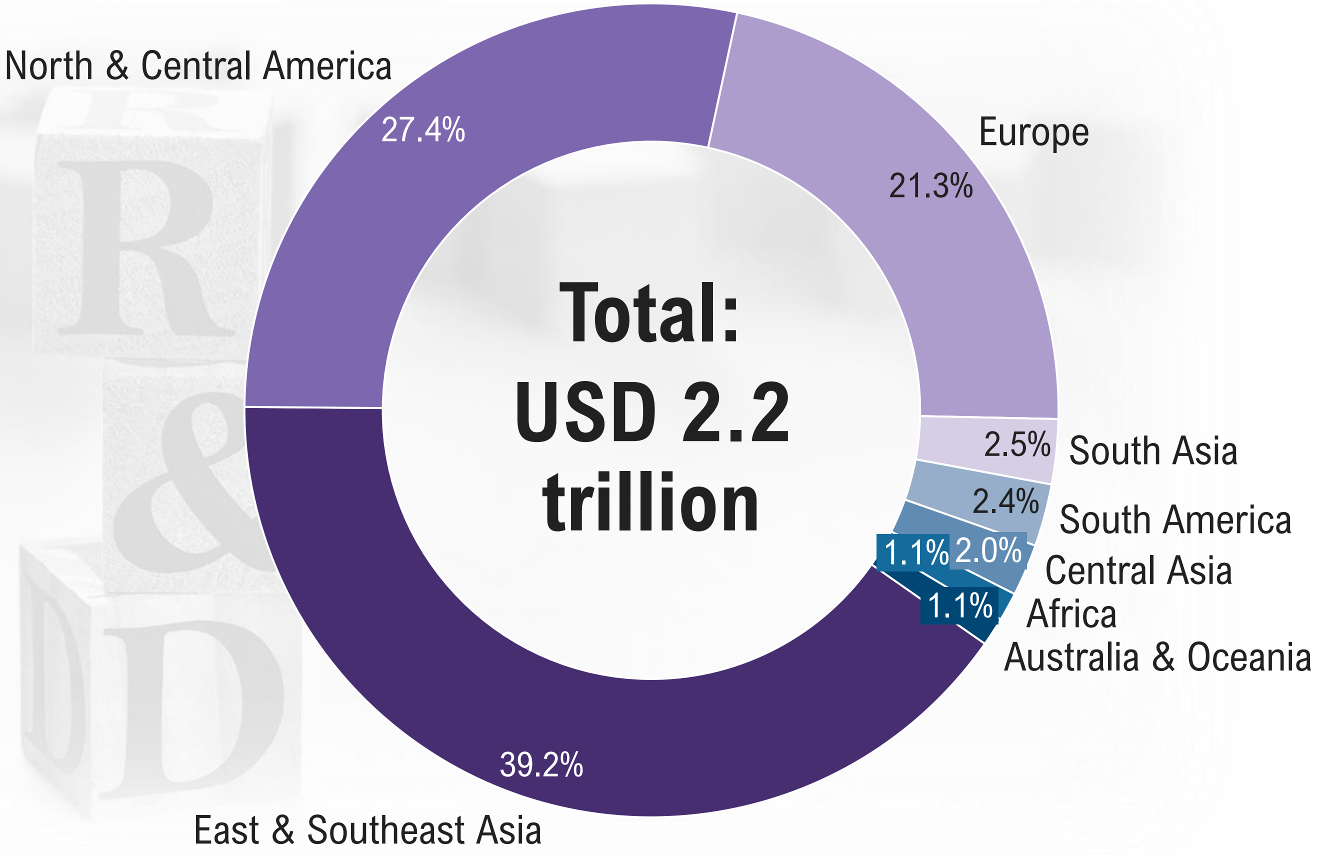


- Devoting capital to **R&D** seems as obvious as it is **essential** for a country to remain or become more innovative
- **Innovation processes are resource consuming** and subject to insecurities such as failure and sunk-costs
- However, R&D investment and innovation are positively correlated – **funding and fostering innovation confers future rewards**
- Considering the process on a microeconomic level, investment decisions signal **expectations regarding the impact of innovation** and **potential future returns:** Highly-funded innovative ideas herald future promise to stakeholders and **trust in the process of innovation** to be completed successfully

1) Here, we use the GII results from 2019, since GERD were available for the latest year of 2019
Sources: WIPO; OECD; Roland Berger

Regionally, R&D expenditure is highly unbalanced – Investment gaps between the Global North and South highlight innovation underperformance

Share of global R&D expenditure, by region, 2017 [%]



- **R&D expenditure** differs between countries, but **are particularly striking when aggregated by region:** Differences in **levels of income** between the Global North and South determine the latter's **potential ability to invest in R&D**
- Poorer countries in the regions of the **Global South** in Africa, South America and South Asia are trapped in **an innovation underperformance cycle**: **The less money** (available to be) **invested in R&D, the lower the abilities of a country or region to innovate** – resulting in less innovative firms, lower profits and less prosperity that can be derived or shared from technological advances
- This **vicious cycle of lack of R&D funds** and subsequent innovation underperformance also defines aspects of the so-called **poverty trap**, describing a knock-on effect mechanism that – ultimately – makes it very difficult for such nations to escape poverty
- In 2017, almost **USD 2.2 trillion were invested globally in R&D**, compared to USD 722 billion in 2000. This threefold increase highlights the growing importance of inno-vation for economic stability and prosperity

Sources: NSF; Roland Berger

Technology & Innovation

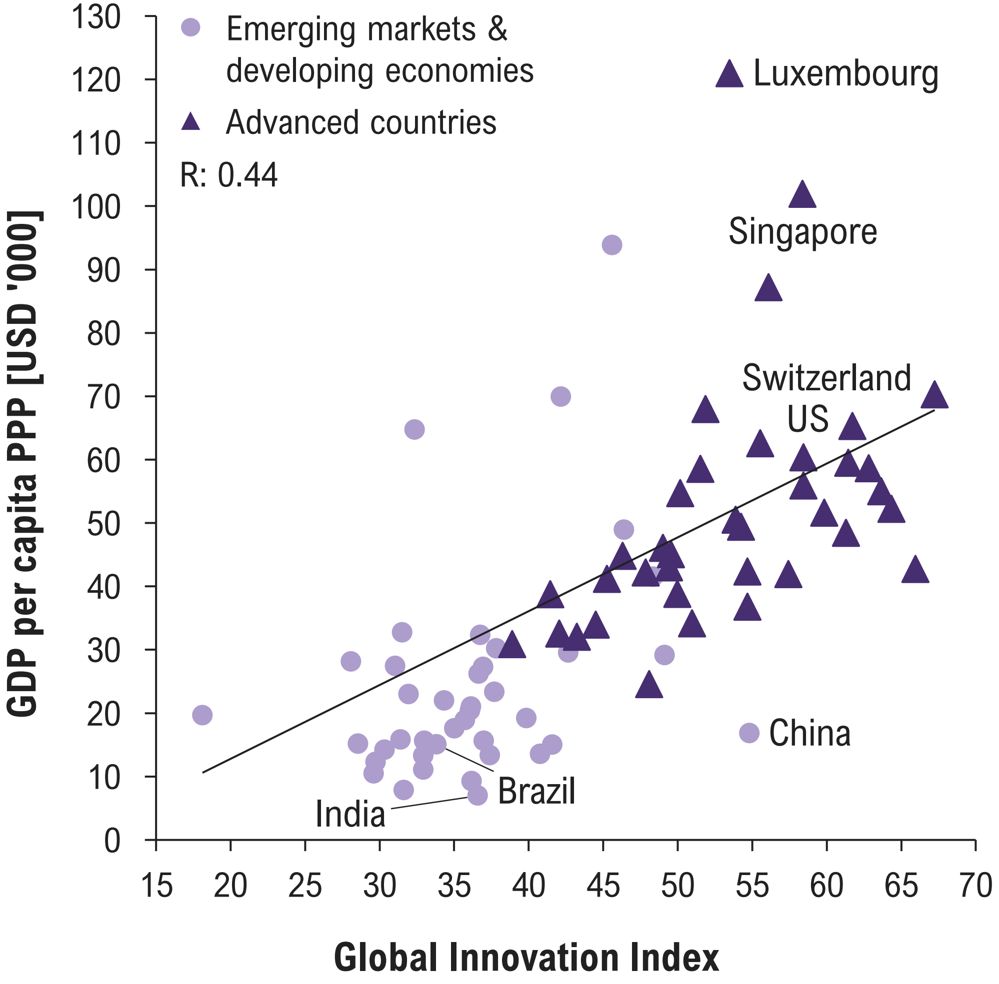
1
Value of Innovation

2
Frontier Technologies

3
Humans & Machines

Technological innovation and prosperity are highly interconnected – Lack of either factor is mutually disadvantageous

Global Innovation Index related to GDP per capita PPP, 2019[1)] [USD]

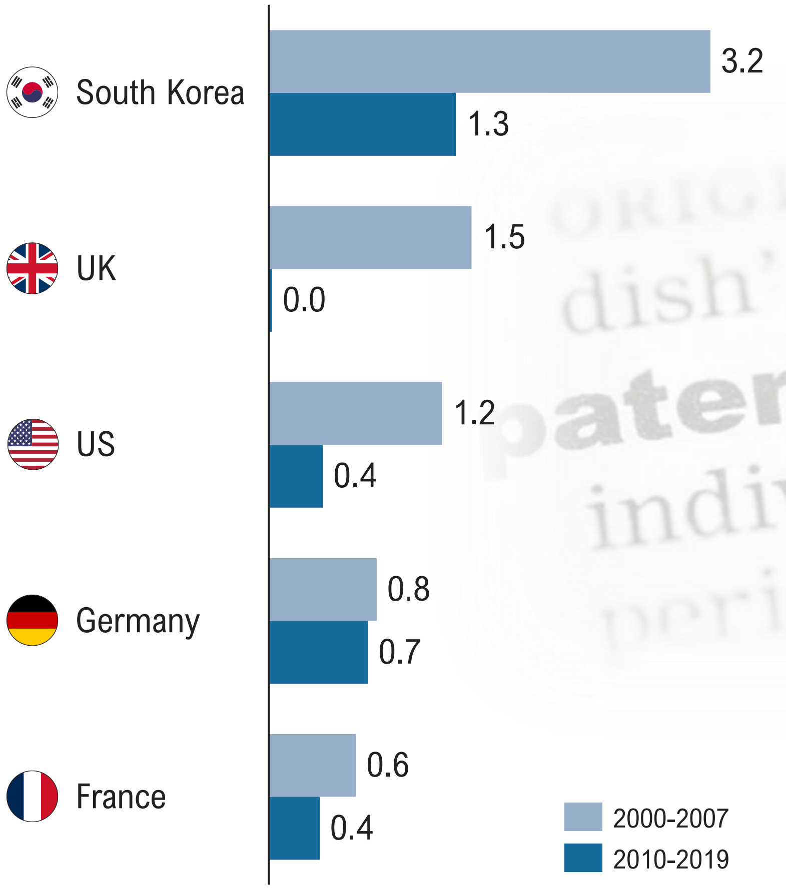


- A nation's ability to innovate is an essential engine of **productivity, growth and prosperity**
- Evaluating the Global Innovating Index from a GDP perspective, the correlation is clear**: The higher (lower) countries score on innovation, the higher (lower) their GDP per capita**
- **China is an exception** in **having successfully built up its innovation strength,** yet the country has a **comparatively lower GDP per capita** – largely due to relatively lower levels of income among a sizeable rural population
- In the long run, the relationship between the **development of innovation and prosperity is reciprocal:** Nations require a certain level of wealth to invest into R&D. However, a distinct ability to innovate also leads to higher levels of income
- Many **developing countries lack access concerning skills, investments and institutions** to close the technology-innovation gap. Factors such as established networks of higher education and research institutions as well as significant numbers of technology companies involved in leading-edge R&D – both evident in developed countries – are notably absent
- Further evidence of this gap is found in number of articles published in scientific and technological journals: In 2018, in the **least developed countries only 11 articles** were **published** per million people whereas in **OECD** member countries, the comparative number was **1,048**

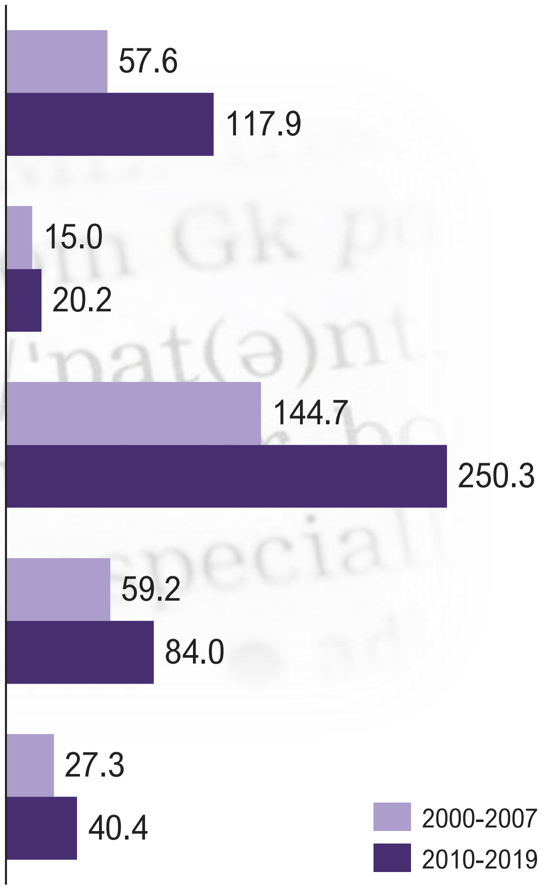
1) World Bank GDP per capita, PPP, current international USD
Sources: WIPO; World Bank; UN; Roland Berger

Developed countries are faced with a productivity paradox: Although innovations are rising, contributions of productivity to GDP growth decline …

Average GDP growth contributions by multifactor productivity[1)] [percentage change at annual rate]



Average patents granted by country and year[1)] ['000]



> The **productivity paradox** describes the seemingly counterintuitive development in which the **contribution of productivity to GDP growth decreases even though technology advances**

> This "more innovation, less productivity" observation is evident in **many developed countries**, and is attributed to several factors:
- Today's **technological breakthroughs** pale into relative **insignificance** compared to past transformative innovations
- Adjustment lags: While the pace of innovation has not slowed down, **adoption requires progress synced with organizational and business model changes**
- **Technology diffusion** breaks down
- **Structural challenges**, such as demographic change and a **shift towards the comparatively less productive service sector**

1) 2008 and 2009 data omitted due to the global economic recession
Sources: OECD; WIPO; MIT Technology Review; Roland Berger

Technology & Innovation

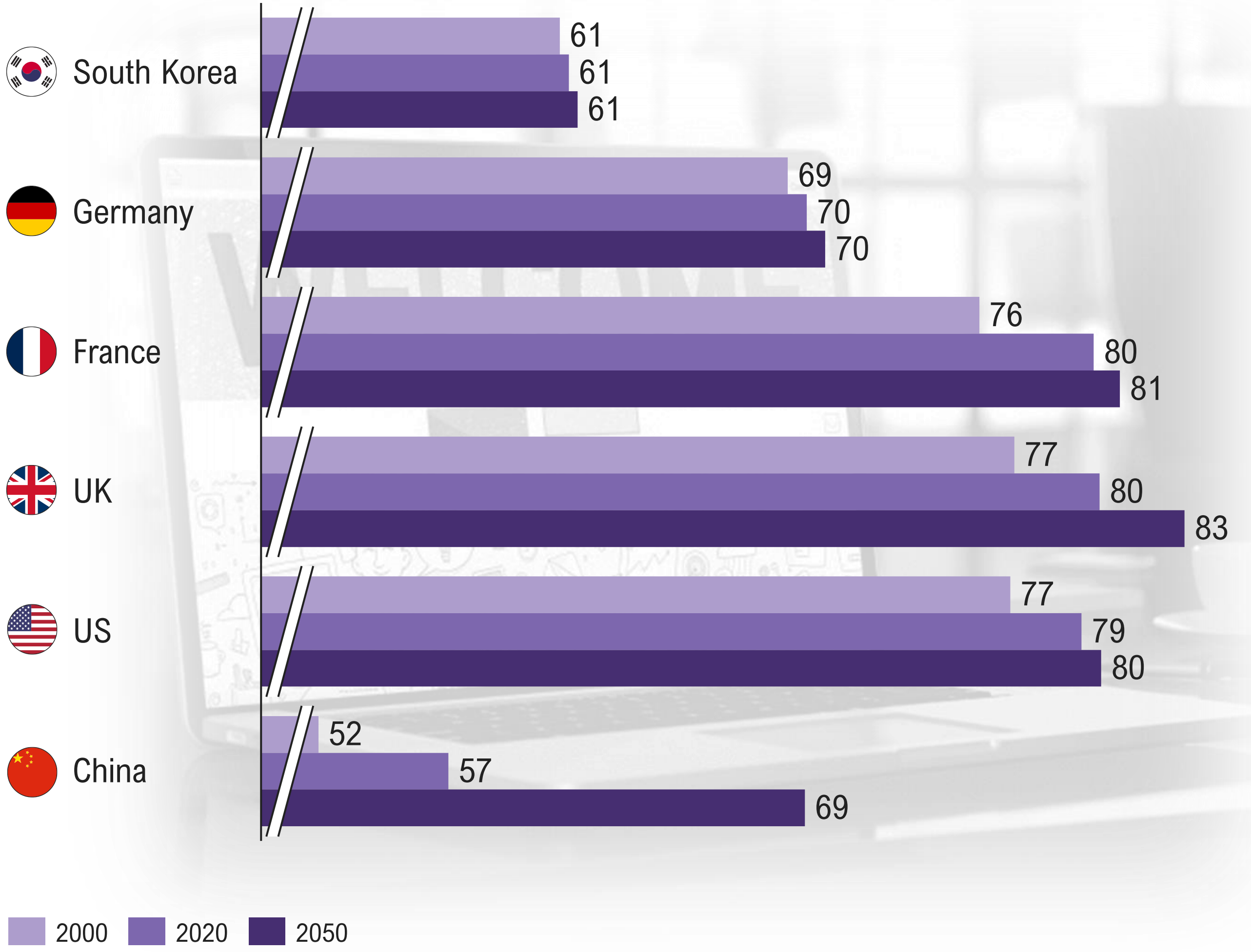
1 Value of Innovation

2 Frontier Technologies

3 Humans & Machines

… potentially leading to a higher decoupling of innovation and economic growth in the future – Structural trends include services shift

Services' share of Gross Value Added (GVA) of total GVA [%]



Sources: Oxford Economics; IMF; Roland Berger

- The **services sector** is, in general, **more labor intensive**, when compared to the **manufacturing sector**, with **the latter** being comparatively **more likely to experience productivity-increasing innovations**
- The **global economy broadly shifts** away from manufacturing **towards services.** Already evident in **developed economies**, **services as a share of total GVA have reached high levels**; herein, the UK, the US and France display exceptionally pronounced shares compared to other countries
- In the long run, the observed **decline of productivity growth** can partially be explained by such **structural changes**, that – in the main – are affecting developed countries but will also affect emerging countries such as China
- But not all services are created equal: **Modern services** (broadly understood as ICT enabled services where proximity of buyer and supplier is not a key factor) are **able to increase their levels of productivity through technological innovations**; they are also considered to be more crisis resilient compared to traditional services

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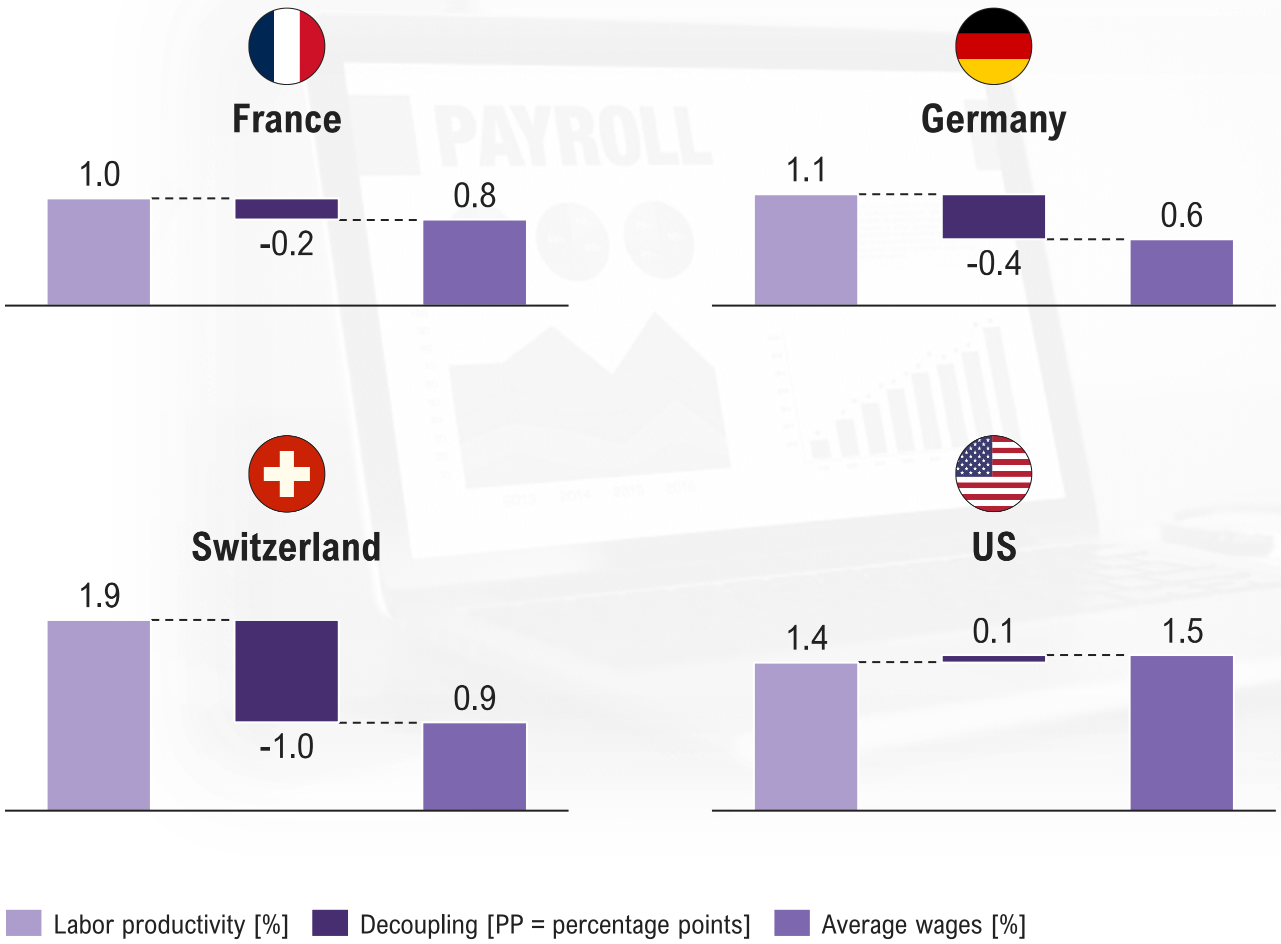
Growth rates of labor productivity and real labor income are also decoupling – More innovation does not translate to an equivalent rise in wages

Average annual growth rates of labor productivity and average wages, 2010-2019 [%, PP]



- The **decoupling of average wage growth from average growth of labor productivity** can be explained by two effects: The expansion of the global supply chain (putting pressure on wages) and – of primary interest in this context and analysis – the **technological change**
- Underlying macroeconomic mechanisms imply an **increased competition between technologies and workers**, especially low skilled workers
- On the one hand, **new technologies can displace labor**, implying that increases in average wages remain below labor productivity gains
- On the other hand, **new technologies create new jobs**. This implies a higher demand for workers – leading to increases in average wages above average labor productivity gains
- As the nature of technological progress evolves, the **balance between labor displacement and job creation is exposed to shifts**
- Especially the **advent of ICT is likely to have tipped the balance towards labor displacement**, leading to a declining demand for labor, and thus to a decoupling of the growth of average wages and average labor productivity

Sources: OECD; ILO; Roland Berger

High levels of investments made by leading countries confirm that technology remains central to their economic growth

Leading countries: Selected investments in frontier technologies

To build a national network of **500,000 charging stations by 2030 in the US,** President Biden's USD 1 trillion infrastructure investments plan includes a **USD 174 billion investment in the EV market**

EU is to invest **USD 10.9 billion** (2021-2027) in digital transformation, including **AI, supercomputing, cyber-security** and **digital skills**

France plans to invest more than **34 bn USD** in the **next 5 years** in nuclear reactors and semi-conductor plants

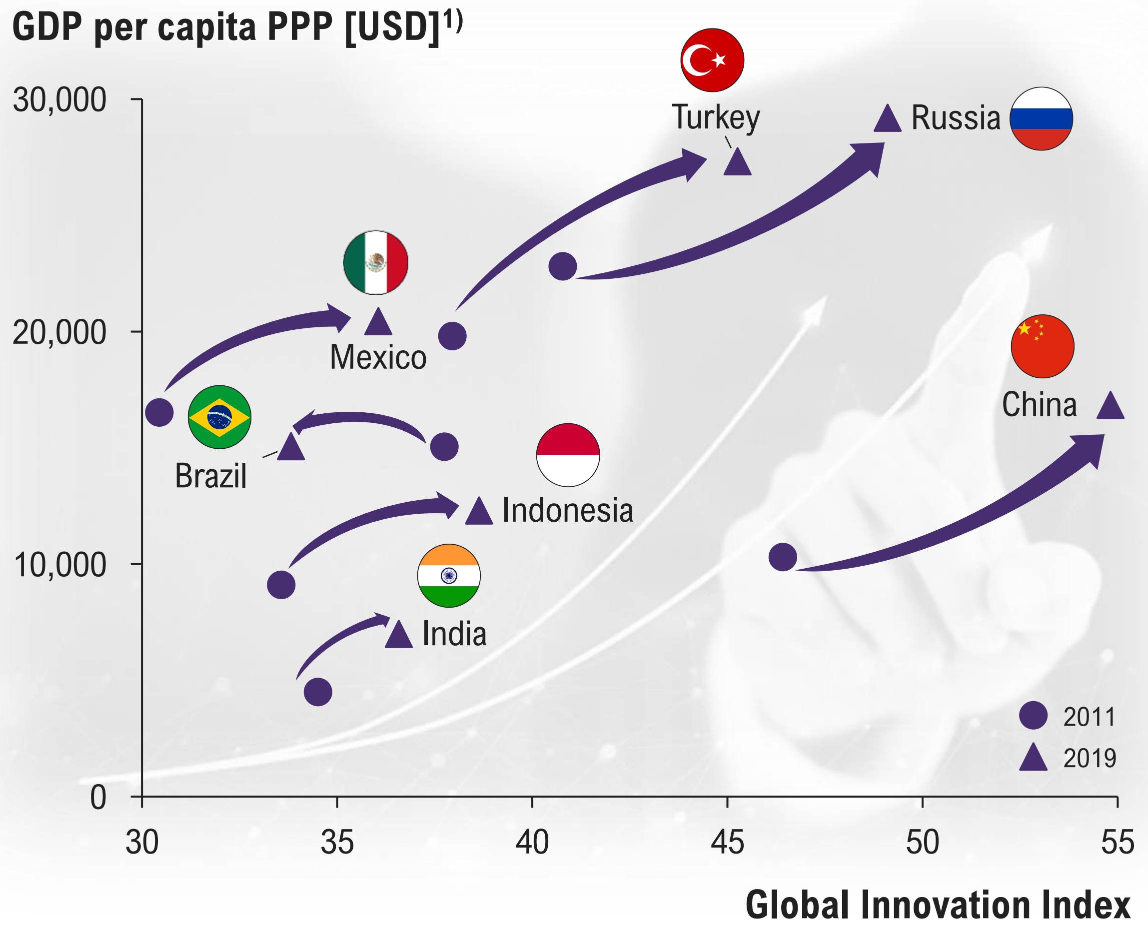
Part of a larger post-COVID stimulus package, **Germany** is planning to invest **USD 2.4 billion** in **quantum technology**

China has announced an investment of **USD 1.4 trillion** by **2025** to develop **AI** software and for the installation of **5G** networks

Sources: Bloomberg; NY Times; CNN; European Commission; BMF; IDC; Roland Berger

For emerging countries, boosting innovation enables per capita GDP growth to become intrinsic and sustainable

Global Innovation Index plotted against GDP per capita, 2011 and 2019 [index, USD]



- Economic growth can be sustained by multiple factors, such as a country's **natural resources** supplying global markets, or by the strength of its labor market in terms of **human resources**
- Such **factors** are faced with crucial limitations – they are almost always **finite**, and any growth derived is therefore **not sustainable**
- **Sustainable, long-term growth is achieved through technological progress and innovation**. This holds true especially for most of the emerging countries that – compared to developed countries – have been experiencing significant economic growth
- Under this consideration, it becomes apparent that their growth is linked to an **increase in their ability to innovate**. Almost all of these emerging countries have moved up along the prosperity-innovation scale: While their **GII value increased, GDP per capita income rose, too**
- **Brazil** appears to be an **exception,** displaying a lesser GII value and a near static GDP per capita development
- For **emerging countries** to catch up with developed countries, **it is essential to maintain momentum** and reinforce the dynamics that started this journey of innovation. Competing on price may defeat this goal – quality of products and services increasingly support abilities to innovate in the longer term

1) World Bank GDP per capita, PPP, current international USD

Sources: WIPO; The World Bank; UN; Roland Berger

In the future, emerging countries have the potential to maintain their momentum – A combination of factors supports this development

How emerging countries (can) increase their technological competitiveness

Technological competitiveness

1. For an **emerging economy being relatively close to developed markets is an advantage**, also in terms of FDI. Equally, **similarities promote closer ties**: Stabler political conditions, including declining levels of corruption, relative ease of doing business, openness of markets and low tariffs as well as infrastructure improvements **increase attractiveness to investors**

2. **Capital inflows bring technologies that are new to emerging economies**. Newly-created production hubs can act as an incentive for local companies to imitate or adapt such technologies. Over time and beyond mere job creation, investments necessitate a strong(er) educational base

3. The **FDI stimulus boosts the local economy, breaking open aspects of the poverty trap while laying foundations for a wealthy middle class to emerge and grow.** Savings levels rise, allowing for investments in education or business and commerce; in turn, public revenue increases

4. **Building up sectoral supply chains attracts further investments.** The economy depends less on external influences and companies; spillover-effects add further benefits

5. In order **to transform an emerging country from a (global) production hub into a competitive innovation leader**, governments need to **incentivize investments** in new technologies **through subsidies, tax incentives and stable governance; robust educational systems** play a significant role in maintaining future progress and technological competitiveness

Sources: World Economic Forum; Voxeu; IGC; Roland Berger

In emerging countries, ongoing investment in cutting-edge technologies are facilitating future economic growth

Emerging countries: Selected investments in frontier technologies

As the fastest growing sector in **Indonesia**, its **digital economy** is predicted to **reach USD 124 billion by 2025** up from USD 44 billion in 2020 – almost exclusively **driven by private investment**

Under **Thailand's Industry 4.0** digital economy plans, **investment** in digital and new technology infrastructure is expected **to rise by 20.5% to more than USD 6.6 billion** and up to USD 8.4 billion in **2022**

To increase **Kenya's share of renewable** energy on total energy supply **to 80% by 2030**, investments of **USD 30-50 billion** are planned

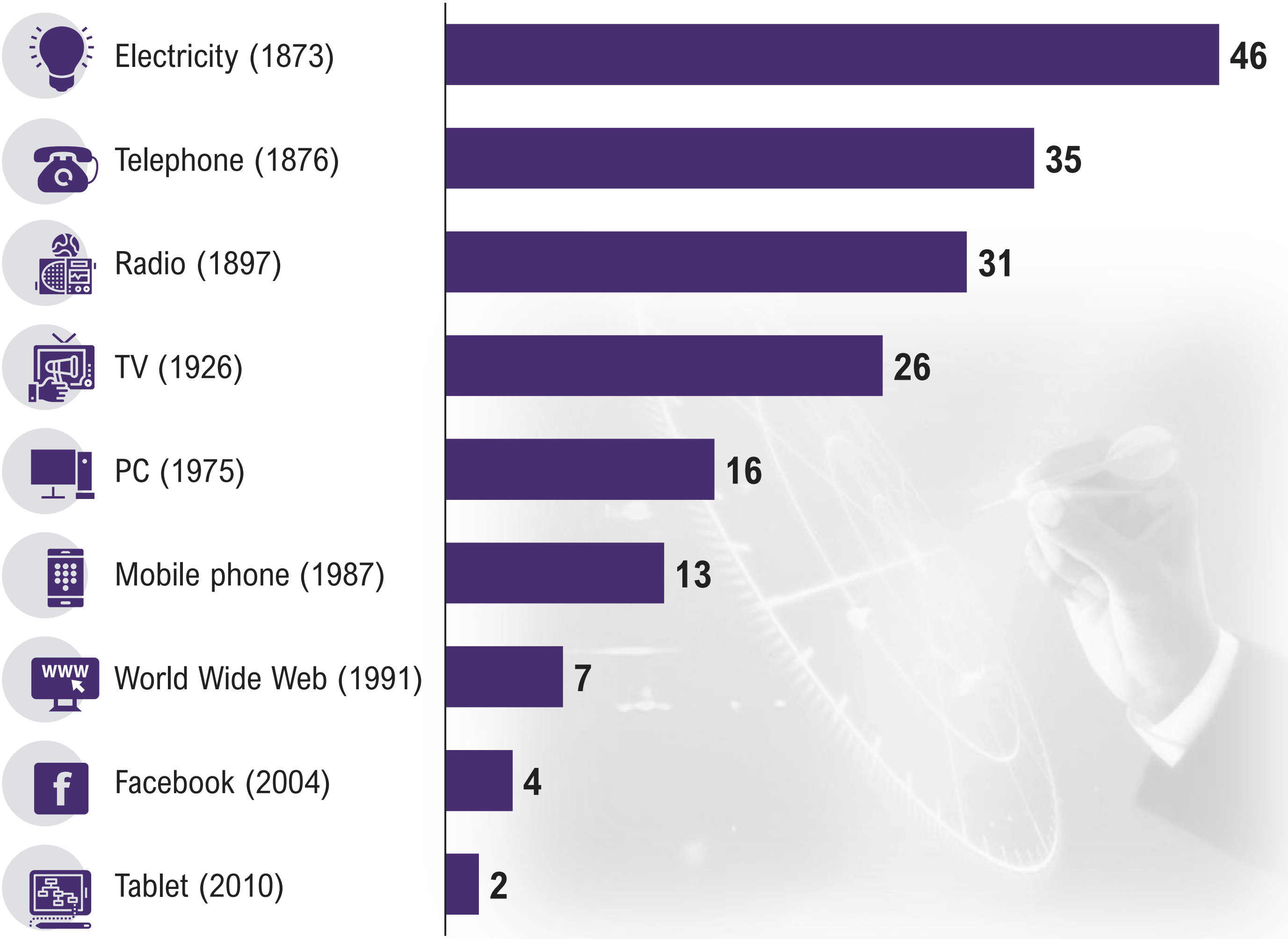
Saudi Arabia has allocated USD 500 billion to launch NEOM, a fully automated high-tech hub and free trade zone, including zero-carbon city The Line, which is expected to add **USD 48 billion** to its GDP **by 2030**

Malaysia's 2021 federal budget allocated over **USD 242 million** for a new **Industry Digitalization Scheme** to focus on **Industrial Revolution 4.0** technologies, with a view to accelerate activities to **2023**

Sources: KfW; WEF; ORF; Roland Berger

Adoption of technology has gained speed – Technological innovations manifest more readily while having a stronger than ever impact on society

Number of years until 25% of US population adopted technology after year of invention



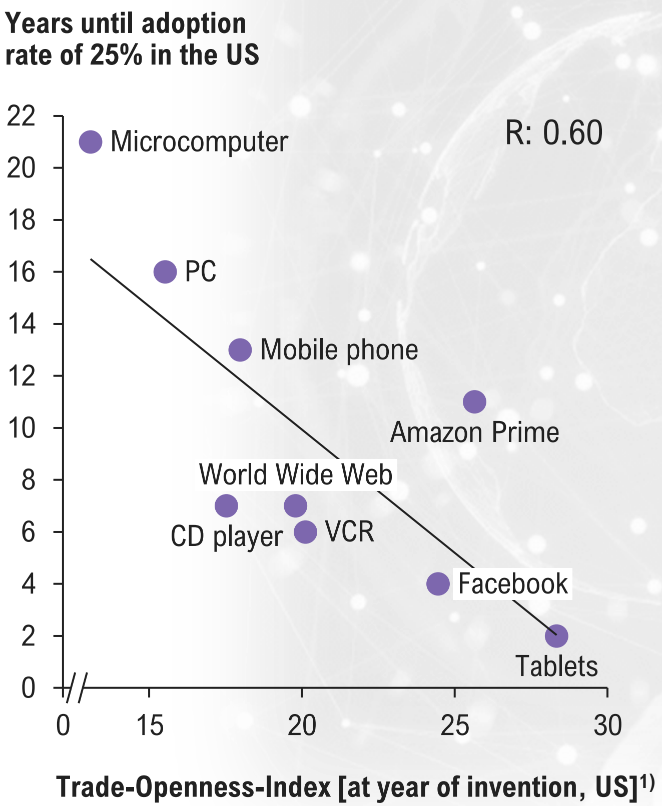
- According to the OECD, **innovation is the most important contributing factor to long-term economic growth**
- For innovation to unfold its wider impact on economic growth, **it is crucial that the technology diffuses through the economy** and is readily adopted by users
- Interestingly**, time of adoption has been speeding up:** While electricity, invented in the late 19th century, took nearly half a century to be used by one quarter of the American population, it only took two years for tablets (launched in 2010) to reach a comparable adoption rate
- Different technological inventions are hard to compare since their impact on society and the economy almost always differ – however, the **increasingly dynamic pace is notable**
- The faster rate of (new) technology adoption implies that the impact of innovation on economic growth, but also on the society, is **gaining in intensity**. The speed also reflects a faster than ever changing world

Sources: Pew Research; OECD; Roland Berger

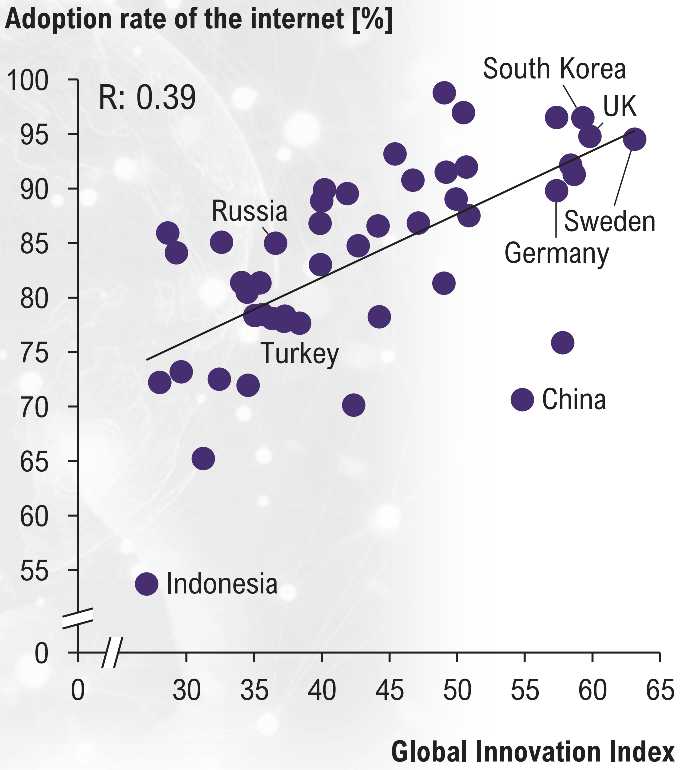
Historically, rates of adoption of innovations have been facilitated by globalization – Network effects strongly influence pace of adoption

Globalization and network effects foster technology diffusion

Trade Openness Index related to years until adoption rate of 25% of US pop. [index, years]



GII related to Internet adoption rate for selected countries [index, %]



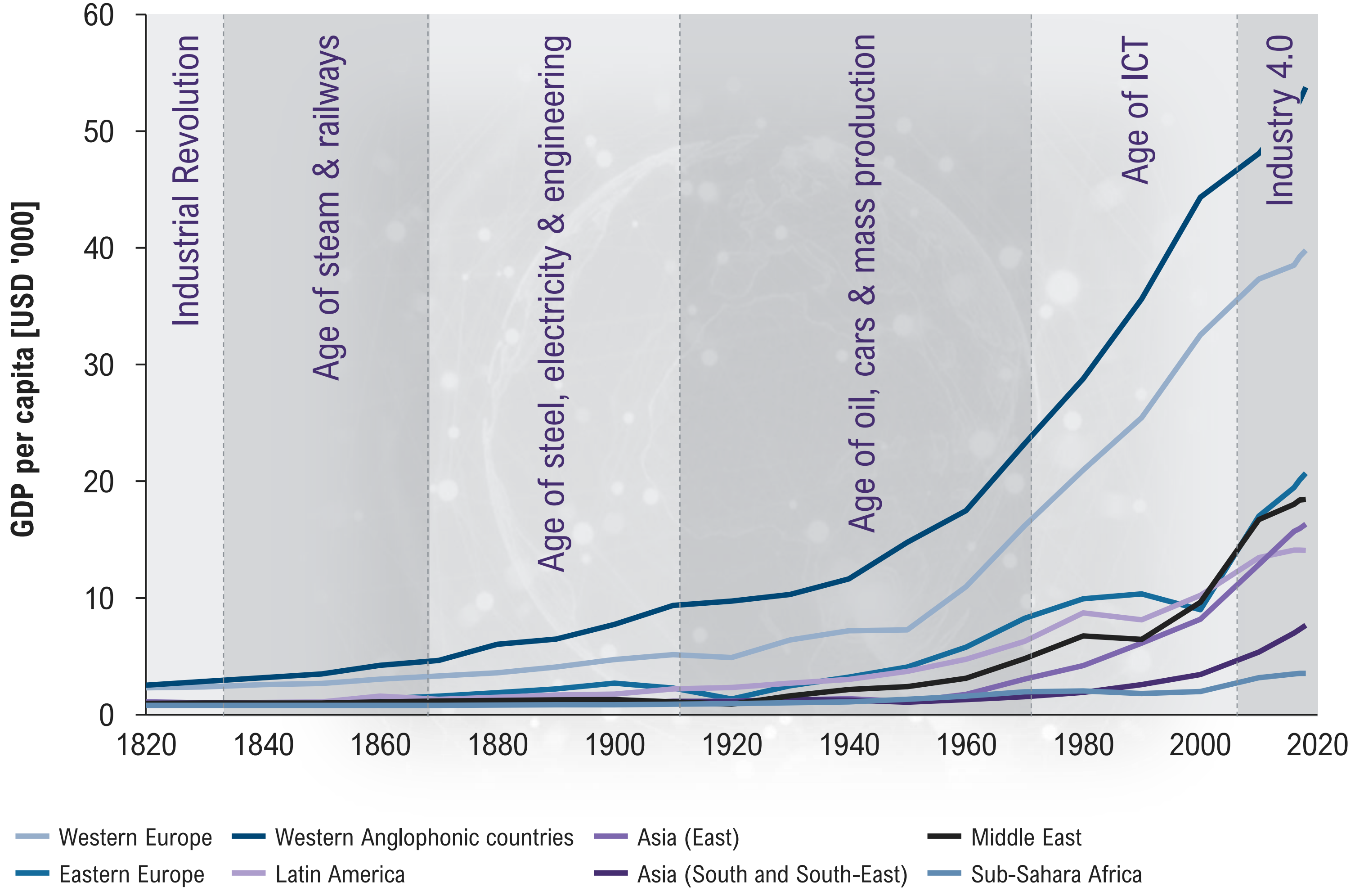
- > The rate of adoption of innovations is profoundly linked to **networks** and societal **interactions**, particularly if technologies become more useful when used by the many – often beyond their original or intended purpose. Such technologies are said to benefit from **network effects**. A prime example is the Internet, originally only used by the military and academia
- > **Globalization** – fostering interactions – represents one of the **main drivers** of the observed **acceleration in innovation adoption**. Empirically assessed, the higher the Trade Openness Index (a measure of globalization), the faster the rate of adoption of technology
- > Due to so-called **Slowbalization**, which describes a **decrease in the dynamics of globalization of the last decade**, the development of faster technology adaption might have come to an end
- > It is also important to consider **network effects** to such an extent that **further diffusion to other technologies** takes place. Where technological development is already more advanced, technological innovations are adopted faster

1) The Trade Openness Index relates the total values of imports and exports to the GDP of a country in a specific year [%]

Sources: Pew Research; OurWorldinData; World Bank; ITU; WIPO; Roland Berger

Technology has been changing our world for centuries – Prosperity first arose in places of technological inventions and innovations

Development of technological breakthroughs and GDP per capita [USD]

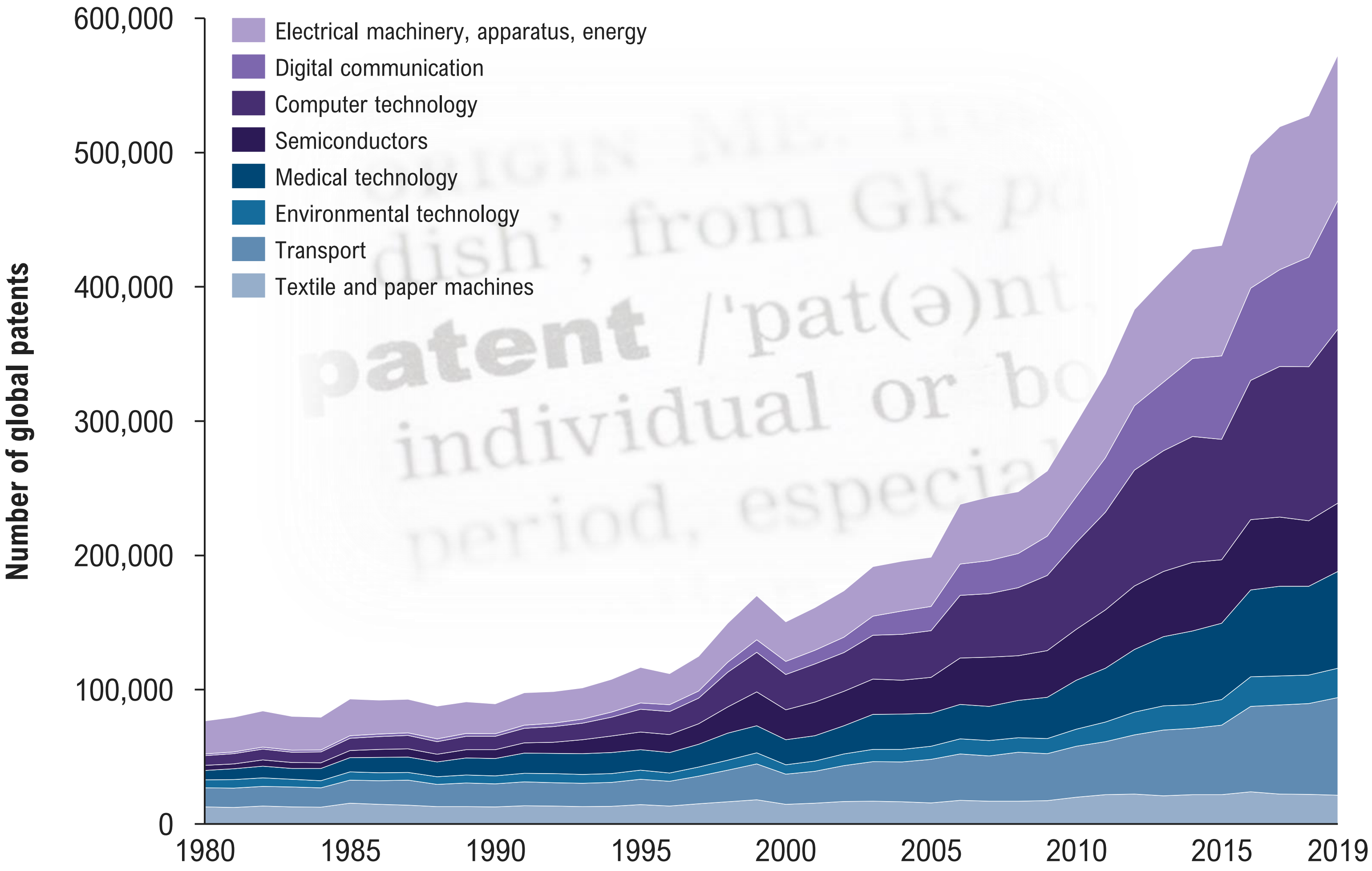


- The global economy has been transformed ever since the Industrial Revolution. At every step, **transformation was initiated by a technological breakthrough**
- These breakthroughs were accompanied by further innovations and technological progress, **bringing new and previously unknown prosperity**
- In the long-run, the paths of growth of **Western European and Western Anglophonic countries appear to be predictably exponential**. Periods between technological breakthroughs appear temporary
- **High economic prosperity and the region of origin of technological breakthrough correspond**. While Western regions have always experienced higher prosperity, Sub-Sahara Africa has been not able to catch-up at all

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

Patents in selected industries foretell the next technology wave – Current trends depict an explosion of patents related to digitalization

Global patents in selected industries, 1980-2019



> New **breakthrough technologies** related to Industry 4.0 and digitalization have experienced an **explosion since the mid 1990s,** regarding research and **patents**

> **Patents** closely related to **Industry 4.0** have seen **a tenfold increase** from 36,000 in 1980 to 385,000 in 2019

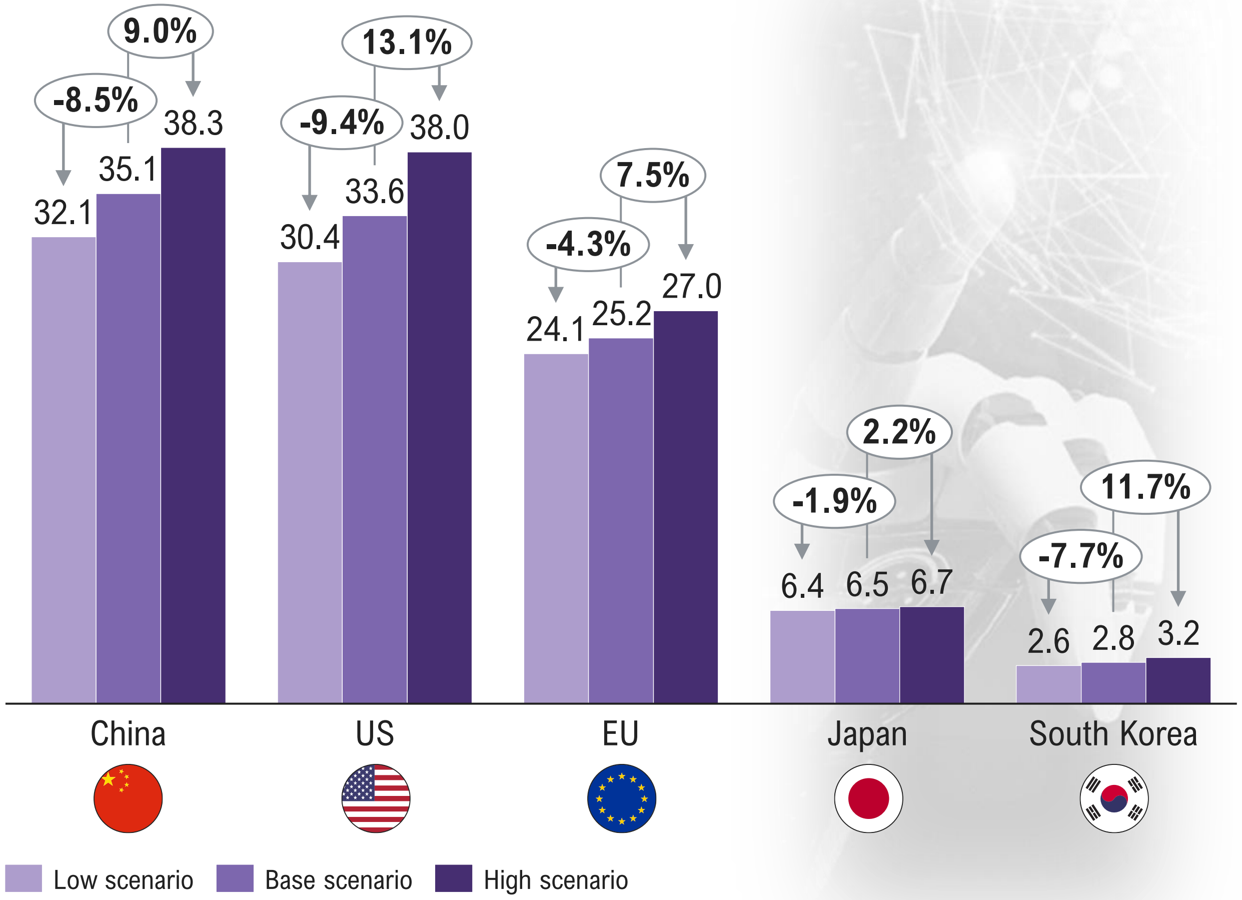
> **Digitalization** has also initiated a **patent push in related fields** such as medical and environmental technology and transport

> Technologies that are related to **older technological breakthroughs** remain unchanged in terms of patent numbers, reaching a **plateau of innovation**

Sources: WIPO; NBER; Roland Berger

The utilization of an increasing number of robots carries significant potential for economic growth

Projected impact of robot deployment on GDP under different scenarios in 2030[1)] [USD trillion]



1) Base scenario: average scenario estimated by Oxford Economics, this scenario is consistent with short-term robot investment trajectories forecast by the International Federation of Robots (IFR); low scenario: 30% less robots than assumed for the base scenario; high scenario: 30% more robots than assumed for the base scenario

Sources: Oxford Economics; IFR; Roland Berger

> **Industry 4.0** comprises innovations that are designed to make **production more efficient.** Cumbersome and **repetitive tasks**, previously carried out be workers, **are now executed by tireless robots**

> By utilizing robots, firms benefit from the so-called **robot dividend:** For the manufacturing sector, this dividend can be **quantified to an increase of 0.1% of output (per worker), when robot stocks are increased by 1%**

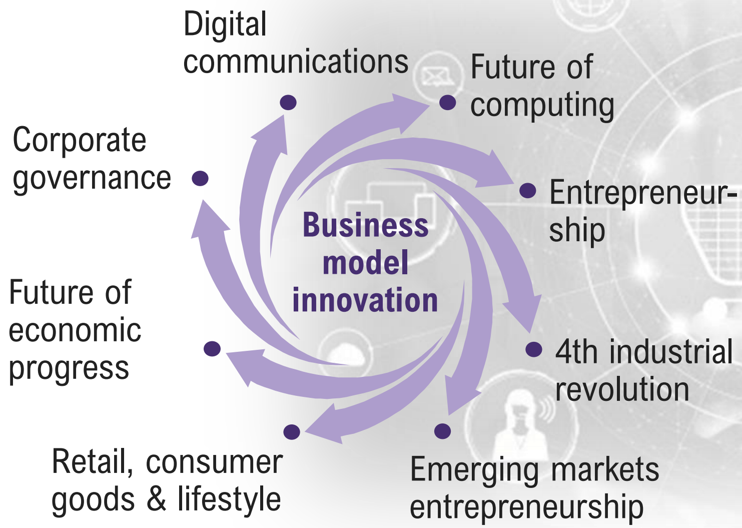
> Aggregating this dividend for entire economies **until 2030** under a scenario assumption where **30% more robots than in the base scenario** will be deployed, **implies higher growth across the board.** In a low scenario – with 30% fewer robots than in the base scenario – the opposite, i.e. a reduction in GDP growth, is evident for all economies considered

> **Globally**, the **high adoption scenario** would **boost global economy by 5.3%** above the baseline scenario – which is equivalent to adding **an extra USD 4.9 trillion to the global economy that year** – or around the same as the projected German GDP in 2030

Business model innovation dynamics – as part of Industry 4.0 – affect many interconnected sectors

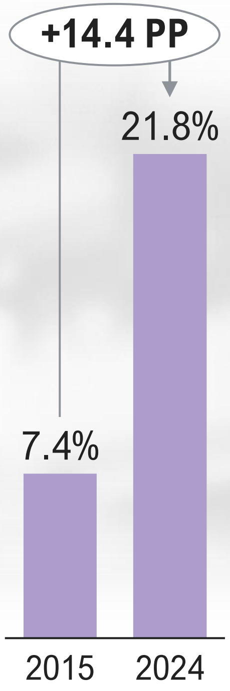
Doing business keeps on moving to the Internet

Factors interconnected with business model innovation



Global retail e-commerce sales [USD trillion]

Share of e-commerce on total global retail sales [%]

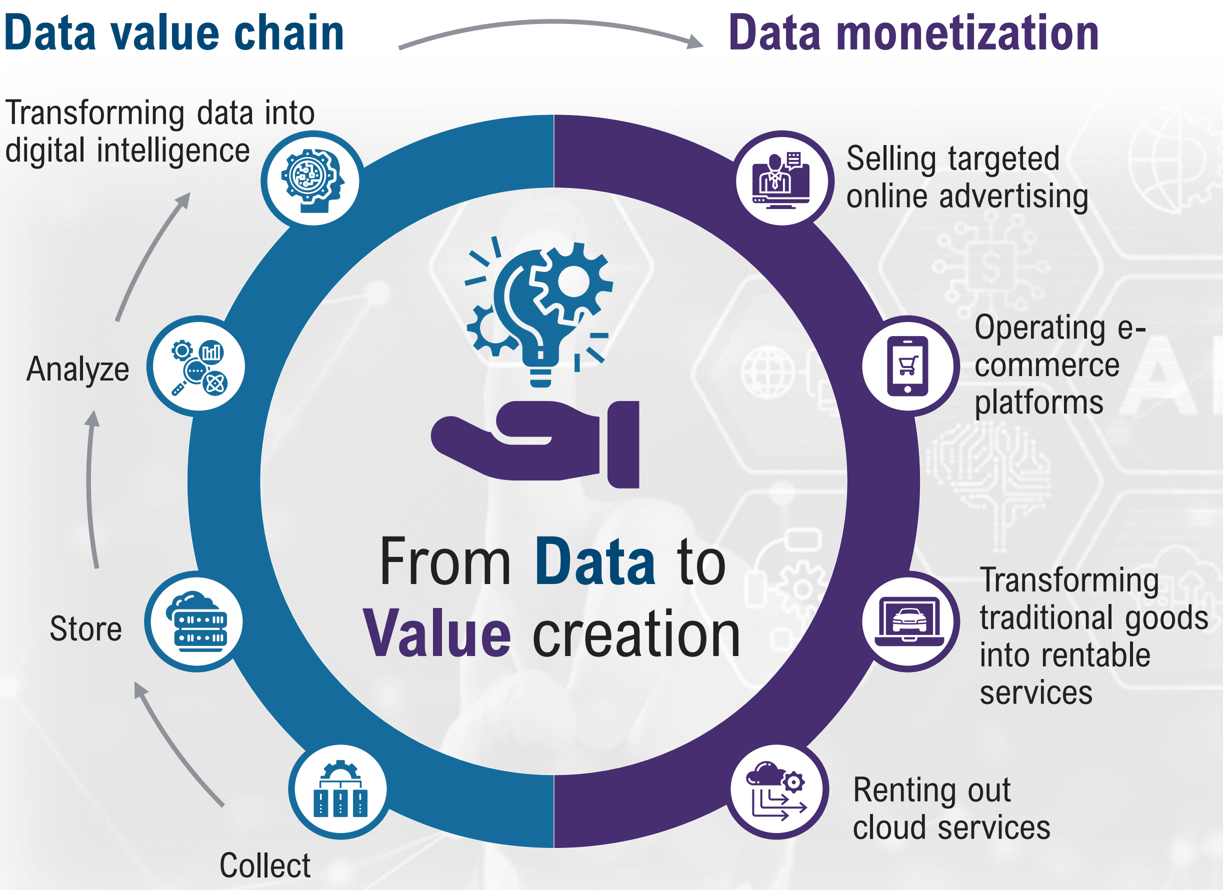


- **Industry 4.0 has** not only enabled new technologies, such as IoT, it has also profoundly **changed the way people interact, com-municate and trade**
- As a result, **business model innovation** is self-evident, affecting many different socio-economic factors
- One of the most significant changes observed is the **shift from physical commerce to online retailing: e-commerce.** Today, purchases are often and conveniently made remotely, from almost any location via a smart de-vice, facilitated by e-commerce sites and apps, and the ubiquity of Internet access
- For the future, the **increasing trend of e-commerce** and online retailing **is expected to continue unabated**

Sources: WEF; Emarketer; Roland Berger

Digitalization enables new market opportunities – Significant future growth is expected along the data value chain, particularly in data monetization

New business models enabled by digitalization



Total data traffic [EB[1)]/month]

- A further, **entirely new business model** arising from digitalization is **data monetization,** meaning the generation of measurable economic benefits from available data sources
- **Social media user data** is a ready data source destined for monetization: Disclosing **personal data** (voluntarily) and **patterns of social media use enables collation and data aggregation of user preferences**, gleaned with the help of AI. Companies can then carry out **targeted advertising**, maximizing revenues via **more views, clicks** and, ultimately, **purchases**
- In the future, predictions see **data traffic substantially increased**, leading to more opportunities for data monetization

1) EB refers to exabytes (= 1 billion gigabytes)
Sources: UNCTAD; Ericsson; Roland Berger

Roland Berger

Technology & Innovation

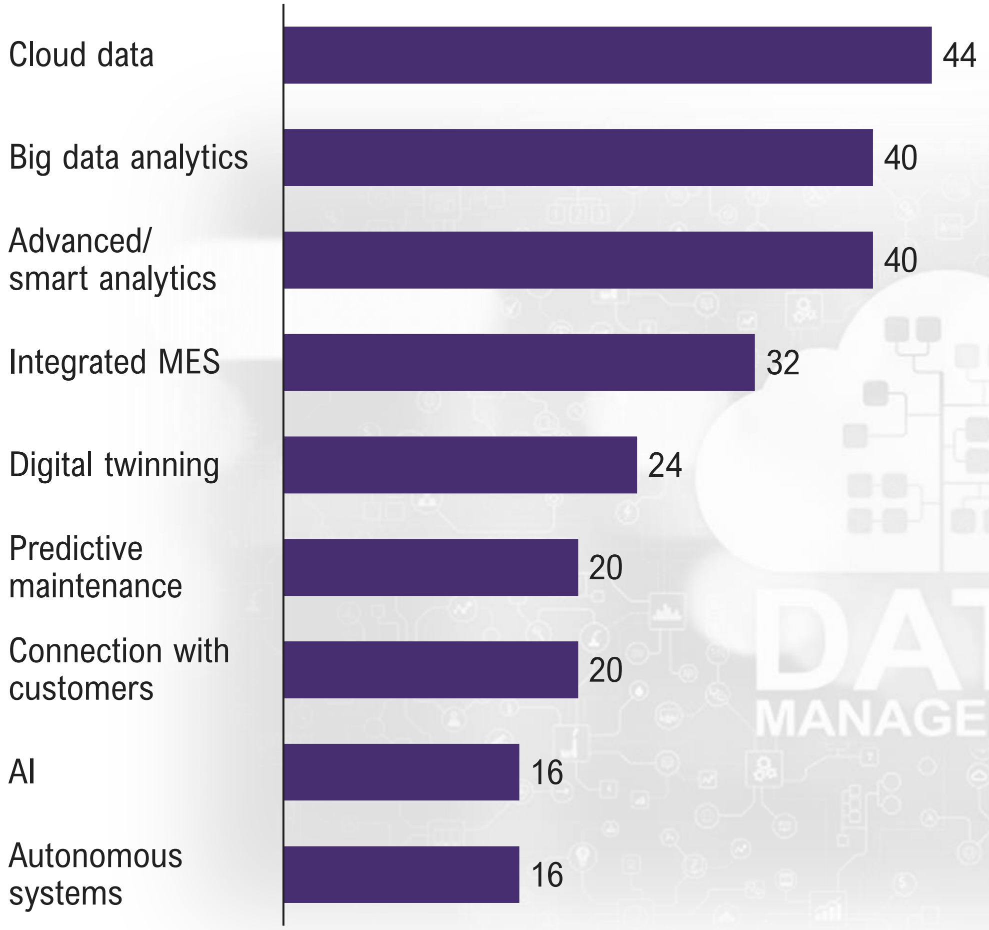
1 Value of Innovation

2 Frontier Technologies

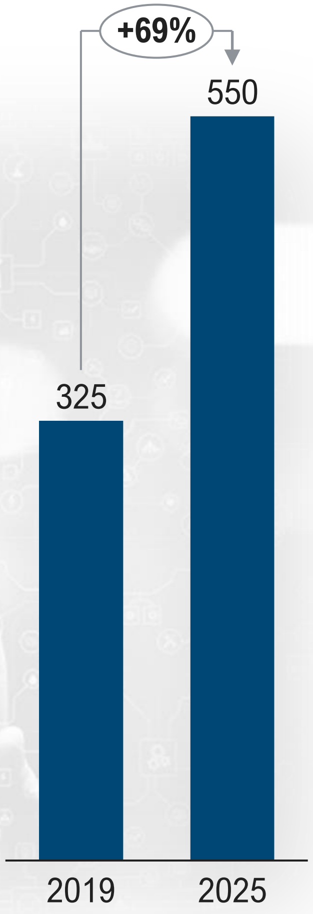
3 Humans & Machines

Companies predominantly use digital technologies that can exploit and process data driving further growth of the data economy

Share of medium sized firms using selected digital technologies, example Germany, 2021 [%]



Value of the data economy, EU27 + UK [EUR bn]



- The **data economy comprises the generation, use and re-use of data.** To strive in and maximize the value of the data economy, the necessary hardware as well as the right software is fundamental
- Firms using digital technologies aim to **improve data management, automation of processes, efficient reporting processes** and **quality improvements**
- The **current value** of the **global data economy** is estimated to have reached **USD 3 trillion**
- For the **EU27 countries + UK,** the European Commission estimates a **growth of almost 70% of the data economy until 2025**

Sources: WEF; European Commission; Roland Berger

Technology & Innovation

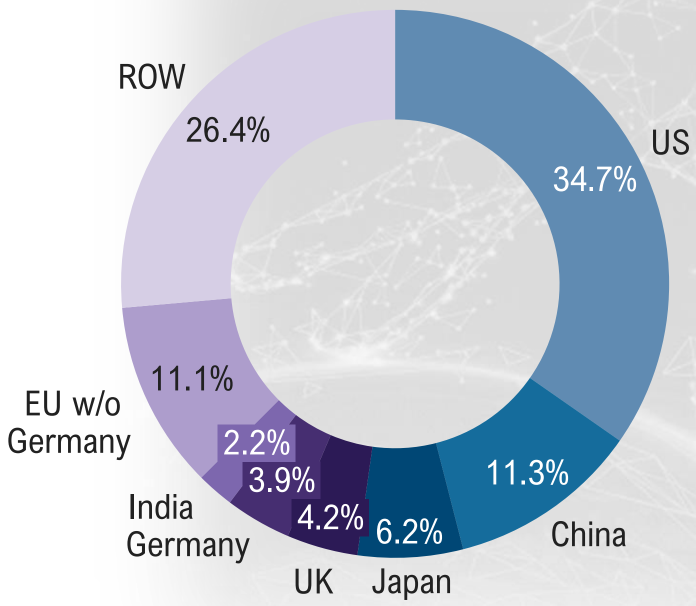
1 **Value of Innovation**

2 Frontier Technologies

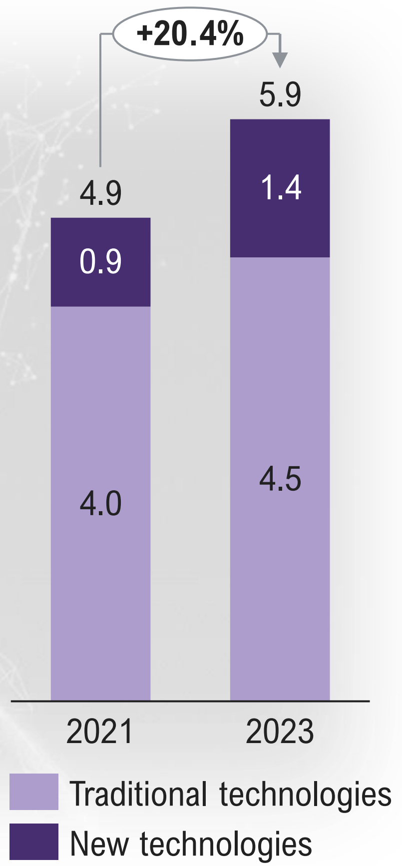
3 Humans & Machines

A well-developed, mature ICT industry acts as a solid foundation for future technological innovation while adding significant economic value

Market share by country/region in the ICT industry, 2021 [%]



Global ICT spending [constant USD, trillion]



- The **ICT industry** has been **one of the most important industries** for many decades; it has enabled most influential technological, societal and economic changes in human history
- **Communication** is as **affordable** as never before; computers have become **pocket-sized** while being more powerful than ever, media and entertainment are a **24/7 click away** and subject to **mass consumption**
- At the same time, the sector's potential remains widely open, not least due to its role as the **bedrock of new innovations**
- Thus, it is expected that **USD 5.9 trillion** will be **spent on ICT applications** in 2023, with the share of spending on **new technologies** such as AI, blockchain and robotics **continuing to rise**
- Since ICT is considered essential for further innovations and technological breakthroughs, **being a world leader in ICT carries forward the best possible chance to remain in this position** for the foreseeable future
- The **US** holds the biggest market share for ICT by a considerable margin showing that American firms (and their partners) working in **this sector have a competitive advantage**

Sources: bitkom; IDC; Roland Berger

Roland Berger

When it comes to the prerequisites to deploy frontier technologies, advanced economies are still leading the rankings

Frontier Technology Readiness Index [FTRI] ranking and its pillars, 2021

Country	FTRI ranking (overall)	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
US	1	14	17	2	20	2
Switzerland	2	7	13	13	3	3
UK	3	17	12	6	11	14
Sweden	4	1	7	16	15	16
Singapore	5	4	9	18	4	18
Netherlands	6	6	10	15	8	23
South Korea	7	19	27	3	9	8
Ireland	8	24	6	21	1	87
Germany	9	23	16	5	10	39
Denmark	10	2	4	25	21	5

> Current developments in the ICT sector are not the only **factor deciding a country's readiness** regarding up-and-coming **frontier technologies. Other indicators,** such as levels of education and skills, R&D investments, as well as market and financing structure, **are important, too**

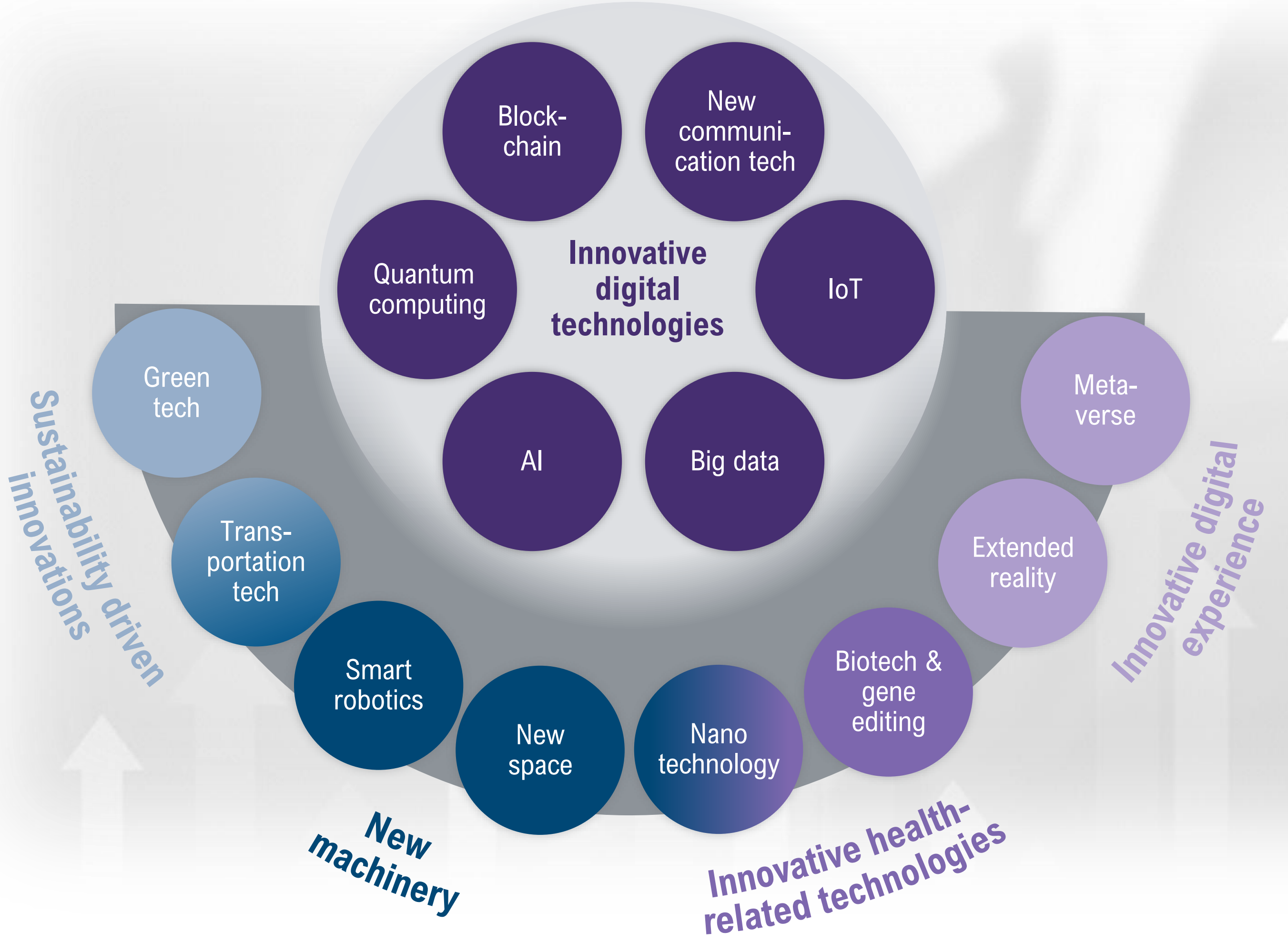
> **Only advanced countries** can be found among the **top 10 of the Frontier Technologies Readiness Index** (FTRI) reflecting their strengths in the pillars of the index

> Being **ready for frontier technologies** also points toward a certain **stability** when it comes to **future economic growth.** Taking the lead regarding technological innovation and progress implies competitive advantage and future prosperity

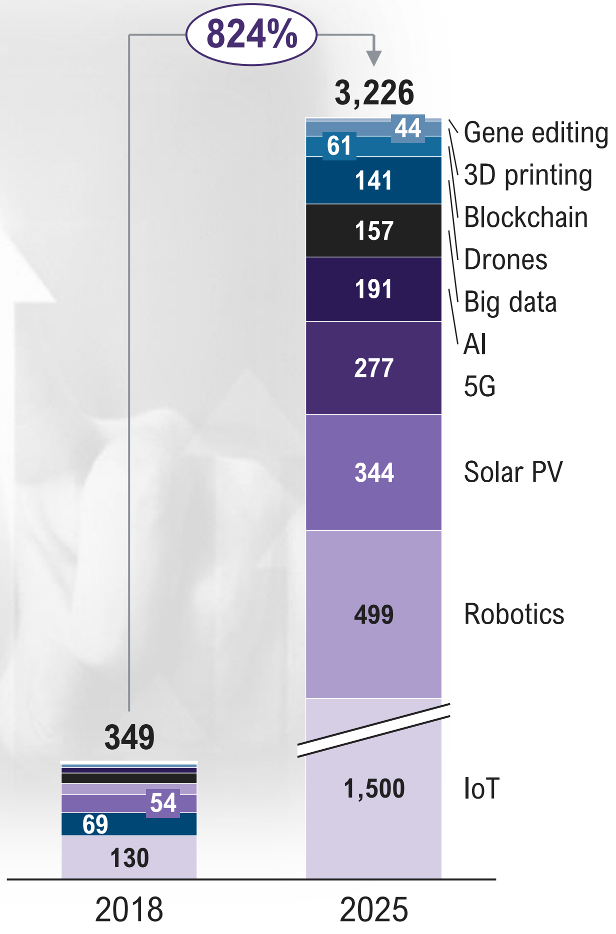
Sources: UNCTAD; Roland Berger

Selected technologies will see a tenfold increase in market size – An analysis of relevant innovations up to 2050 is called for

Selected frontier technologies and their categorization1)



Global market size of selected technologies2) [USD bn]



1) Selected frontier technologies discussed on the following slides 2)Selected frontier technologies according to UN
Sources: UNCTAD; Roland Berger

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 at the same time** 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

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
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]

2021 127 qubits → **Projected development of computing power** → **Future**

- In the future, **quantum computing** could **transform a broad range of sectors** such as finance, pharma, energy and security
- **In 2021**, IBM revealed a quantum computer with a computing power of **127 qubits**, nearly double the capacity of a 2020 64 qubit computer and **announced a 1,000 qubits computer for 2023**, implying an exceptionally fast scale-up in this technology. Some scientists predict a computing power of **100,000 qubits by 2050**
- 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

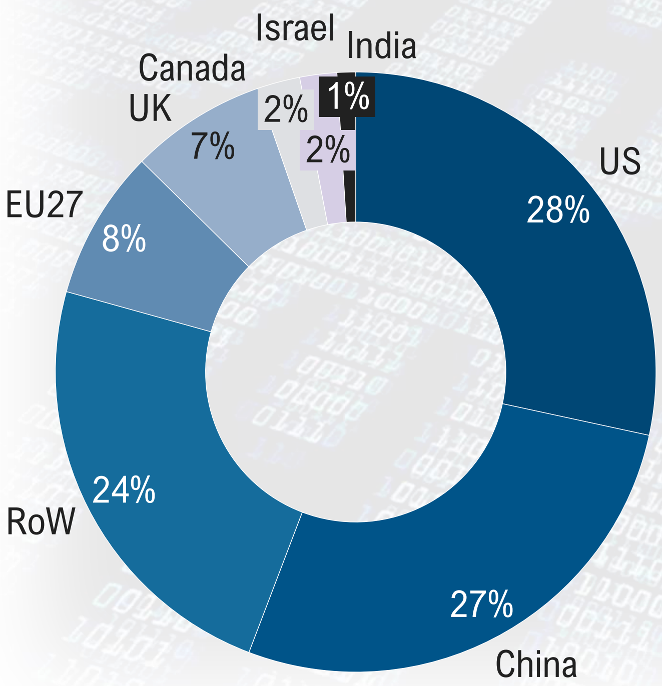
1) Grover's algorithm can speed up an unstructured search problem quadratically and therefore demonstrate the superior speed of quantum computers

Sources: Gao; Helmholtz; arXiv; Techcrunch; IBM; Roland Berger

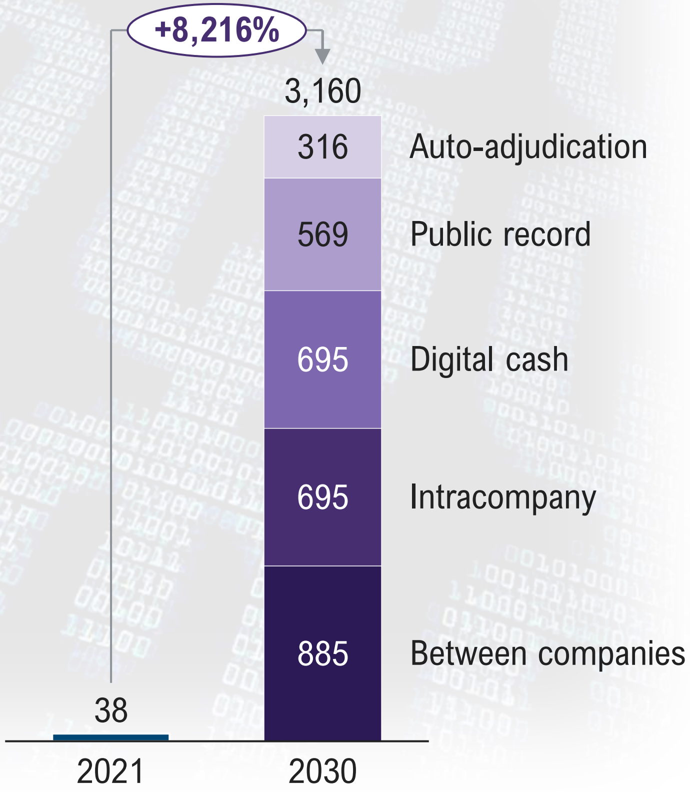
As another core digital technology, blockchain continues to change and impact processes by its unique ownership-defining characteristic

Blockchain technology's use goes well beyond crypto-currencies and financial services

Blockchain startups, share of number established between 2009-2018, by country (total number: 1,211) [%]



Blockchain business value for different use cases [USD bn]

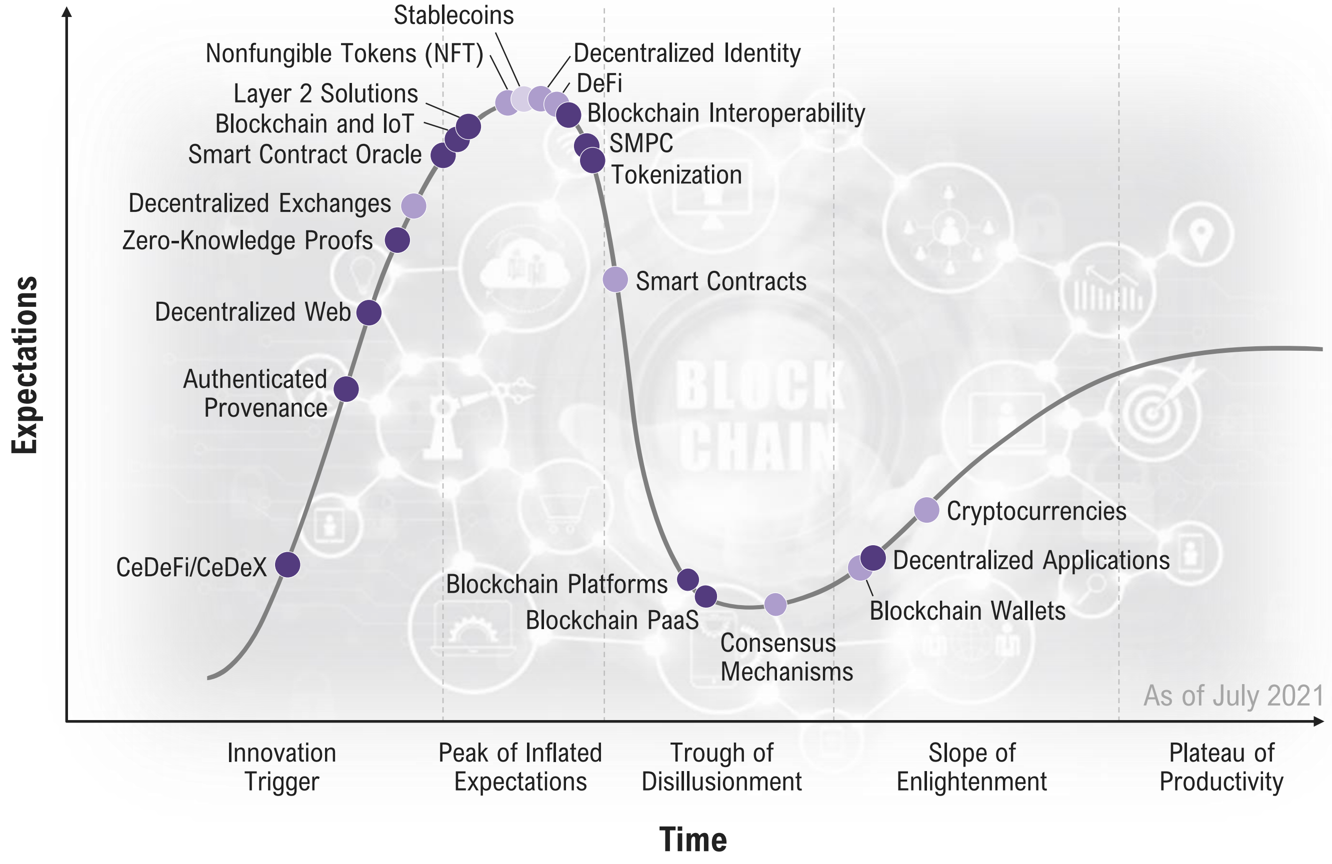


- Blockchain is a **system of recording information** in using **distributed ledger technology** (DLT) that makes it difficult or impossible to alter, hack, or cheat. DLTs are recorded with an **immutable cryptographic signature** called a hash, and **distributed across the entire network of computer systems on the blockchain**
- Currently there are **several areas of application** that use blockchain technology: In the **financial sector**, it is used to transfer money, for money exchange or lending
- The immutable aspect of blockchain makes it **particularly useful in other sectors where ownership is a paramount consideration**: Smart contracts are used **in insurance** and in **real estate,** but also for **non-fungible tokens** (NFTs) – currently fueling a **digital art market** craze
- **In the future, blockchain can be applied more widely** to store data at highly secure levels; it could also be applied to casting votes securely in elections, for example

Sources: European Commission; Gartner; ZDNet; University of California Berkley; Forbes; Consensys; Techrepulic; Roland Berger

Most blockchain applications will fully penetrate the market in well under a decade – Decentralization will make trade more efficient

The Gartner Hype Cycle[TM] for blockchain applications, 2021



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

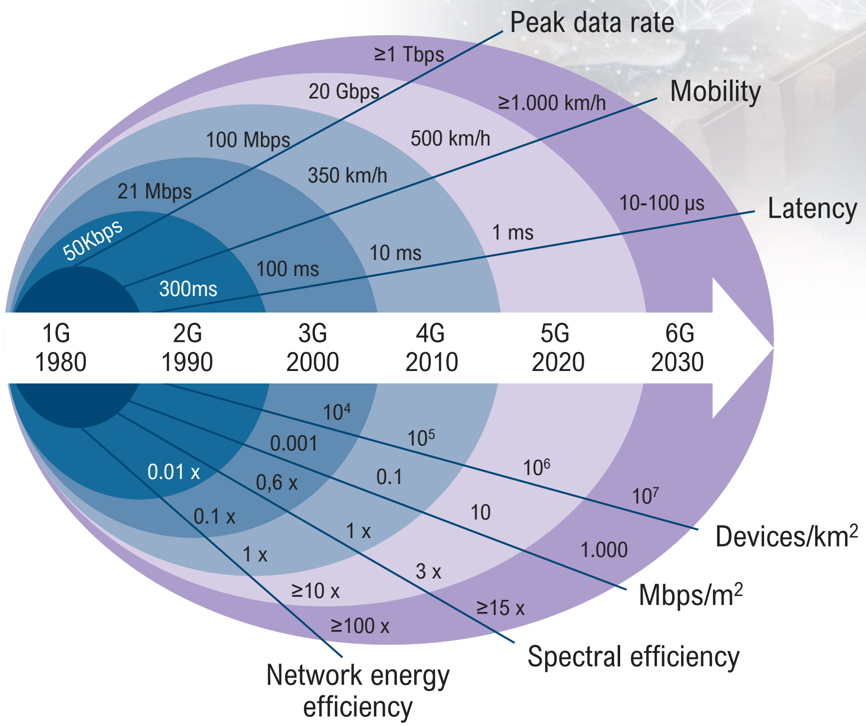
Sources: Gartner; Etherium; 101blockchain; Roland Berger

- Gartner's **Hype Cycle for blockchain applications** assigns **different key stages to the life cycle** of said technologies, charting an expectation 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 increasing trading efficiency** since a central intermediary is substituted by 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
- **Centralized-decentralized finance (CeDeFi),** which is expected to reach its plateau of productivity in 5-10 years, combines aspects of centralized finance with decentralized finance
- **CeDeFi comes with unique advantages** such as the possibility to **exchange vetted tokens or projects**. Furthermore, it resolves certain DeFi limitations regarding earning multiple yields and tokens simultaneously

New communications technologies are being developed faster supporting fundamental innovation over 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 **was protracted:** 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.** Comparatively faster advanced, **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 in more **special purpose networks and smaller sub-networks,** e.g. in networks of drone swarms

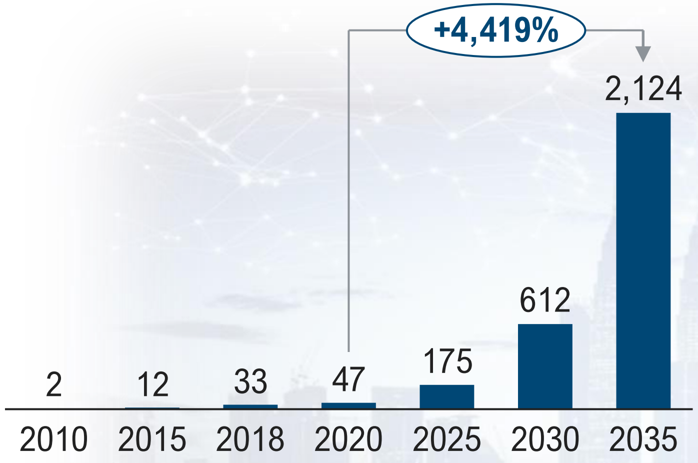
> The **higher data rate technology paves the way for more innovations**: Instant volumetric sensing (scanning and virtualizing 3D objects instantly), requires 6G's data transfer capabilities. Equally, fully **autonomous vehicles** or **smart interconnected infrastructure are data-hungry areas** where 6G is essential

1) LTA: Lighter than air

Sources: HCIS; 6G World; IEEE; Spatial Information Industry Outlook 2016; Roland Berger

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

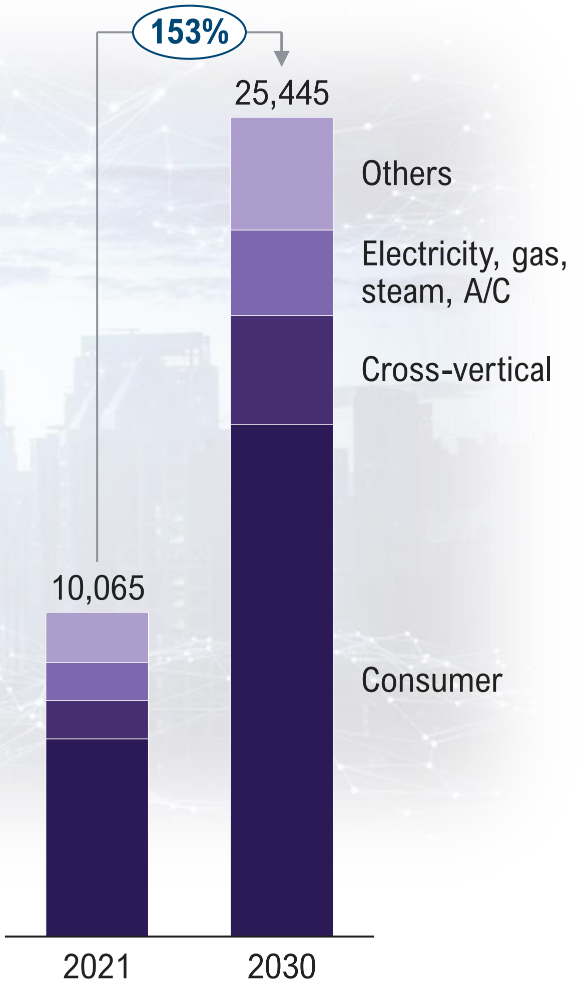
Amount of data created, worldwide [zettabytes[1]]



What happens in 60 seconds on the Internet[2]

- 500 hours of content created on YouTube
- USD 1.6 million spent online
- 198 million emails sent
- 9,132 connections made on LinkedIn
- 69 million messages sent via WhatsApp/ Facebook Messenger

Connected devices worldwide [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 intercon-nected 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 **hindered large-scale deployment of IoT. 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

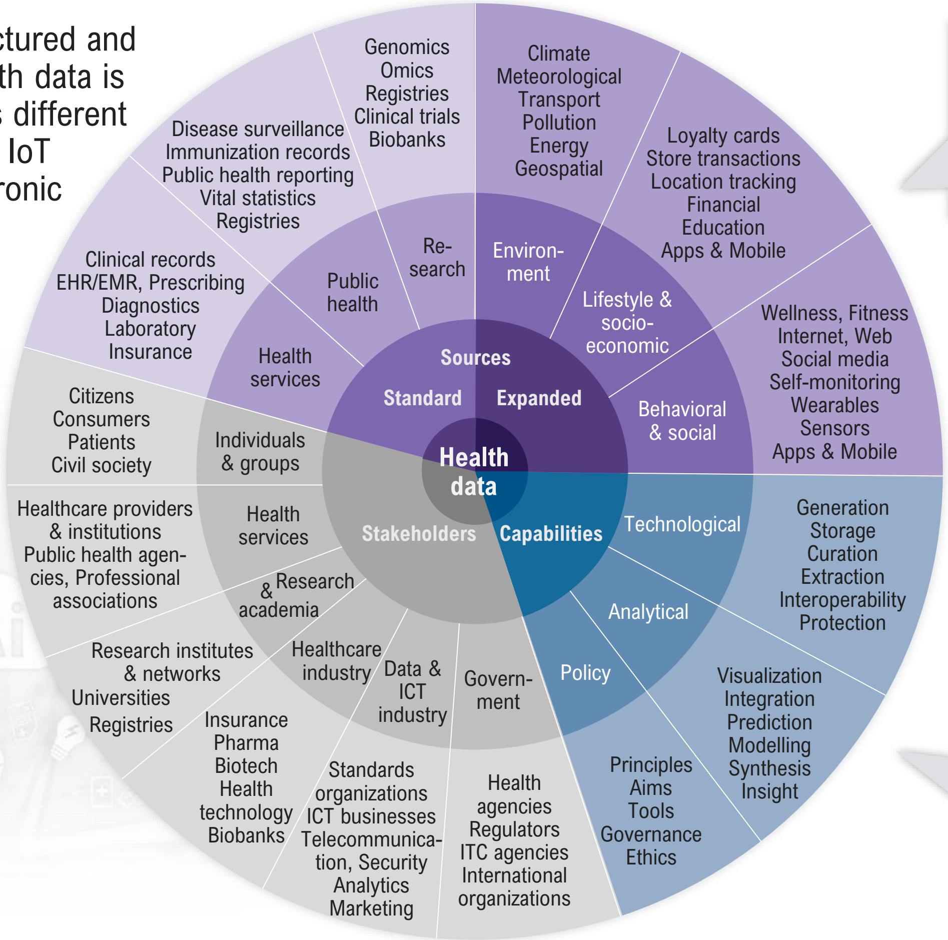
1) 1 zettabyte = 1 billion terrabytes; 2) 2021 data
Sources: Transforma Insights; Statista; Roland Berger

The more data are created the more important it is to analyze them with big data – The health sector is a typical example of a field depending on data

Health data ecosystems map highlights fragmented, unstructured data origins, devices and systems

Health data ecosystems fragmentation

The mass of structured and unstructured health data is spread out across different sources including IoT devices and electronic medical records



Four dimensions of big data in healthcare

Volume

AI enables healthcare providers to parse through large amount of data and perform complex analytical tasks quicker and with greater accuracy

Veracity

Establishing trust and accuracy in big data through error-free and credible data assurance is imperative in the healthcare industry

Variety

IoT devices and social media will add to a broad range of data sources. Combined analysis of multiple sources can create new actionable insights

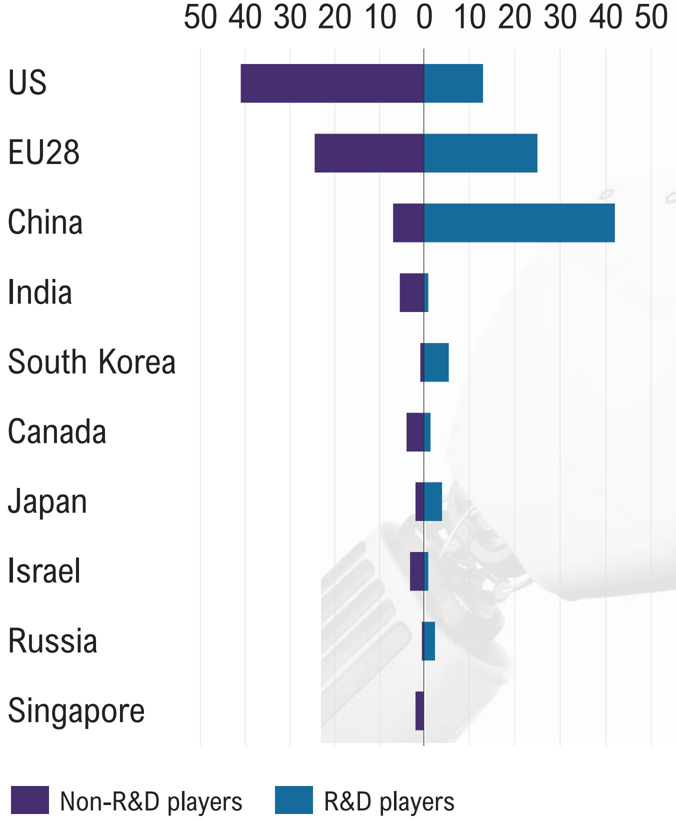
Velocity

In this time-sensitive industry, to maximize the value of big data, meaningful insights must be extrapolated in real time

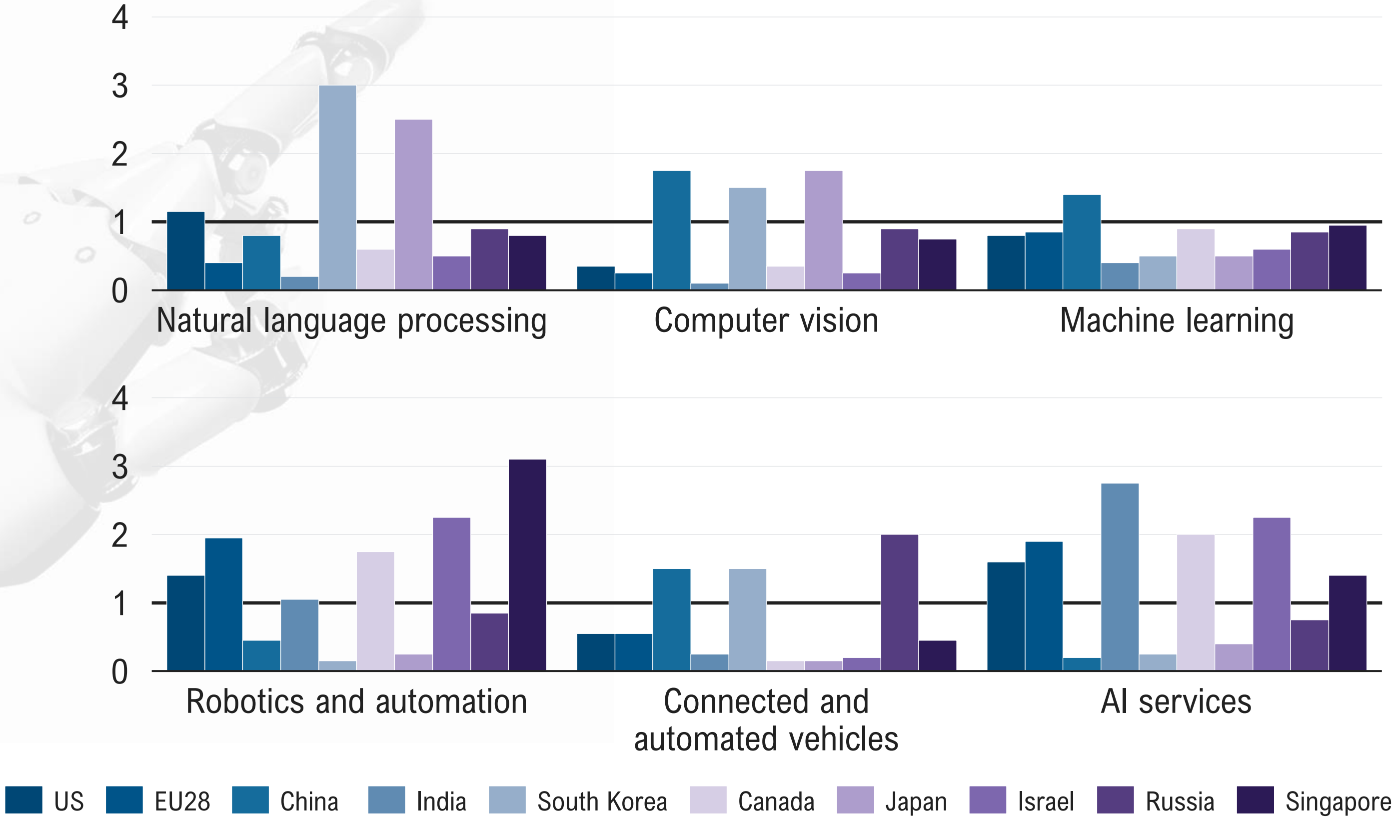
Sources: WHO; Visualcapitalist; Roland Berger

Increasing amounts of data allow continuous optimization of artificial intelligence – Handling data will be a key competence in the future

Number of AI players[1)] [% of world total]



Revealed comparative advantage of leading geographic areas for AI domains[2)] [world average = 1]



Scientists define the **development of artificial intelligence** as the **activity devoted to making computer systems perform tasks normally requiring human intelligence**, such as visual perception, speech recognition, decision-making, and translation between languages. **Intelligence** denotes the ability of **an entity to function in the pursuit of an optimal goal**. AI technologies improve machine intelligence in an **incrementally continuous** way

1) 2009-2018; selected by leading geographic areas; R&D players are involved in at least one research or innovation activity; Non-R&D players are solely involved in industrial activities
2) 2009-2018; revealed comparative advantage is an indicator to measure a country`s specialization against the world average which is normed to 1

Sources: European Investment Bank; European Commission; Stanford University; Roland Berger

Increasing amounts of data allow continuous optimization of artificial intelligence – Possible future applications could transform lives

2030

Healthcare

AI will be used to address and prevent health problems through tools such as advanced AI prediction applications, virtual nursing assistants and smart wearable devices that detect health issues when they occur reducing unnecessary hospitalizations

By 2030, we'll see a substantial uptake of these tools by individuals as well as the public and private sectors.

Prof. Nicole Hartley

2035

Trust, ethics & governance

Organizations will be required to provide transparent reports on how they govern and assure their ethical use of AI and data; they will be held responsible for breaches of trust

Most people are more willing to use AI when there are mechanisms in place to assure AI is being developed and used in a trustworthy manner.

Prof. Nicole Hartley

2030–2040

Sustainable business

AI will make it possible for businesses to run a carbon-neutral enterprise from 2030 to 2040

AI will provide tremendous opportunities from 2030 onwards to work towards a more circular and efficient economy. You will see a lot of smart systems optimized for product demand, producing outputs in a way that is less wasteful, both financially and environmentally.

Dr. Belinda Wade

By 2050

Service innovation

AI technology will read emotions to personalize each customer experience, and everyday interactions will be a mix of humans, AI-enabled machines and hybrids

In the future, increased usage of AI technology will provide insights into people's emotions – sensors will be able to pick up facial expressions and through AI can sync with other data sources from a customer to alert an organization as to how the individual customer is feeling, so they personalize offerings in real-time and make experiences engaging and seamless.

Prof. Janet McColl-Kennedy

Sources: University of Queensland; Roland Berger

Green technology innovations perfectly illustrate multi-varied beneficial interdependencies among new technologies, including AI and big data

The innovation landscape for renewable power integration

Electrification of end-use sector
EV smart charging
Renewable power-to-heat
Renewable power-to-hydrogen

Digital technologies
Internet of things
AI and big data
Blockchain

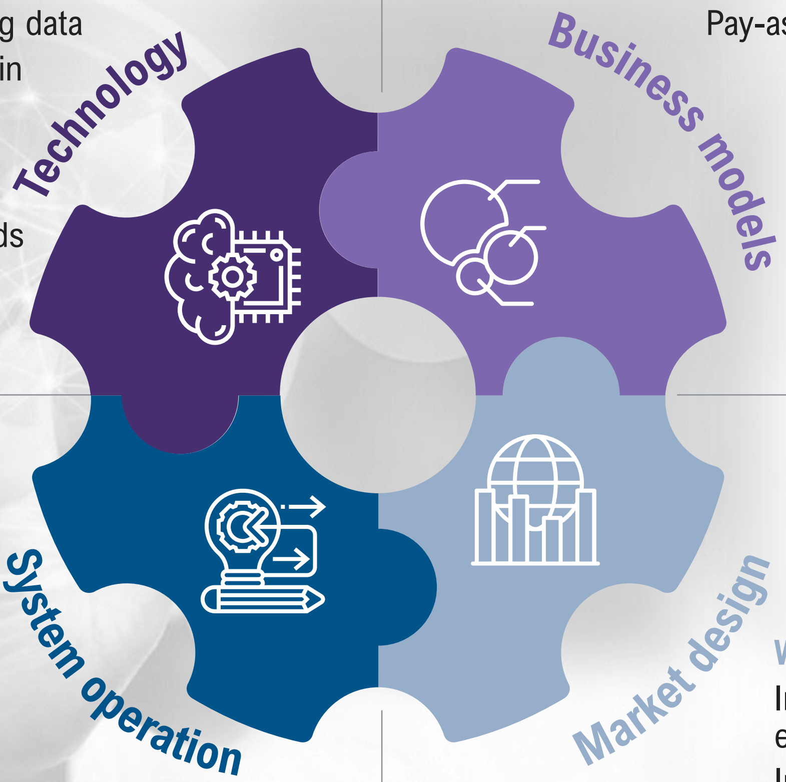
Electricity storage
Utility-scale batteries
Behind-the-meter batteries

New grids
Renewable mini-grids
Supergrids

Dispatchable generation
Flexibility in conventional powerplant

Enabling renewable energy supply
Community-ownership models
Pay-as-you-go models

Empowering the consumer
Aggregators
Peer-to-peer electricity trading
Energy as-a-service



Grid reinforcement deferral
Virtual power lines
Dynamic line rating

Disrupted energy sources operation
Future role of disruption system operators
Co-operation between transmission and distribution system operator

Accommodating uncertainty
Advanced forecasting of variable renewable power generation
Innovative operation of pumped hydropower storage

Retail market
Time-of-use tariffs
Market integration of distributed energy resources
Net billing schemes

Wholesale market
Increasing space and time granularity in electricity markets
Innovative ancillary services
Re-design capacity markets
Regional markets

Sources: Irena; Roland Berger

Solar power – as a leading green power source – offers a promising pipeline of innovations in materials, solar cell architecture and applications

Technological innovations in the solar power industry

Innovation in materials and architecture

Bifacial solar cells

Bifacial cells can generate electricity not only from sunlight received on their front, but also from reflected sunlight received on the reverse

Thin film architecture

Thin film technologies are often referred to as second-generation solar PV. The materials used to produce thin-film cells are only a few micrometers thick. Although cheaper to produce, they have historically had lower efficiency levels

Tandem/hybrid cell architecture

Tandem solar cells are stacks of individual cells that each selectively convert a specific band of light into electrical energy, leaving the remaining light to be absorbed and converted in the cell below

PERC cell architecture

The key improvement is the integration of a back-surface passivation layer – a layer of material improving the cell's efficiency in three ways: It reduces electron recombination, increases absorption of light and enables higher internal reflectivity

Innovative applications

Floating PV

Floating PV is an exciting emerging market, with the potential for rapid growth. Demand for floating PV is expanding, especially on islands (and other land-constrained countries), because the cost of water surface is generally lower than the cost of land

Building-integrated PV (BIPV)

BIPV solar panels are a cost-efficient application also known as solar shingles. They are multifunctional as they can be adapted to a variety of surfaces (e.g. roofs, windows, walls) as an integrated solution, providing both passive and active functions

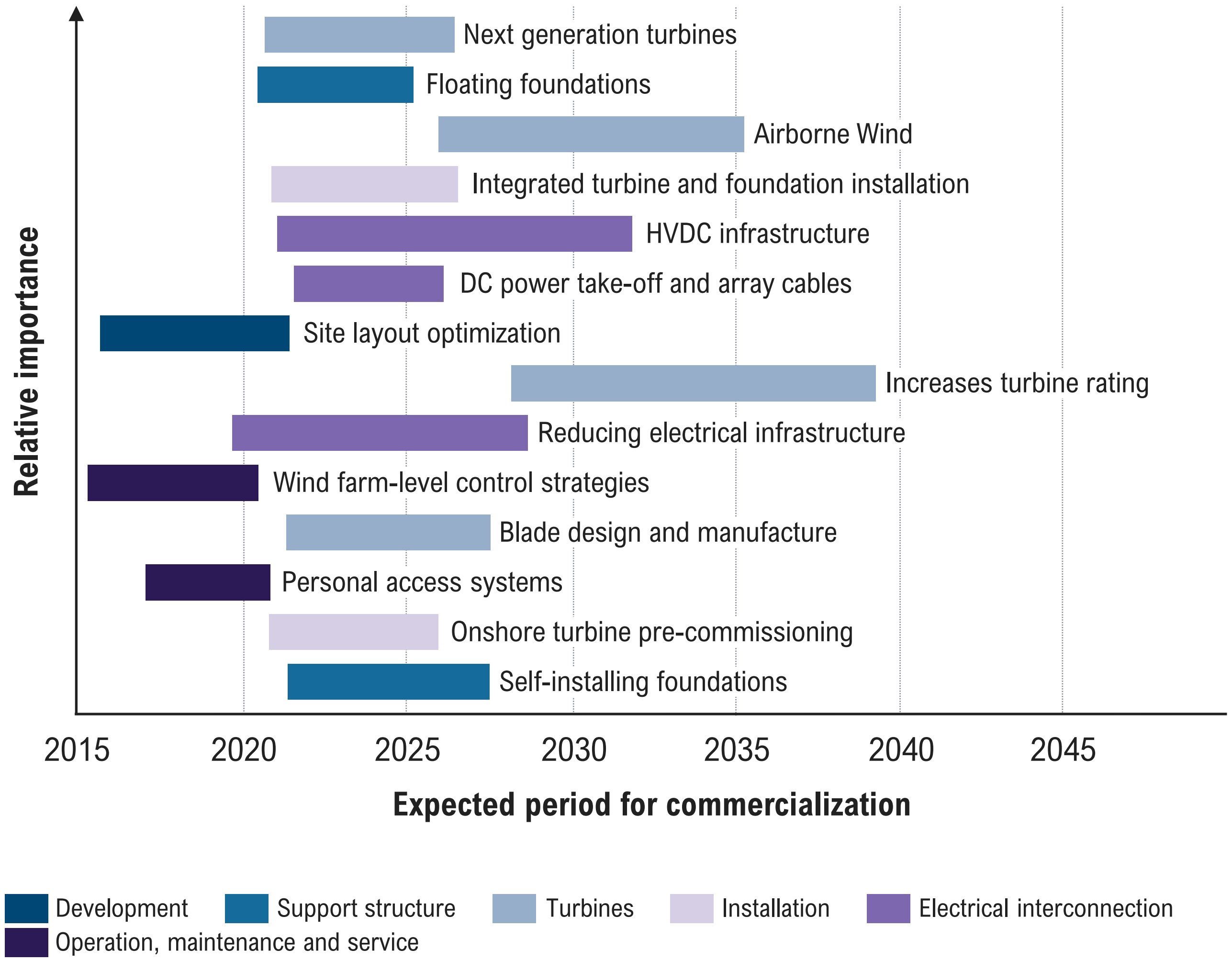
Solar trees

Solar trees have leaf-like solar panels connected through metal branches using sunlight to make energy. They are more ergonomic and space-efficient than solar panels, taking nearly 100 times less space while producing the same amount of electricity

Sources: Irena; Roland Berger

Wind energy shows clear potential to expand – Next-generation turbines and floating foundations comprise the most important innovations

Innovations in offshore wind technology



> **Wind energy** constitutes – alongside solar power – an important and **essential part of the renewable energy mix**. As such, further future innovations, including those advancing efficiency increases, are a must

> **Efficiency increases** can be attained in several ways: better turbines, more efficient installations, higher electrical interconnection, but also through an innovative support structure

> **Innovations in blade, drivetrain and control technologies** will lead to **next generation turbines.** Such turbines will be larger and more reliable and will have higher capacity ratings

> **Floating foundations** will also have a significant impact in the wind energy sector, being **more flexible and cheaper** than fixed structures. Especially countries with deeper sea levels will benefit from this technological innovation

> **Significantly reducing construction costs** and materials, **airborne wind energy** could bring a profound change within the wind energy generation mix itself. Being comparable to the shape of a kite and taking advantage of the concentrated traction force of the wind, airborne wind energy has a **significantly lower visual impact on its environment**

Sources: Irena; IET; Airborne Wind Europe; Windeurope; Roland Berger

Beside the source of energy, its storage is also essential in order to reduce the use of fossil fuels – Innovations in battery technology are promising

Frontier battery technologies and projected timeline until commercialization

Parameters	Na sulfur	Na ion	Solid state battery	Li sulfur	Fe air	Zn air	Al ion	Li air	Paper battery
	Technology								
Technology readiness level[1)]	8	8	6-7	6-7	5-8	5-7	4	4	3-4
Implementation	By 2021	By 2050[2)]	By 2030	By 2030	NA	NA	By 2050	By 2040	NA
Energy density [Wh/kg]	150-240	75-150	500	400-650	250	350-500	400	1,500	0.06-0.108
Cycle life[3)]	2,500	300-1000	300-1,400	200-1,400	500	180-1,100	405-10,000	1,200	4)
Applications	Energy storage, Transportation	Energy storage, Transportation	Consumer, EV	Energy storage, Transportation	EV	Consumer, EV	Consumer, Energy storage	EV	Consumer, Cosmetics, Medicine

Energy storage · Cosmetics · Medicine · Transportation · Consumer · EV

1) Technology readiness level on a scale from 1 to 9 with 9 as the highest level; 2) Due to projected depletion of Lithium and Cobalt from the Earths surface; 3) Cycle life of batteries is the number of charge & discharge cycles that a battery can complete before losing performance; 4) Battery shelf life of 4 months

Sources: futurebridge; Prescouter; European Commission; The Faraday Institution; BASF; Roland Berger

> The **global demand for batteries** will increase from 184 GWh in 2018 **to 2,623 GWh in 2030** with highest demand increase in electric mobility batteries. In 2020, **Li-ion batteries** have an energy density of up to 300 Wh/kg, but further advances are necessary

> The development of new batteries is often **driven by sustainability aspects,** such as the integration of **smart functionalities,** e.g. sensing or self-healing properties

> Beyond developments in battery layout, other factors include an **increasing focus** on **cross-cutting areas**, such as issues in manufacturing and **recycling**

Electric vehicles are a common sight today, but the aviation sector faces major challenges in decarbonization and electrification

Timeline of electric/electrified aviation

Projected development in aviation technologies

Today
Electric air taxi – first manned flights

2020-2025
Electric air taxi enter service for urban mobility
# of pax[1]: 2
Range: 150 nm[2]

2025-2030
Market entry of small hybrid-electric aircraft for business or commercial use
# of pax: 10-15
Range: 700 nm

2030-2035
Airlines offering regional scheduled flights based on hybrid-driven aircraft
# of pax: 50-100
Range: 850 nm

2035-2050
Market entry of battery-powered aircraft on short-haul flights
# of pax: <150
Range: 290 nm

Electric air taxi
Taxi
2020-2025
CO_2 reduction: 80-100%

Hybrid-electric aircraft
H2
2025-2030
CO_2 reduction: 10-40%

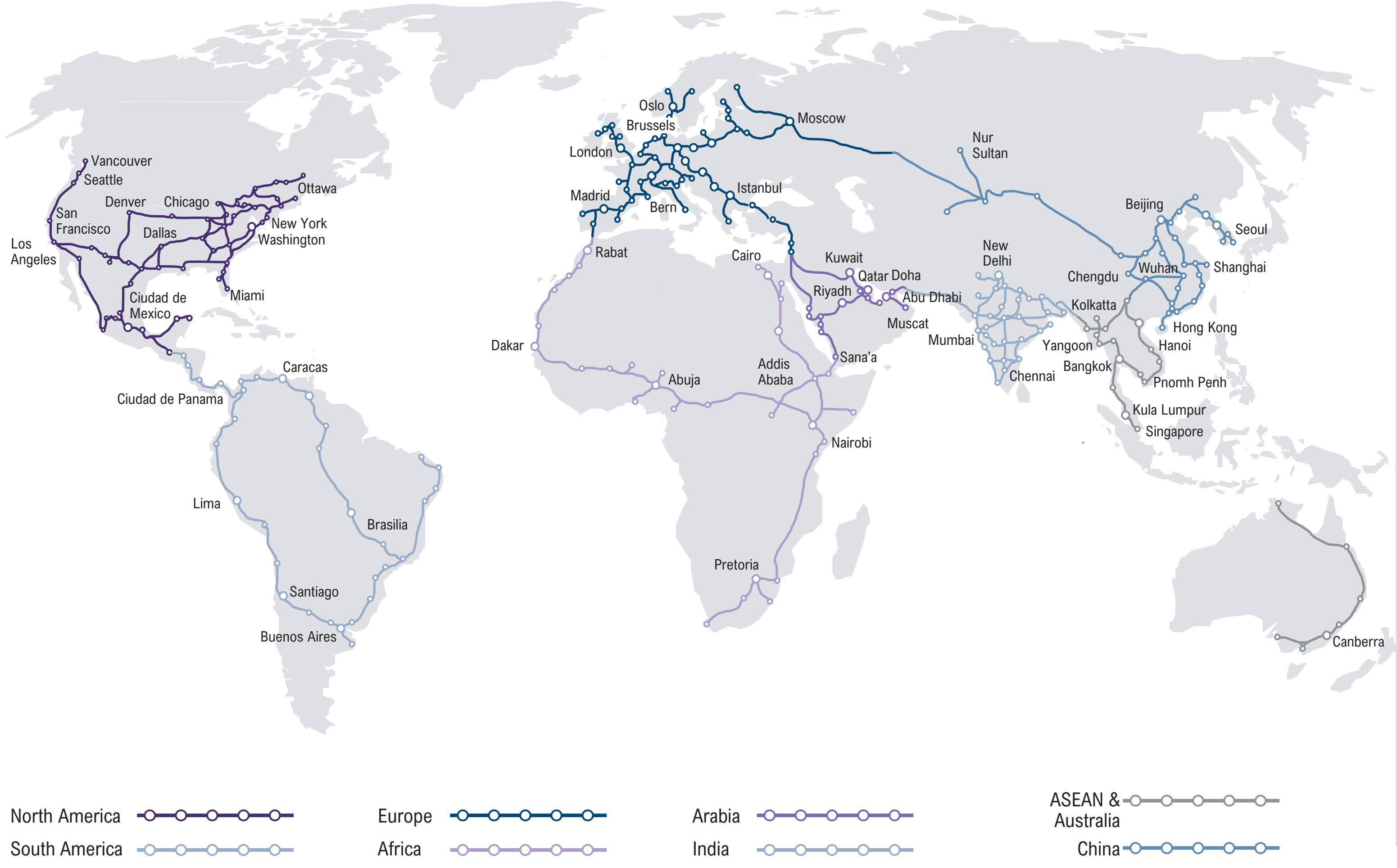
Fuel cell powered aircraft
from 2035
CO_2 reduction: up to 100%

Electrified aviation is a technological breakthrough that **will transform aviation**. However, there are **continuous developments** already underway regarding **increasing fuel efficiency**; a selective analysis shows that in 2020 **advanced turbofans** enabled a 20% increase in efficiency; in 2025, **new engine architectures** will enable increases of up to 25%. Aircraft with **new designs**, such as **blended wing bodies**, could **increase efficiency by up to 50% in 2040**, and aircrafts with a **double-bubble fuselage** could also provide an efficiency increase of 20% in the future

1) # of pax: number of passengers; 2) nm: nautical miles
Sources: IATA; Roland Berger

Getting from A to B like never before: Visionaries in the hyperloop sector project a worldwide hyperloop network in 2050

A futuristic global hyperloop network transporting travelers and freight

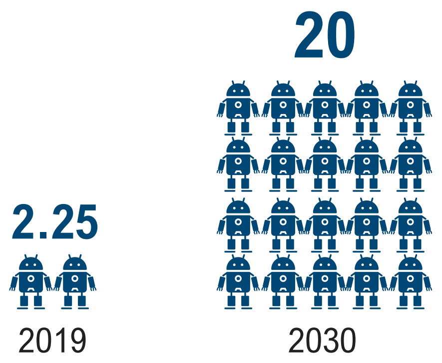


- **Hyperloop** is an ultra-high-speed ground transportation system for passenger and cargo which consists of sealed and partially **evacuated tubes**, connecting mobility hubs in large metropolitan areas, and pressurized vehicles, usually called **pods**, which can move at **very high speeds**, thanks to contactless levitation and propulsion systems as well as to low aerodynamic drag
- This futuristic vision of an **88,500 km fully operational hyperloop network** projects over **1.4 million passengers** travelling each year via this network. Beside passengers, **28 million tons of freight** will be transported per year in this manner
- This could lead to an annual **revenue opportunity of USD 271 billion** and an avoidance of **6,288 m tons of CO_2 emissions** – assuming hyperloops are powered by 100% renewable energy

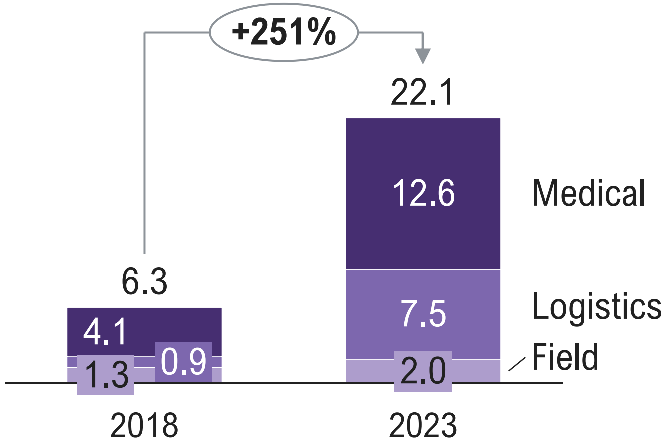
Sources: Zeleros; Interesting Engineering; Roland Berger

Smart robotics is a growth area expected to play a significant role across a variety of applications – Asian countries lead in terms of robots deployed

Robots in use worldwide [m]



Service robots for professional use, turnover of major applications, 2019 [USD bn]



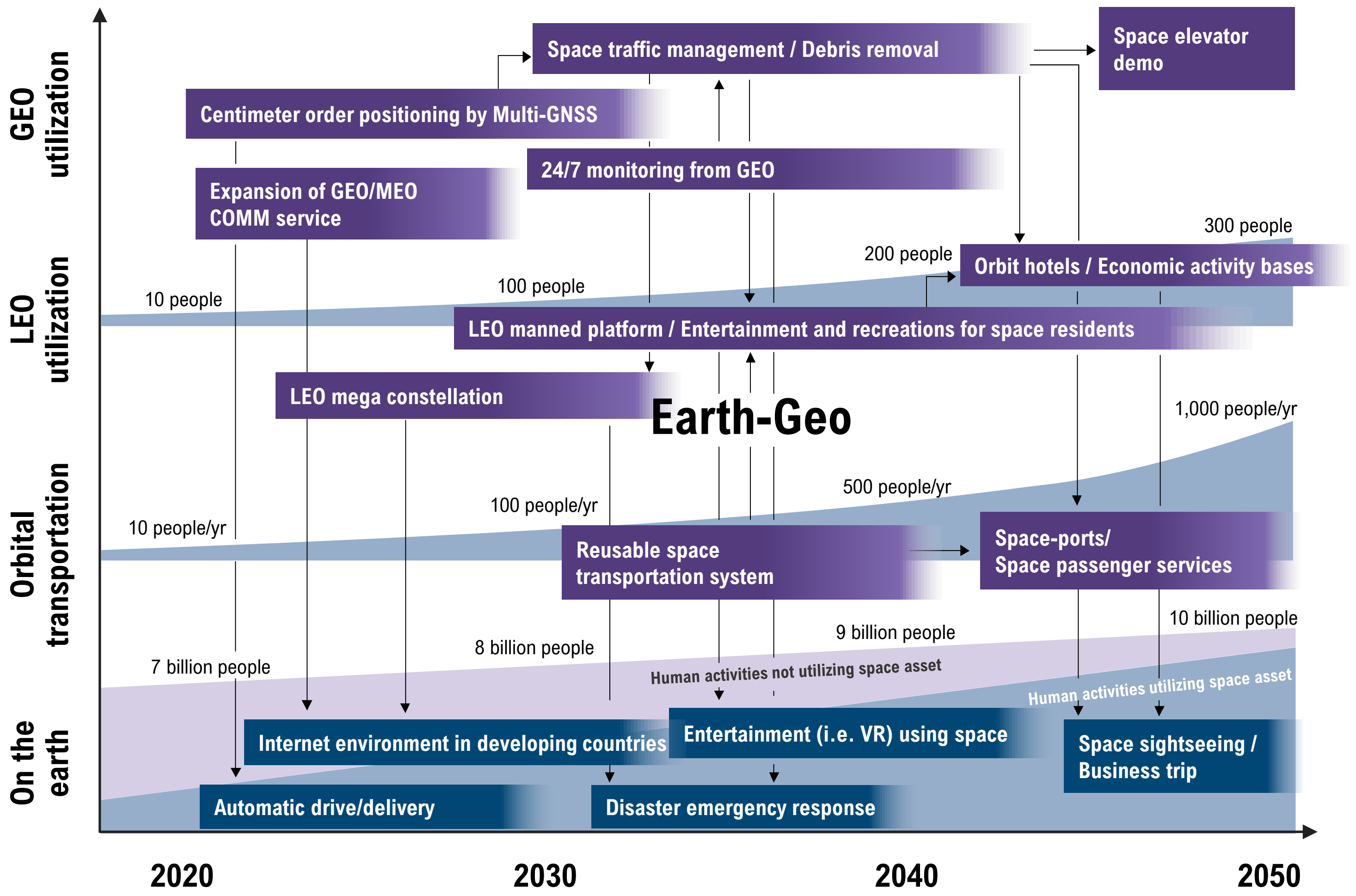
Country	Number of industrial robots per 100' employees in manufacturing, 2019	Industrial robots, newly installed in 2020 ['000]
Singapore	918	5
South Korea	868	31
Japan	364	39
Germany	346	22
US	228	31
Italy	212	9
Spain	191	3
China	187	168
France	177	5
Canada	165	3

- > **Smart robots** are **autonomous AI systems** that are capable of **learning** from and **interacting** with their environment – this allows for **collaboration with humans**
- > Pending further developments in AI as well as robotics, future smart robotics will see considerable **growth in service robots for professional applications in medicine, logistics and field use;** for example, smart robots could be deployed in the maintenance industry to repair or retrofit water pipes
- > Based on the theory of swarm behavior, **swarm robotics** champions the idea to deploy a group of small/cheap(er) smart robots equipped with sensors to identify defects in buildings or infrastructure

Sources: IFR; SPARC; Oxford Economics; Roland Berger

Human activities utilizing space assets will see continuous growth to 2050 – Space activities depend on orbital distances to Earth and commercial appeal

Projected evolution of space activities up to geostationary orbit[1)]



> **Depending on altitude,** i.e. distance from the Earth, there are **different current activities and planned future endeavors in space:** For example, satellites can be in a low earth orbit (LEO, altitude of 500-1,200 km), a medium earth orbit (MEO, 5,000-20,000 km) or a geostationary orbit (GEO, 36,000 km)

> Sizeable leaps in public and private scientific and technological innovation and funding in areas of **transportation, robotics** and **spacecraft architecture** are essential to secure future space exploration and commercialization

> **Transportation systems** could develop from today's reusable rockets to space ports with space passenger services as well as orbital multistage low-cost mass transportation vehicles **in 2050**

> For commercial and scientific **space utilization**, researchers foresee the **manufacturing, recycling and assembly** of materials and devices **in space**

1) Orbit: refers to the curved path of a celestial object or spacecraft round a star, planet, or moon, especially a periodic elliptical revolution
Sources: Satellite Today; JSASS; Roland Berger

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

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

Past — Future

2000´s — 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 and 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. In the future, surfaces **properties** could be evolved to become **self-healing** due to nanotechnology

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

Sources: medium; Graphenea; Valuer; Mecs-press; European Comission; Roland Berger

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

Application	Definition	Benefits	Risks
Digital health/ Personalized medicine	Tailored medical treatment using AI to combine data from genetic sequencing, diagnostics, and biomonitoring	Misdiagnoses plummet & healthcare outcomes improve	Access disparities due to costs or location; personal health data misuse or manipulation
On demand medicine production	Cell- & gene-based therapies, combined with improvements in drug design & 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 & 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 neurol. disorders. Enhanced cognition & expanded perception	Tension between augmented & non-augmented individuals; new cyber/bio vulnerabilities
Bio-manufacturing	Bio-design and production of enhanced or highly specified materials, medicines and food	Improved speed & reliability in design & making novel materials, medicines	Increased potential for misuse & workforce restructuring
Environmental restauration	Large-scale ecological intervention through biotechnology, reforestation, or ocean engineering creates, manipulates, rescues damaged environments	Barren or depleted lands turn productive; mitigation of manmade & 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

Sources: National Intelligence Council; Roland Berger

… such as 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		Any changes, including potential off-target effects, are limited to the treated individual.		If the person has children, the edited gene is passed on to the future generations.
Next generation		The edited gene is not passed down to 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** – i.e. clustered regularly interspaced short palindromic repeats – represents a new milestone in biotechnology, having 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**, waiting to be rolled out further. Diseases that are caused by genetic disorders, e.g. Huntington's or sickle-cell disease, could be overcome by gene editing treatments – as well as other diseases, such as cancer
- Reflecting a **monumental step in biotechnology**, the two scientists that discovered the CRISPR/Cas9 genetic scissors process, **Emmanuelle Charpentier** and **Jennifer Doudna**, were awarded the **Nobel Prize** in Chemistry in 2020
- 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**

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

Our immersive future: The concept of extended reality merges physical and digital worlds …

The many realities that extend, mix and augment our future lives

Innovative technologies that aim to create a form of virtual experiences

Extended reality (XR) is used as a term for **any immersive reality that could include all senses and future interactions via human-machine interfaces**

Mixed reality (MR) is a combination of **VR** and **AR** systems creating a **hybrid environment**

Augmented reality (AR) lets us view the physical world directly or indirectly and adds virtual objects

Virtual reality (VR) is a fully digital experience that, by using a headset, creates an audio-visual and potential physical virtually simulated environment

Market size of extended reality technologies, [bn USD]

- **Extended reality (XR)** has the potential to **impact large parts of our economy** across a wide range of sectors going forward: In **engineering** and **healthcare**, XR will open new possibilities in working methods and visualization possibilities
- The ability to interact with **virtual products** will also disrupt the **retail sector**. New possibilities in the **personalization of advertising** will change the **marketing** sector
- A particularly impactful point concerns **education and training**, where XR offers entirely new opportunities for academia as well as businesses to interact with learners and objects in novel ways
- **Future progress** towards extended reality is based on the **innovation of core technologies** such as AI, but also includes hardware devices and data transfer via cloud systems and 5G

Sources: Bloomberg; Prescient & Strategic Intelligence; Ionos; IPlytics; Mobile App Daily; Huawei; Roland Berger

… towards a metaverse where networked, real-time and frictionless virtual economies run in parallel to our traditional world …

A timeline of the web, from Web 1.0 to the future metaverse

1990 → Future

	Web 1.0	Web 2.0	Metaverse
Dimensions of interaction	Read	Read & write	**Read & write & own**
Content	Static content	Interactive content	**Virtual economies**
Organization	Companies	Platform companies	**Network of different participants**
Infrastructure	Personal computers	Cloud & mobile devices	**Blockchain cloud**
Control	Decentralized	More centralized	**Decentralized**

> There are several definitions of the **metaverse**, however it can be described as a **network of three-dimensional, real-time virtual worlds** through which an individual moves with the same identity, objects, data and rights – simultaneously with an unlimited number of other individuals

> The structure and characteristics of the metaverse can be **described by nine points: The metaverse is …**

- … a place of **continuous existence** – virtual life continues also for offline people
- … a **virtual environment**, that will react to people inhabiting and using it
- … **not tied to platforms** – the experience is frictionless between platforms
- … a place to **socialize**
- … a place where people actively engage with content and therefore **catalyze creativity**
- … **limitless** regarding user capacity, world or experiences
- … **integrated** into everyday activities and engagements
- … **decentralized** – ownership will be distributed via blockchain technology
- … **user defined** and shaped by the people living and participating in the metaverse

Sources: Forbes; Investopedia; Grayscale; Roland Berger

… immersing real-world technological innovations into the metaverse they enable – Shifting the human-machine relationship into another dimension

Core enabling technologies and innovations of the metaverse

Hardware
Innovations in physical technologies and devices used to access, interact with, or develop the metaverse

Computer
The enablement and supply of computing power to support the metaverse

Networking
The innovation provisioning of persistent, real-time connections, high bandwidth, and decentralized data transmission

Virtual platforms
The development and operation of immersive digital and often three-dimensional simulations

Interchange tools & standards
Innovating and defining de facto standards for interoperability

Payment services
Innovations support digital payment processes, platforms, and operations

Content, services & assets
Innovations regarding the creation, sale, storage, secure protection and financial management of digital assets

> The futuristic metaverse is a place where the **multivariate cross-utilization of the key innovations here analyzed will come full circle** – existing not just in the physical world but also in an entirely virtual universe – a place they helped to create

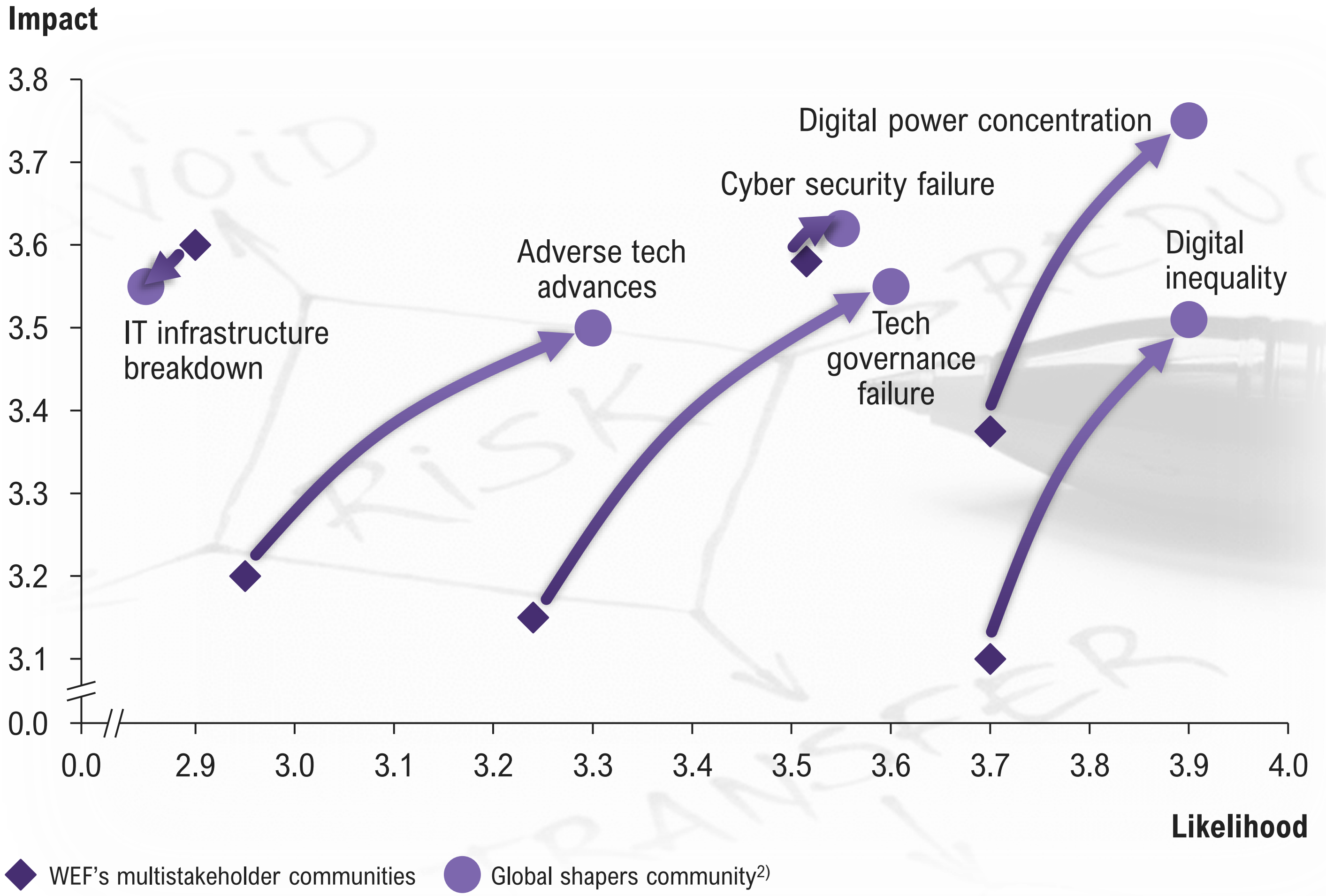
> Currently, the metaverse is mainly used in the world of **computer games**. However, it will emerge in other **business areas:**

- **Meta Platforms** (formerly Facebook), strives to be seen as a metaverse company. Already one fifth of its 63,000 employees are said to be working on necessary technologies. The company postulates that this will be **the most important topic for the next 10-15 years**
- According to its CEO, **Microsoft is** working on an **"enterprise metaverse"**
- **Nvidia,** the computer systems design services company, is building a **metaverse for engineers**
- Video game platform **Roblox** aims to give users and developers ways to create digital worlds, where **shopping** and **running a business** is possible

Sources: Bloomberg; Meta Platforms; Matthew Ball; Reuters; Press research; Roland Berger

The relationship of humans with machines is fraught with technological risk – Risk perception regarding innovations in the younger generation are higher

Global risks landscape[1)] for technological risks



> The **global risks landscape for technological risks,** according to a survey by the World Economic Forum, reflects the **perceived likelihood and impact** of such risks around the world

> Intergenerationally, the potential of technological risks are felt quite differently: Survey results for participants that belong to the **younger generation** mostly **perceive such risks to occur more likely** and **with higher impact**

> Differences between the generations were most notable regarding risks pertaining to **adverse tech advances, tech governance failure, digital power concentration** and **digital inequality** – indicating a more acute awareness of the **growing gap** between **the technological "haves" and "have-nots"** in the younger generation

> Two exceptions: **Breakdown of critical information infrastructure** and **failure of cybersecurity** measures are not perceived significantly more likely and/or of higher impact compared to the older generation surveyed

1) The global risks landscape is based on a survey carried out by the WEF. Respondents were asked to evaluate the perceived likelihood and impact of global technological risks on a scale from 1 (very low) to 5 (very high); 2) The Global Shapers Community is the WEF's network of young people driving dialogue, action and change

Sources: WEF; 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, such as the metaverse, point to further societal changes

Future of work

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

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 – the Collingridge dilemma

Fusion of humans & machines

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

Cybersecurity

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

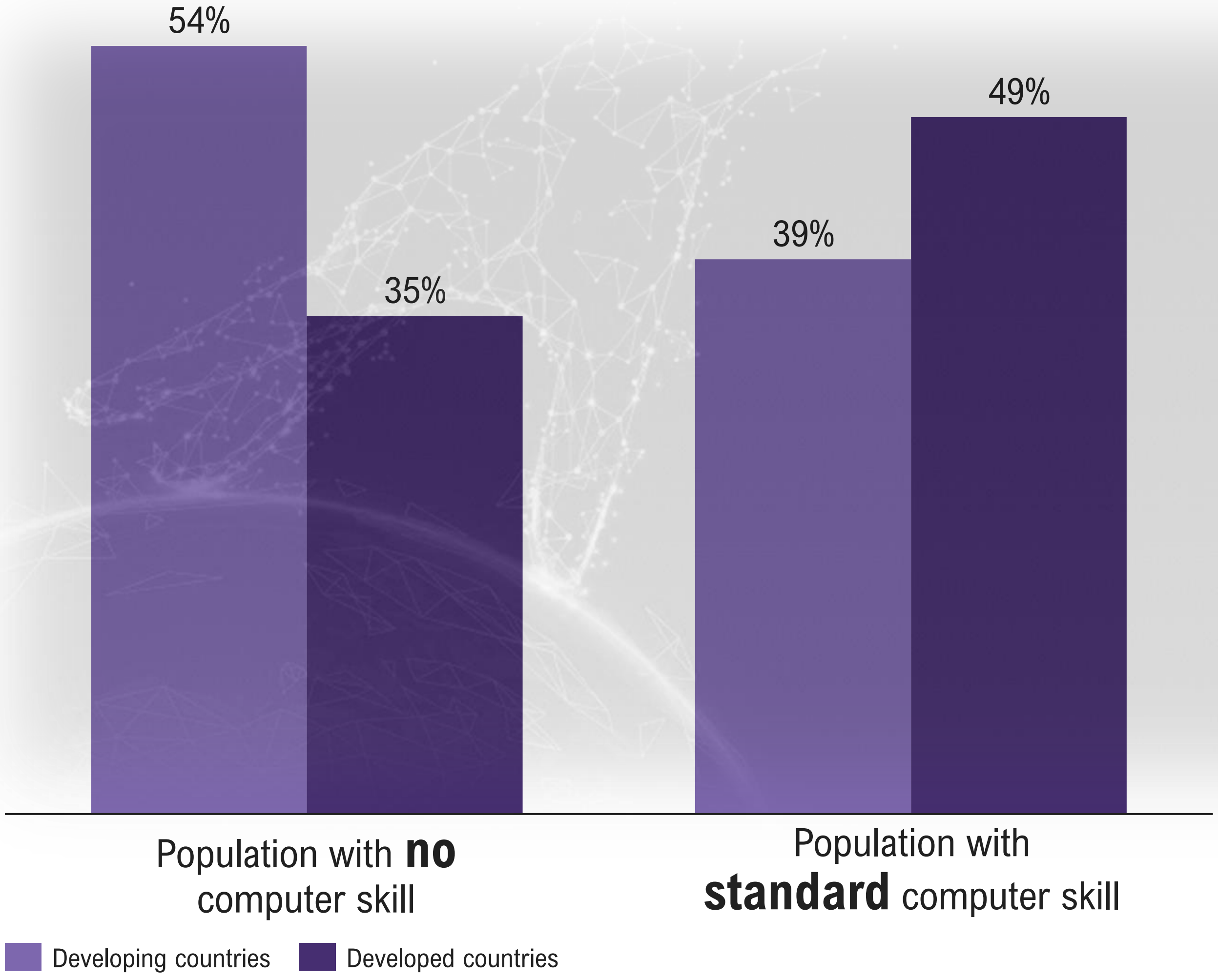
Machine behavior & AI

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

Sources: Roland Berger

However, unequal technological advances and diffusion have led to a digital divide – within countries and between world regions

Prevalence of computer skills in world regions [%]



> Technological advances also affect **social structures,** potentially carrying negative effects. From the contrasting picture of the distribution of computer skills across developed and developing countries, it is evident that **society is divided within a country,** but also **within regions** due to fast, relatively exclusive innovations and technological progress

> To level up, one consideration is to **rethink products under different price points.** Consumers that cannot afford high-end technology should be offered **lower priced versions that focus on inclusivity and standard i.e. essential functionality** (so-called **frugal** products) instead of high-end, high-specification product characteristics

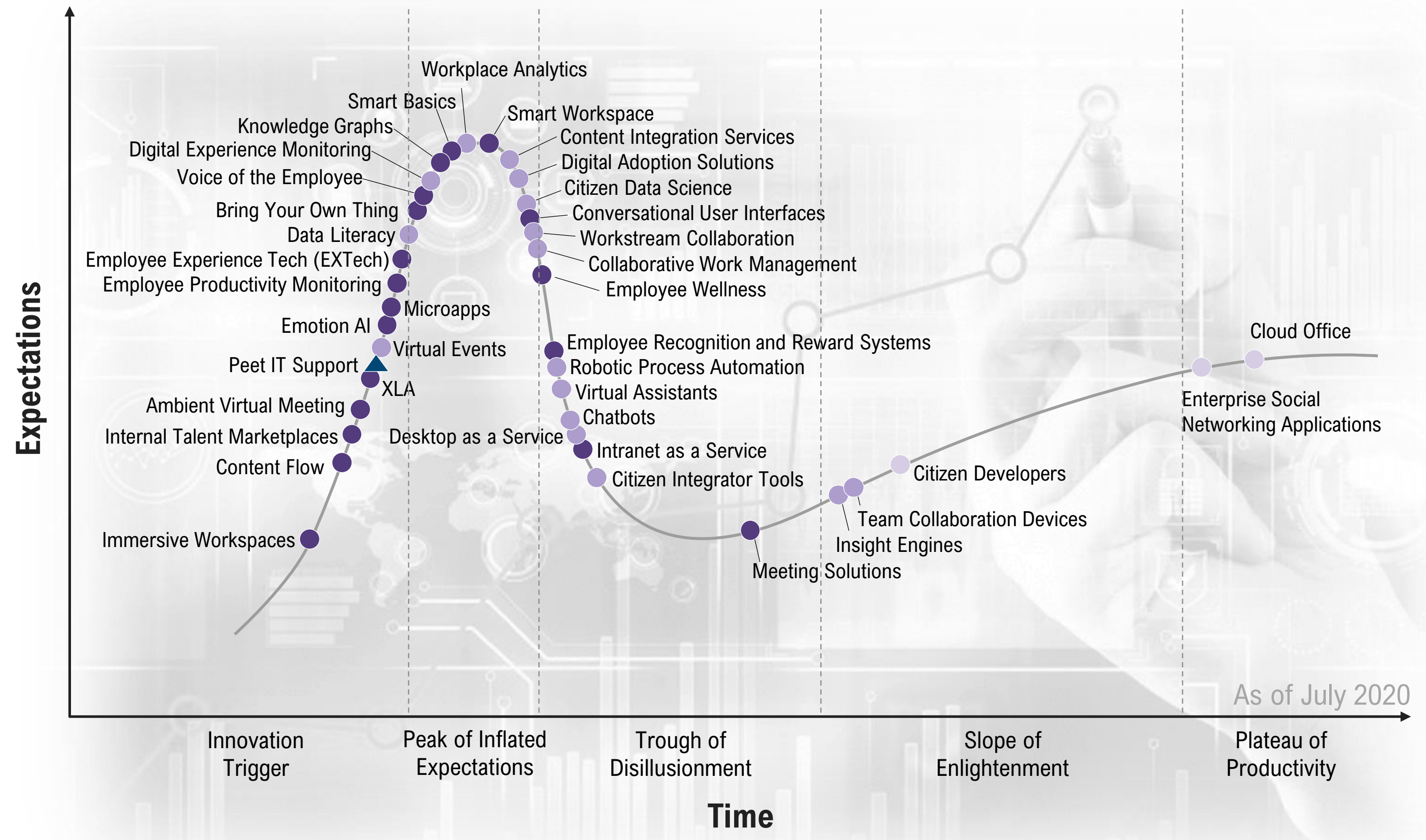
> Additionally, **access to new technologies** can be made **more equitable** when their **use is made simpler. More intuitive handling allows easier adoption** for a wider, more inclusive customer base, for example for the older, often less tech savvy generation

> Where **technological advances and innovations have profound implications for society,** governments as well as companies ought to consider the needs of different social demographics

Sources: UNCTAD; Roland Berger

Workplaces have experienced a push to digitalization due to the pandemic – Other innovations are yet to impact our working life

Gartner Hype Cycle for the Digital Workplace in 2020



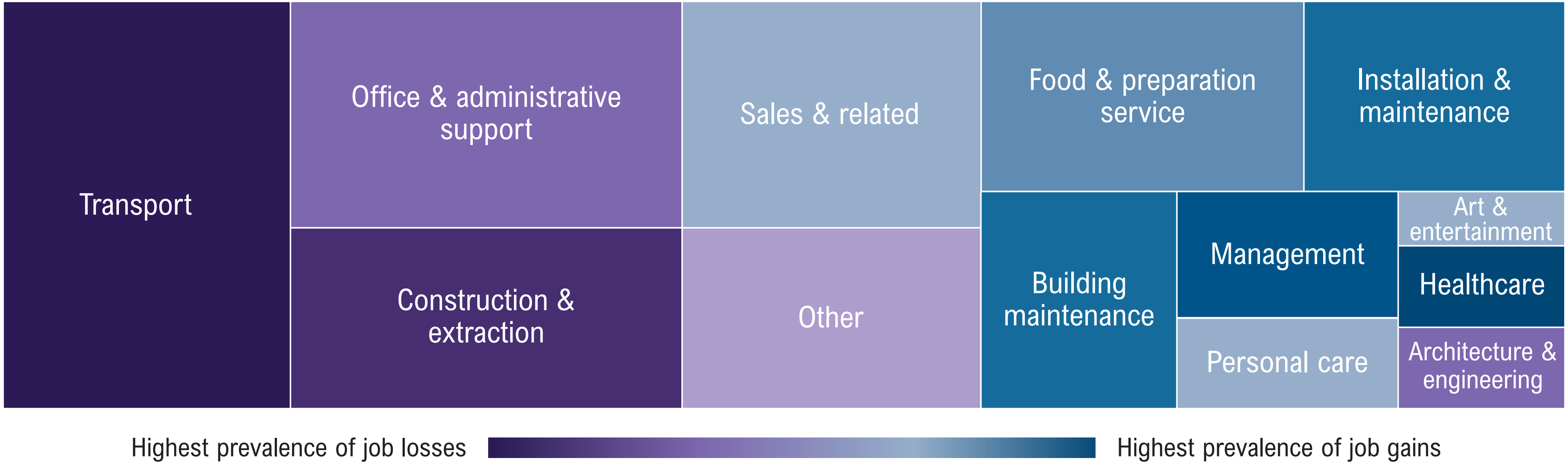
Plateau will be reached: <2 yrs. 2-5 yrs. 5-10 yrs. more than 10 yrs.

- Some areas of **workplace digitalization** have experienced an **extraordinary push** due to the global **pandemic** and the necessity to stay connected remotely; **concepts debated or piloted** for years have been **put into use almost overnight** in many countries around the world
- However, a considerable **number of digital workplace technologies** are also in a state of **inflated expectations** under an extended time horizon, such as digital experience monitoring and knowledge graphs
- In coming years, **expectations are high** for several workplace and collaborative innovations that have survived unrealistic hypes and will **enhance productivity** in the near to midterm, for instance, **team collaboration devices** and insight engines
- More immediately**, cloud technologies** and enterprise social networking applications have moved towards a more mature – the plateau of **productivity stage**

Sources: Gartner, Roland Berger

The labor market faces structural change: Jobs that can easily be handled by automation, robotics and AI will experience declines – While others benefit

Dynamics of occupations due to automation in the next ten years and relative sizes[1)] of sectors



> Industry 4.0 is causing a **structural change** in the labor market; newly applicable technologies, like AI, **bring considerable transformation potential to occupations.** This development is not simply about **substituting** workers with robots – more broadly, it highlights **new chances in the labor market**

> Over the next decade however, the sector that will **experience the most job losses** is the **transport sector**. **Autonomous vehicles** (AVs), driven by an AI system, will more readily **substitute car, taxi and van drivers**. It is expected that **more than four million jobs are likely to be lost** in a **rapid transition to AVs** beginning in five years time

> In contrast – and driven partly by other factors – the **health sector will experience an increase in labor demand.** Here, **robots** will take on **repetitive and menial tasks**, saving time for healthcare **professionals to focus on socio-emotional and emphatic components** of healthcare

1) The area of the squares represent the size of the respective sector in the global economy

Sources: WEF; Roland Berger

Roland Berger

The future of work will experience a shift in demand to higher skilled computer specialists – Redundant jobs are likely to be substituted by robots

Increasing and decreasing demand across industries for top 15 occupations

	Increasing demand	**Decreasing** demand
1	Data analyst & scientist	Data entry clerk
2	AI & machine learning specialist	Administrative & executive secretary
3	Big data specialist	Accounting, bookkeeping & payroll clerk
4	Digital marketing & strategy specialist	Accounting & auditor
5	Process automation specialist	Assembly & factory worker
6	Business development professional	Business services & administration manager
7	Digital transformation specialist	Client information & customer service worker
8	Information security analyst	General & operations manager
9	Software & applications developer	Mechanics & machinery manager
10	Internet of thing specialist	Material-recording & stock-keeping clerk
11	Project Manager	Financial analyst
12	Business services & administration manager	Postal service clerk
13	Database & network professional	Wholesale & manuf., tech & sci. products
14	Robotics engineer	Relationship manager
15	Strategic advisors	Bank teller & related clerk

> Considering specific occupations supported by latest projections, **shifting dynamics in the jobs market** become apparent: Increasingly **redundant roles will decline** from 15.4% of the workforce in 2020 **to 9% in 2025. Emerging occupations will grow** from 7.8% **to 13.5%** of the total employee base

> However, investigating 26 advanced economies, there will be **around 12 million more jobs available: 85 million jobs will be displaced** by a shift in the division of labor between humans and machines, **while 97 million jobs will be created** by **new divisions of labor** between humans, machines and algorithms

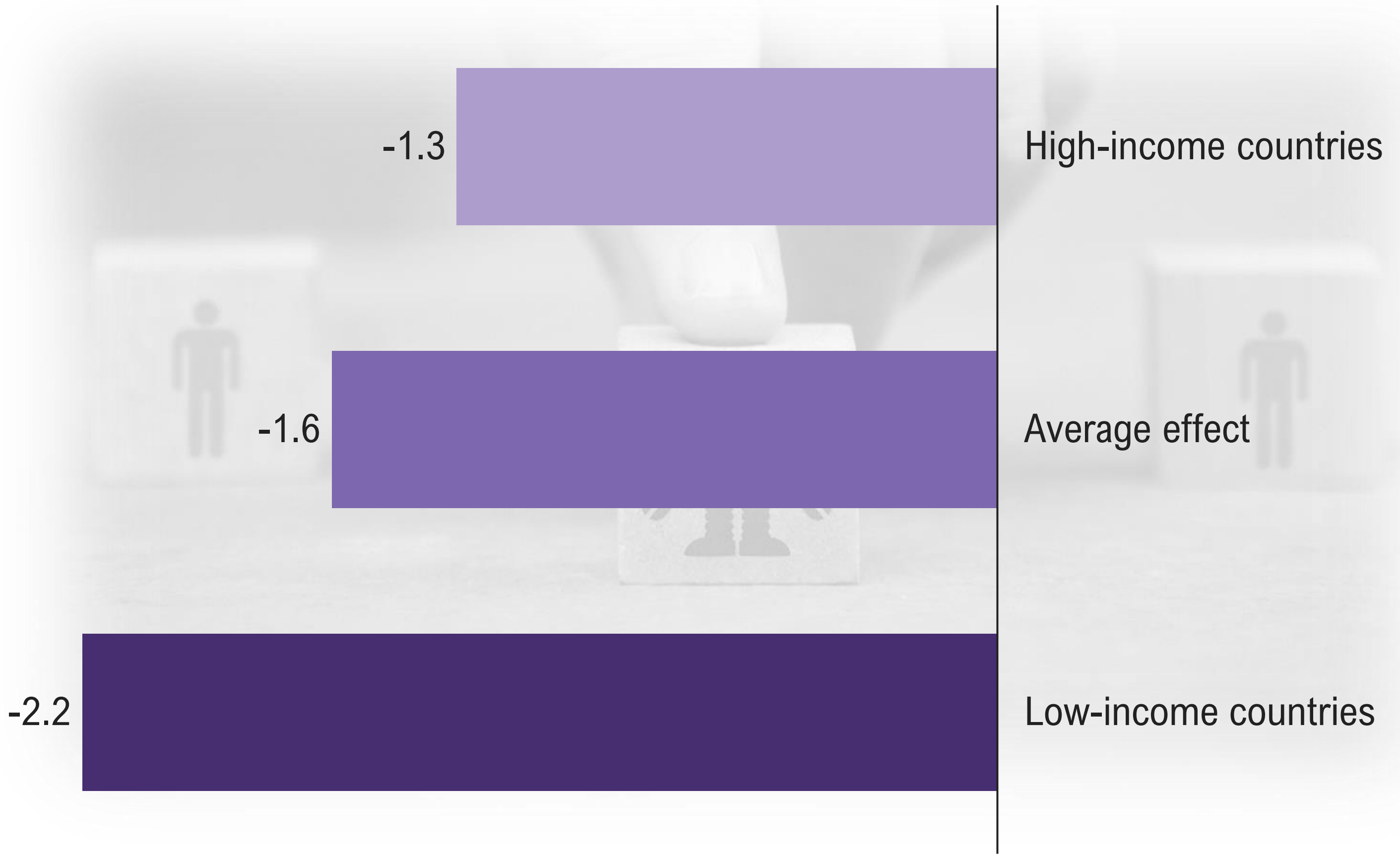
> Emerging occupations reflect new technology adoption and the **increasing demand for new products and services** due to Industry 4.0, especially in fast-growing fields such as the **data economy** and AI

Sources: WEF; Roland Berger

Automation and robotics compete with workers particularly in manufacturing and low-income countries – Each additional robot replaces 1.6 workers

Low-income countries undergo stronger substitutive effects

Changes in the number of jobs due to one additional robot being deployed in the manufacturing sector in the long term[1)], by income level of country

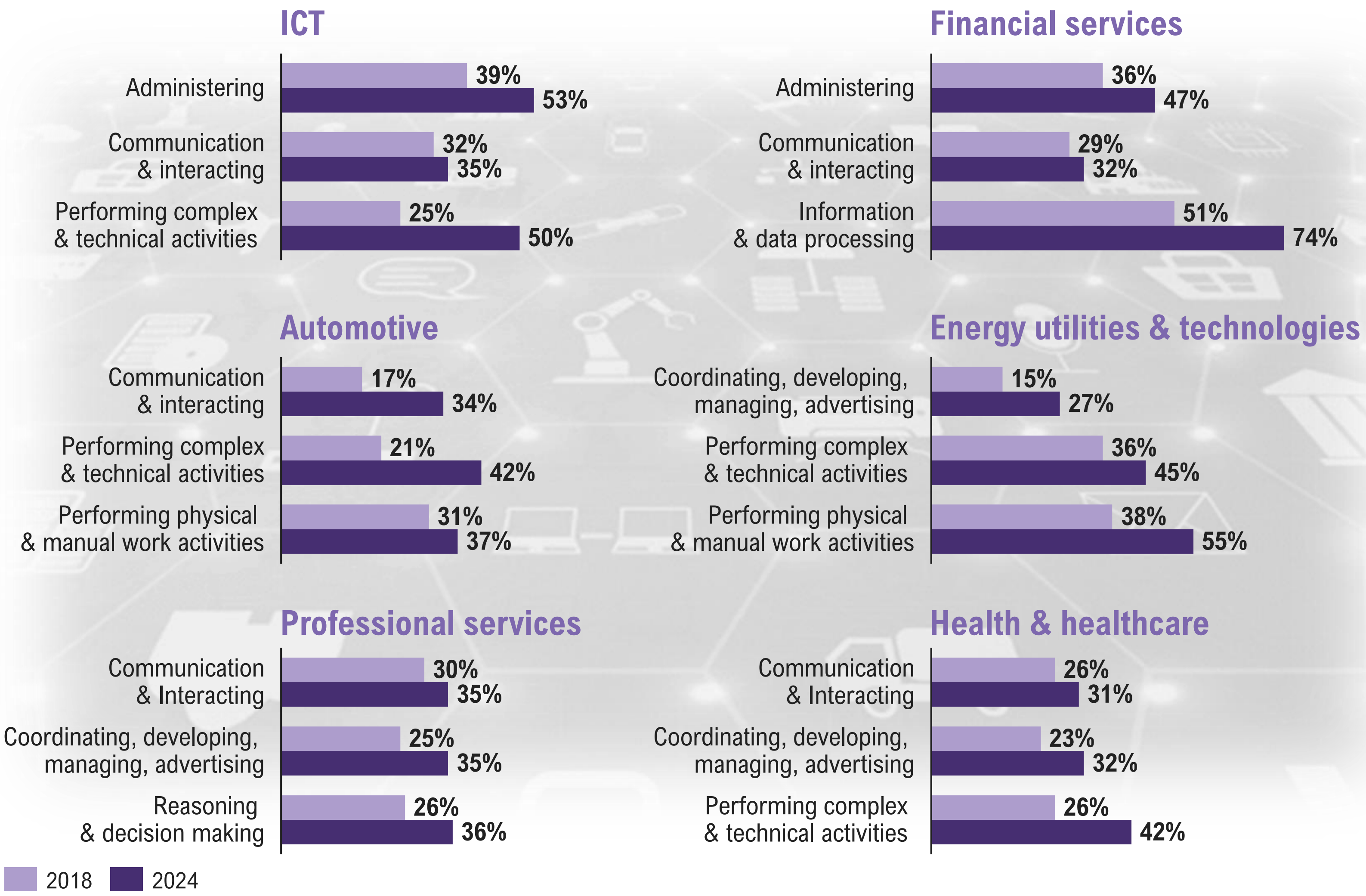


- **Technological progress is having an ambivalent impact** on the labor market. Multiple socioeconomic and political factors determine its **sectoral impact** in which innovations are deployed
- Traditionally, the **agricultural sector** has experienced **progressive levels of automation** over decades, if not centuries, in a steadily increasing number of countries
- In the **manufacturing sector**, **machines represent** a particularly **large competition for workers.** Here, on average, **each additional robot replaces 1.6 jobs.** It is estimated that 20 million jobs will be lost in the manufacturing sector by 2030
- **Low-income countries are particularly affected** since their manufacturing sector is not as heavily automated compared to high-income countries. By the sheer size of its present workforce, **most job losses due to automation will be noted in China**

1) The long-term effect builds over 10 to 15 years after robot installation
Sources: Oxford Economics; Roland Berger

All industries will experience a shift towards automation – Depending on tasks and sectors, machines will either complement or substitute humans

Share of task hours carried out by machines by selected industry [%]

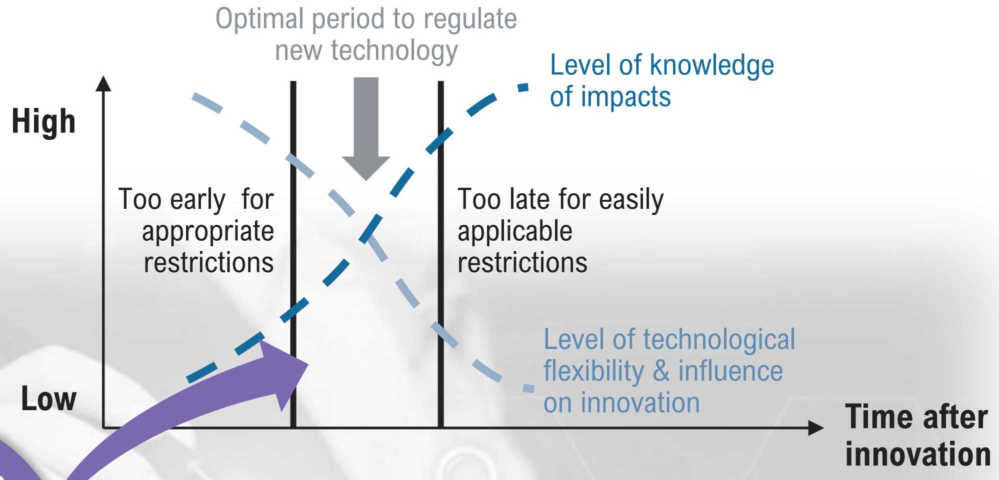


Sources: WEF; Roland Berger

- At first glance, the overall future picture of relatively more machines taking over certain appears **broadly progressive**
- However, an acute **difference lies in the extent of change depending on specific tasks** until **2025**
- Especially tasks that relate to **communication and interaction are affected relatively little by automation.** Such tasks will still be carried out more effectively and efficiently by humans
- Other tasks, however, such as **information and data processing** as well as menial **manual tasks** will predominantly be carried out by increasingly **smart and tireless machines**

Future implications of technological advances regarding humanity are not entirely foreseeable – Regulators face a double-bind dilemma

Innovation governance suffers from the Collingridge Dilemma



Collingridge Dilemma: When is the optimal time for regulation?

Governance of innovation and technology mitigating negative impact on society

Regulations affecting the **general process** of **innovations** & Regulations affecting **specific technology developments & use**

Governance of innovation and technology requires clarification of:

Anticipation (When?) **Inclusion** (Who?) **Directionality** (What? Why?)

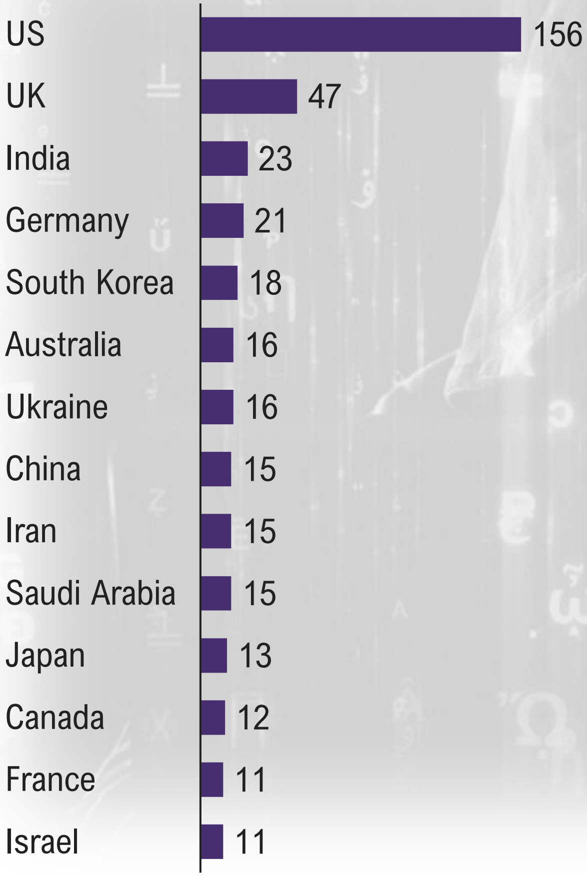
- How do you control technological progress – if we are unable to understand the extent of all its implications? The **Collingridge dilemma** highlights the **double-bind quandary** regulators face regarding innovative technology: On the one hand, there exists an **information problem** where **impacts cannot be easily predicted** until the **technology is developed** and widely **used.** In tandem, there is a **power problem** whereby **control or change is difficult, time-consuming and expensive** once the **technology** is **widely adopted**
- Popular new technologies also carry ethical, economic, environmental and/or health-related implications – a **perfect example** is the **internal combustion engine.** Globally adopted, yet hardly regulated until 20 years ago, society now faces immense challenges to reign in its unforeseen global warming contribution
- Yet, **early regulatory restrictions** may **hinder full deployment** or can be inadequate. But once **technology is prevalent** it **is too costly and difficult** to implement **corrective measures**
- **To minimizing trade-offs, combined regulatory governance** of the **general process of innovation** and the **technology-specific developments** is key. For example, in the pharmaceutical sector, **general process regulations** are reflected in rules regarding animal testing, while regulations concerning **specific technology developments and their use** apply in instances of market approval of medications

Sources: OECD; Roland Berger

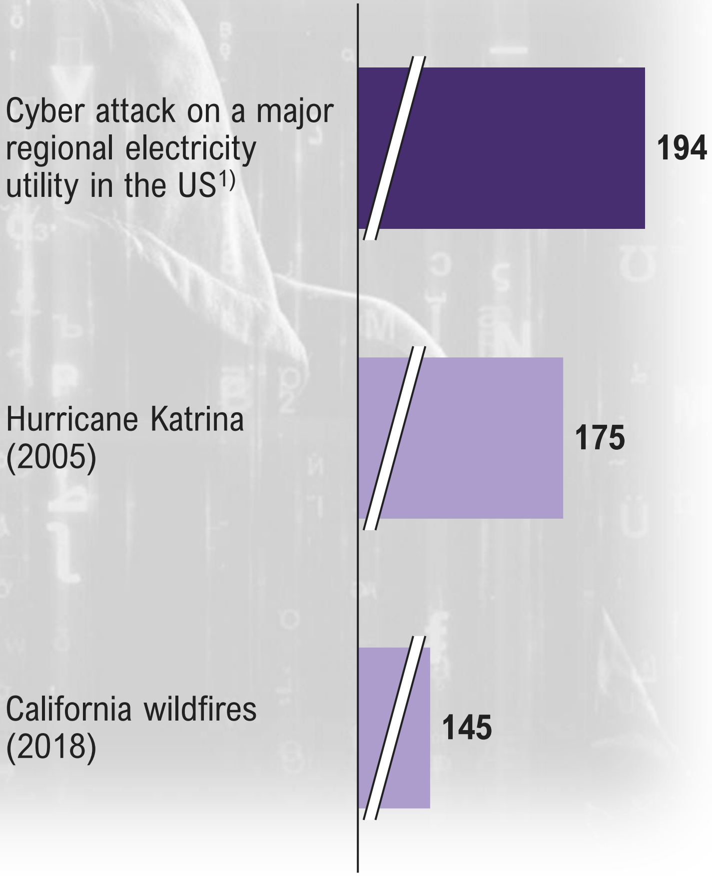
Cyberattacks are on the rise carrying considerable infrastructure and socioeconomic costs – USA is a key target

Cyberattacks are an evolving global and costly phenomenon

Total number of significant cyberattacks, 2006-2020



Estimated losses from disasters in the US [USD bn]



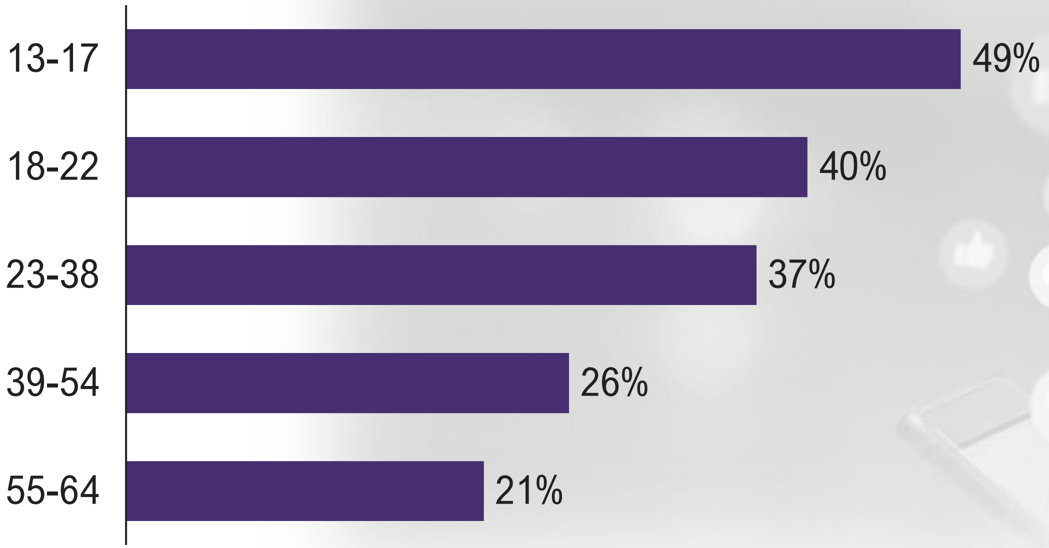
- Cyberattacks are continuing to evolve and use **innovations in information technology** – such as the Internet – as **vectors to commit cyber crimes**. With the rise of the Internet, more (sensitive) private sector data is transferred, while important **public infrastructure is also controlled** in this way, **widening the scope for top risk security breaches**
- In recent years, the **scale and robustness of cyberattacks has increased rapidly** and at a faster rate than our ability to deal with hostile attacks, according to the WEF
- Especially the **USA faces a significant number of cyberattacks,** aimed at both public and private organizations. A major, successfully executed cyberattack aimed at sensitive infrastructure, carries a **potential cost of almost USD 200 billion – a sum considerably larger than the costs** associated with the widescale destruction created by **hurricane Katrina.** Moreover, around 100,000 people could lose their jobs as a result

1) Disruption of power generation across the grid for five days

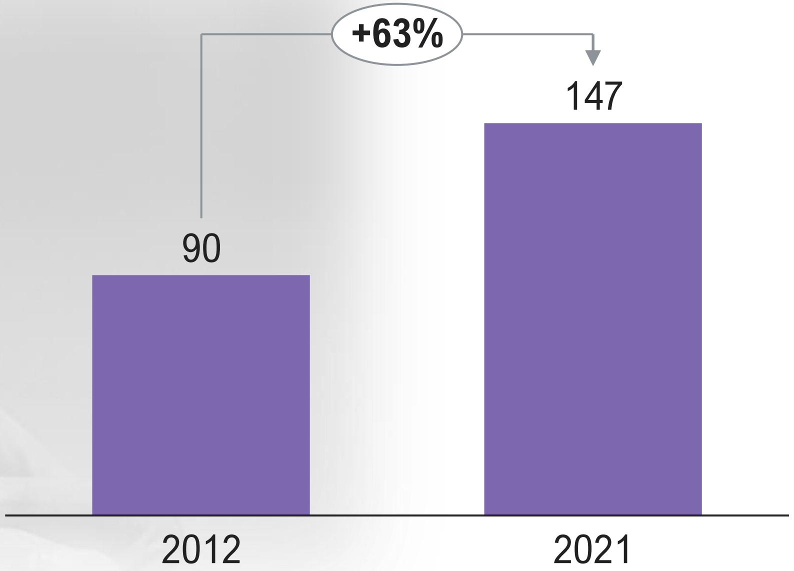
Sources: Visualcapitalist/Specops Software; WEF; FDD & Intangic; Roland Berger

New technologies do not necessary influence society for the better – Younger age groups state a notable addiction to social media

Share of consumers by age that would describe themselves as addicted to social media in 2019 [%]



Amount of time an average consumer spends on social media [min/d]



- > **Social media** has profoundly changed society and clearly has **aspects of intrinsic value**. Bridging geographical divides, for example by bringing family and friends closer together, is a much cited positive. However, other factors are not always so beneficial
- > Today, the **average user spends 63% more time** on social media compared to a decade ago, totaling around **two and half hours per day** – up from an hour and a half in 2012. Social media user behavior varies widely depending on age. In the youngest age group of the **under 18s nearly half describe themselves as "addicted to social media"** – with the next older cohort not very far behind
- > With user data analysis and the help of AI, **social media platforms can deploy targeted individual feeds** and tailor information to users – amplifying so-called **echo-chambers** and Internet bubbles including the **dissemination of misinformation and fake news.** The **proliferation** of untruths and **baseless conspiracy theories** is a global emergency, **profoundly dividing societies while straining socio-political relationships**

Sources: Think Now; Datareportal; Roland Berger

From Facebook to the metaverse – Are social media just the launch pad for a profoundly dynamic change of global society?

The next big thing: The metaverse creates a virtualized society

Metaverse

The **metaverse** enables our current **daily life** to completely move **to a digital and virtual world**, ultimately having a **profound impact** on **society**

Meta world

The new meta world will be persistent, synchronous and live. Individuals will not be able to pause it like in a game. It continues indefinitely, like a parallel world

Meta space

New space will be created which users can acquire. Users can meet in coffee shops, go to concerts or buy clothes in shopping stores in the metaverse – All for their personal avatar

Meta reality

Everybody can be a part of the metaverse and participate in a specific event, place or activity together, at the same time, with individual agency

Meta economy

Individuals and businesses will be able to create, own, invest, sell, and be rewarded with a wide variety of cryptocurrencies – For instance, buying land to build a house in the metaverse, or creating new business models[1)]

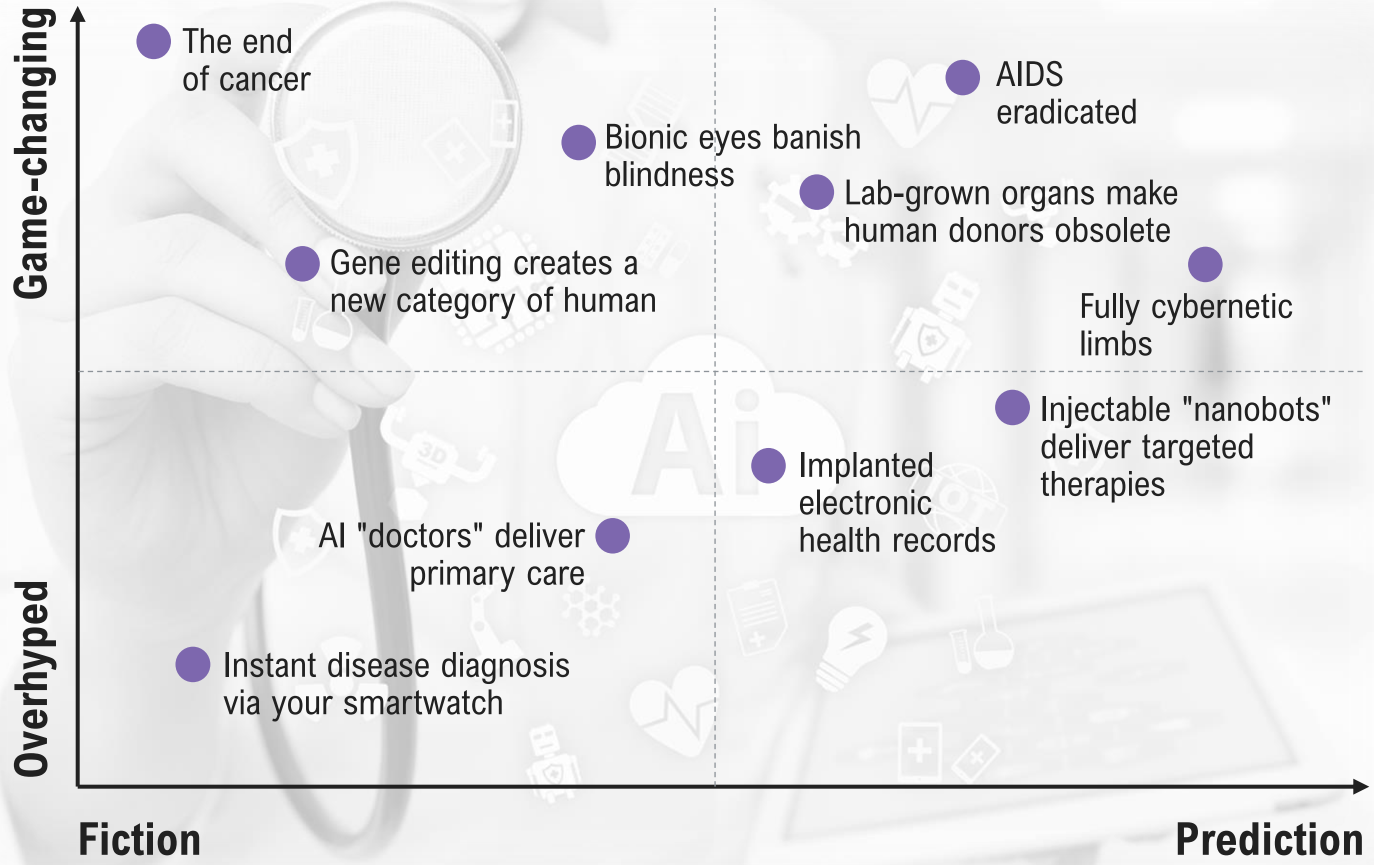
> ***"You can think about the metaverse as an embodied Internet, where instead of just viewing content – you are in it."***
>
> Mark Zuckerberg

1) According to a 2021 study by Wunderman Thompson Intelligence (Into the Metaverse), metaverse users from the US, China and UK are willing to pay up to USD 76,000 for houses

Sources: Matthew Ball, The Verge; Wunderman Thompson Intelligence; Roland Berger

Taking advantage of new technologies enables future medical progress to eradicate many more diseases by 2050 – Quality of human life is increased

Likelihood for selected technological innovation and impact on society for health & medicine in 2050



- Technological progress has always given rise to the **hope that previously incurable and dangerous diseases could be eradicated.** Rapid coronavirus vaccine success based on novel mRNA technologies, for example, has saved 500,000 lives in Europe alone
- Until **2050, medical innovations will further contribute to saving lives** and avert burdensome illnesses. Despite best efforts however, some diseases are unlikely to be curable in their entirety by 2050
- Although **some types of cancer are already curable today,** if cancer were to be entirely overcome by 2050, the impact on society would beyond game-changing. However, its complete eradication is likely to remain **wishful thinking**
- A disease more likely to be curable and/or fully **eradicated** within timeframe is **AIDS.** HIV has claimed 36.3 million lives so far and although medication has become available in recent years to help manage the disease, (premature) death rates are relatively high

Sources: UCSF Magazine; Health Europa; Roland Berger

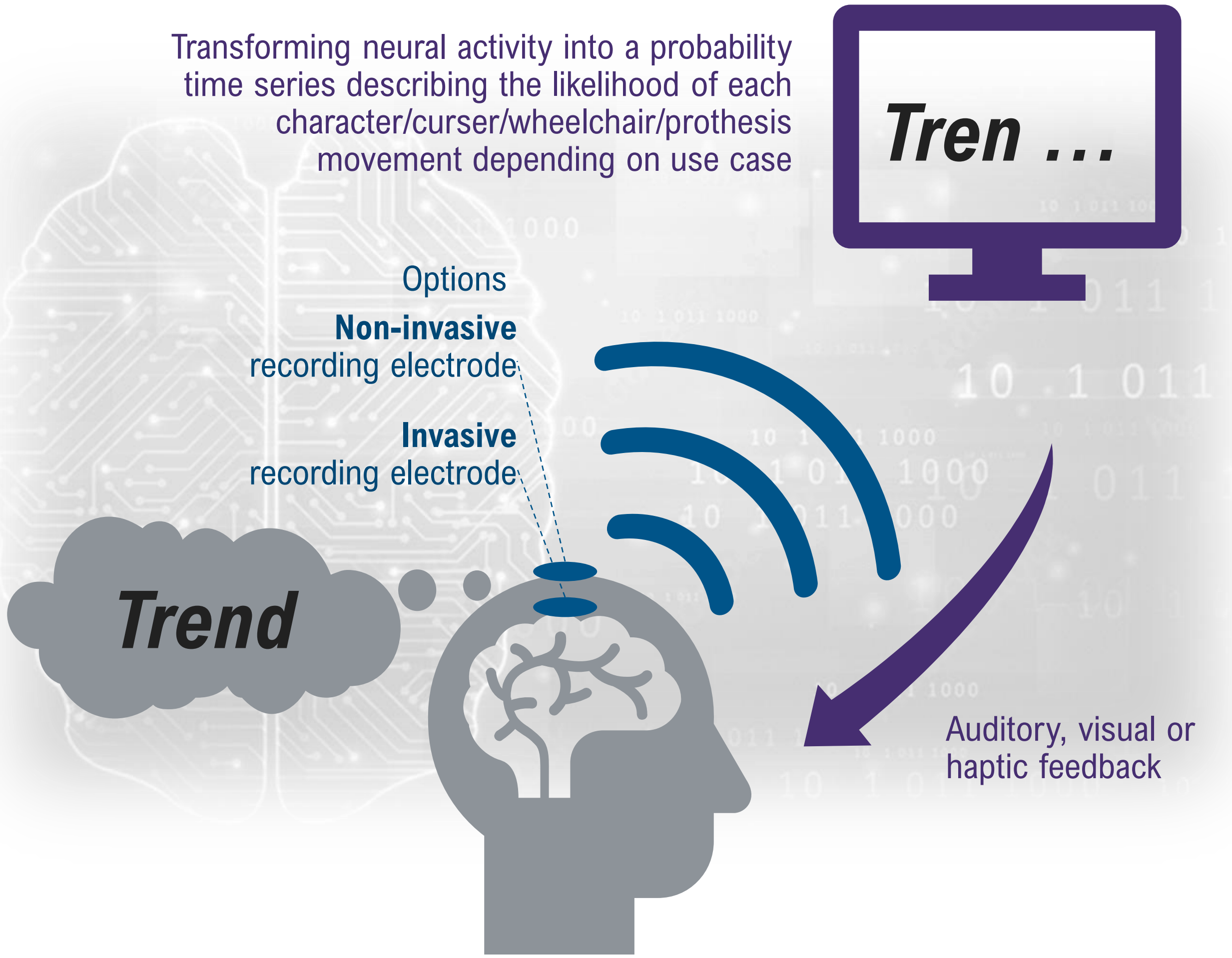
Curing diseases vs. human enhancement – New biotechnologies bring novel and hitherto unresolved ethical and social concerns

Biotechnologies	Ethical & social concerns
Life span extension Extending life span too far beyond current averages	Life-extension is considered unnatural and can put a burden on the society, the environment and the economy (limited resources have to be used for more people, financial cost increase). Furthermore, access to life extension procedures would be unequal
Cyberware For example, exoskeletons, advanced protheses	Using cyberware to ensure therapeutical success is not primarily of ethical concern. However, in certain use cases, such as in military applications or manufacturing, with the effect of dehumanizing people or by providing an unfair advantage, it is highly questionable
Gene therapy Gene manipulation to cure diseases e.g. cancer (see subtrend 2)	Gene therapy is mostly considered as accepted with little to no ethical and social concern as it represent a key technology to cure diseases such as cancer
Human genetic engineering Embryonic gene manipulation e.g. to cure hereditary disorders (see subtrend 2)	Human genetic engineering, which implies embryonic editing removes levels of autonomy in the decision-making process of as yet unborn individuals. Furthermore, edited genes are carried by future generations; concerns are highly dependent on national ethical and legal frameworks
Nanomedicine Medicine that includes complex nanotechnological particles (see subtrend 2)	Here, any distinction between human enhancement and therapy becomes highly blurred. Hybrid humans – nanotechnology combined with humans – can be regarded as highly unethical due to unfair advantages; the impact on the preservation of human identity is a contentious issue
Bioprinting & xenotransplantation Laboratory and animal-based organs (see subtrend 2)	The main concern here arises from the cells used for bioprinting – human embryonic stem cells. A different source are xenogeneic (cross-species) cells, which however, like patients with xenotransplantation, might create issues of personal identity

Sources: Rejuvenation Research; Yale University; Frontiers in Oncology; Springer; Roland Berger

Brain-computer-interfaces could revolutionize human-machine interaction – Controlling devices and machines with thoughts is already possible

Schematic brain-computer-interface



- Machines are increasingly complementing humans. Up to now, these interactions are mostly characterized by so-called **"Human-Machine-Interfaces" (HMI).** An example for HMI are robots in factories that help automate production and are commanded by humans
- As technology progresses, a novel **"brain-computer-interface" (BCI)** emerges. Taking advantage of **electromagnetic flows (neural activities)** in the brain, **AI** and probabilistic models can be used to **transform thoughts into actions**
- For instance, **thinking of writing a word,** neural activities can be collected and processed in such a way that the **computer knows which word to write.** A team of Meta Platforms/Facebook AI experts and engineers aims to deploy an interface able to type 100 words per minute merely by thought – an output far higher than an average typist
- Car manufacturers such as Nissan are also working on BCI technology. Their aim is to **steer cars with thoughts – i.e. brain-to-vehicle technology (B2V).** Connecting the car directly to the brain reduces reaction time significantly, as muscle activation is omitted, reducing emergency braking by around 0.4 to 1 second – long enough to avoid accidents altogether

Sources: Fraunhofer INT; Roth Institut; Nature; Roland Berger

The progression of AI capabilities is expected to be near limitless – Intelligent machines will accomplish more and more ambitious tasks

Timeline of artificial intelligence (AI) achieving human performance with a probability of 50%[1)]

2020

2024 – Telephone banking operator: Provide phone banking services as well as human operators can – without annoying customers more than humans

2025 – One-shot learning: See only one labeled image of a new object, and then be able to recognize the object in real world scenes, to the extent that a typical human can

2026 – Answer questions without definite answers: Give good answers in natural language to factual questions posed in natural language for which there are no definite correct answers

2026 – Write a high school essay: Write an essay for a high school history class that would receive high grades and pass plagiarism detectors

2027 – Generate top 40 pop song: Compose a song that is good enough to reach the US Top 40. The system should output the complete song as an audio file

2028 – 5 km race in city: Beat the fastest human runners in a 5 kilometer race through city streets using a bipedal robot body

2034 – Go (same training as human): Defeat the best Go players, training only on as many games as the best Go players have played

2049 – Write New York Times bestseller: Write a novel or short story good enough to make it to the New York Times bestseller list

2050

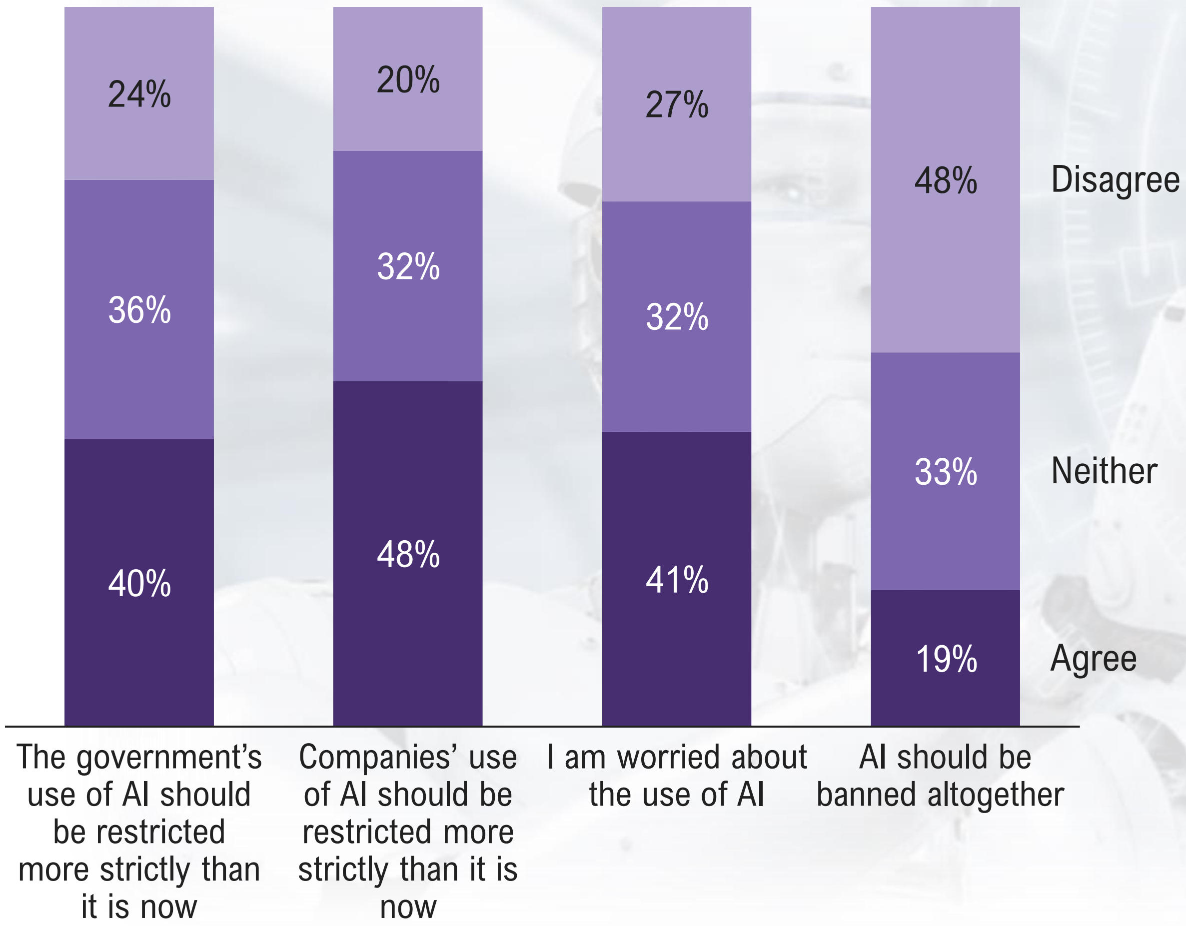
AI experts expect that – with a probability of 50% – around **2060 unaided machines** will be able to **accomplish every task better and more cheaply than human workers.** Around **2140 all occupations** will be **fully automatable**[1)]

1) Based on an international survey of machine learning researchers
Sources: Journal of Artificial Intelligence Research; Roland Berger

Roland Berger

AI's huge power is met with enthusiasm mixed with concerns – Inherent human values must stay central to current and future developments

Results from a global survey about the use of AI, 2019 [%]



Selected views of entrepreneurs and scientists on AI

Greg Shannon, Carnegie Mellon University
"If elements of community happiness are part of AI objective functions, then AI could catalyze an explosion of happiness."

Bill Gates, Microsoft Foundation
"[The power of AI is] so incredible, it will change society in some very deep ways. The world hasn't had that many technologies that are both promising and dangerous."

Elon Musk, Tesla
"Humans must merge with machines or become irrelevant in AI age."

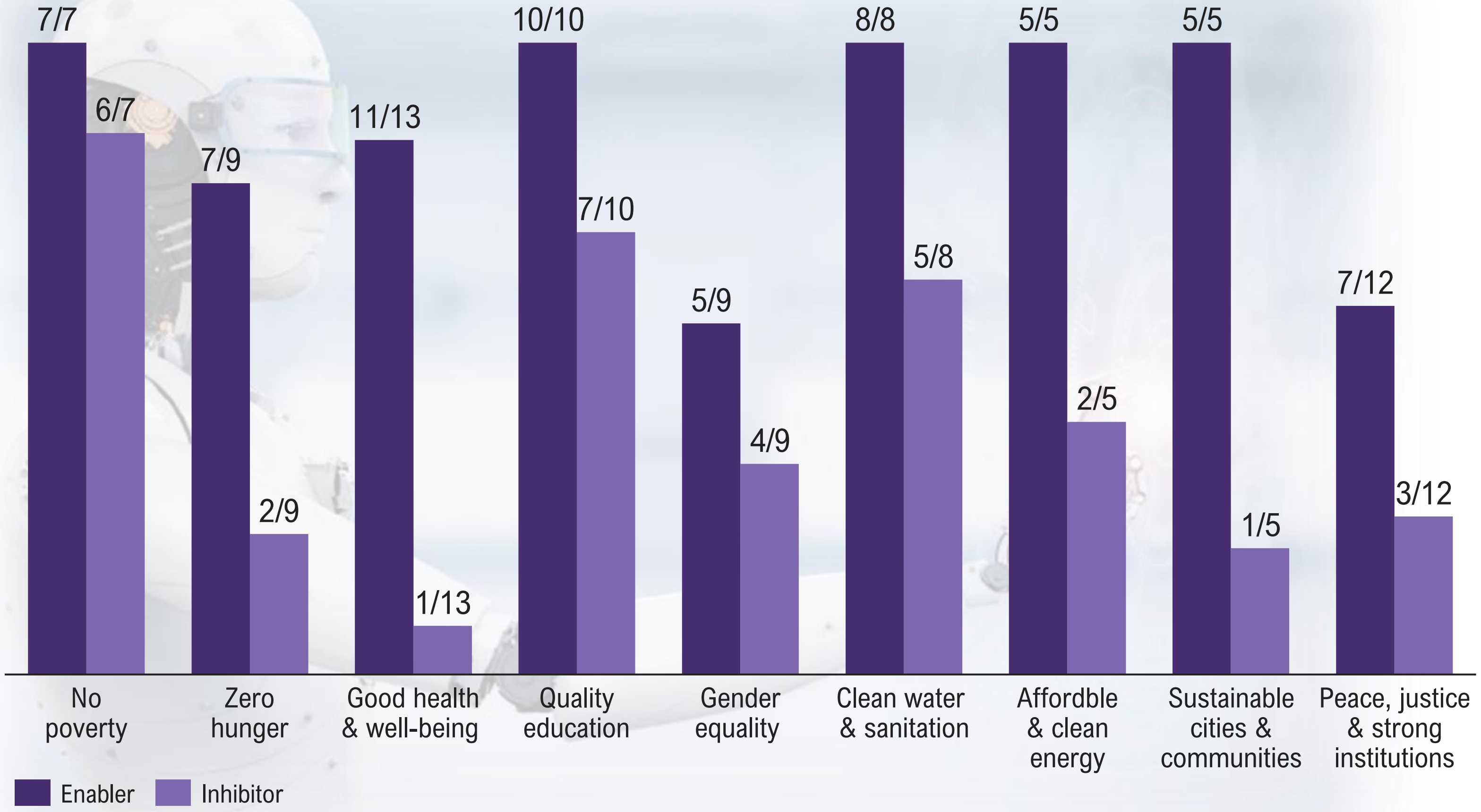
Erik Brynjolfsson, MIT
"We need to work aggressively to make sure technology matches our values."

Jeff Bezos, Amazon
"I think autonomous weapons are extremely scary. [The artificial intelligence tech that] we already know and understand are perfectly adequate [to create these kinds of weapons]."

Sources: Pew Research; CNBC; Ipsos

In terms of societal aspects under global sustainable development goals to 2030, AI is seen as more of an enabler than an inhibitor

The role of AI as an enabler or inhibitor under sustainable development goals to 2030 along defined societal categories[1)]



- > In 2015, the UN outlined 17 global **Sustainable Development Goals** (SDGs) across **social, environmental and economic categories** with a horizon to **2030;** progress is measured against a defined set of targets for each goal – for example, the societal "no poverty" SDG consists of 7 targets
- > In the context of Humans & Machines, we **focus on the consensus** regarding the **role of AI** vis-a-vis **societal SDGs to 2030**
- > According to extensive academic literature in this regard, AI is seen rather more of an enabler than an inhibitor: **82% of the societal targets could potentially benefit from AI-based technologies**, whereas 38% of targets can be negatively impacted by AI

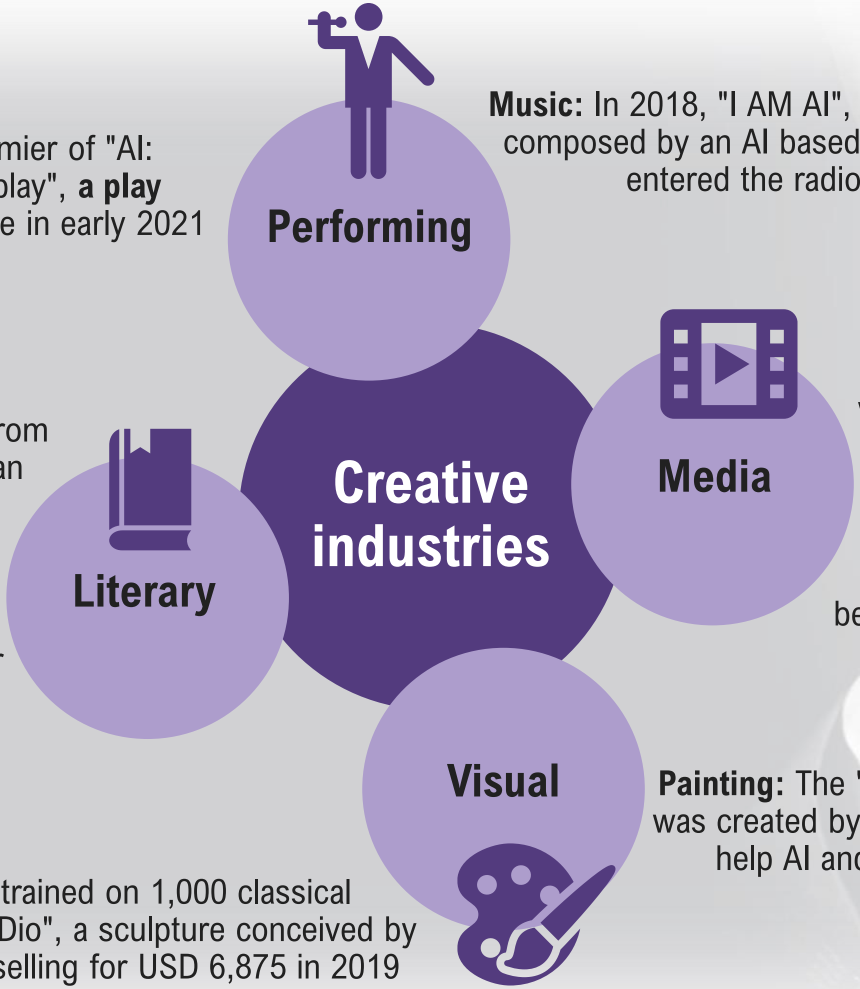
1) Based on a study of how AI can either enable or inhibit the delivery of all 17 goals and 169 targets recognized in the 2030 Agenda for Sustainable Development. Reading example: For the SDG "No poverty" the study found evidence that for 7 of the 7 targets of this SDG AI is an enabler, and for 6 of the 7 targets AI is an inhibitor (i.e. AI can be an enabler and an inhibitor for the same target).
Sources: Nature Communications; Roland Berger

AI's ability to be deployed creatively has already allowed the technology to proliferate in other sectors such as music, art and culture

AI enters the creative realm – Selected examples

Theatre: The world premier of "AI: When a robot writes a play", **a play written by AI**, took place in early 2021

Music: In 2018, "I AM AI", the first music album composed by an AI based virtual artist system, entered the radio charts at number 48



Films: Benjamin, a self-named AI bot, wrote the script for the sci-fi short-film "Sunspring", debuting in June 2016

Installation Art: In Istanbul, the artist Refik Anadol uses AI to illustrate the connection between 1.7 million documents in an immersive media installation, called "Archive Dreaming"

Poetry: In 2018, a team of researchers from Kyoto University and Microsoft created an AI-made poem convincing online judges it was written by a human

Horror Story: In 2017, MIT researchers trained an AI named Shelley to write horror stories based on 140,000 Reddit post

Painting: The "Portrait of Edmond de Belamy" was created by the collective Obvious with the help AI and sold for USD 430,000 in 2018

Sculpture: An AI trained on 1,000 classical statues created "Dio", a sculpture conceived by artist Ben Snell, selling for USD 6,875 in 2019

Sources: RAND; THEAITRE; AI ARTISTS; MPG; WEF; MIT; Roland Berger

AI's future journey is rooted in the computation of human perceptions – Efforts are needed to counteract embedding discriminatory bias into systems

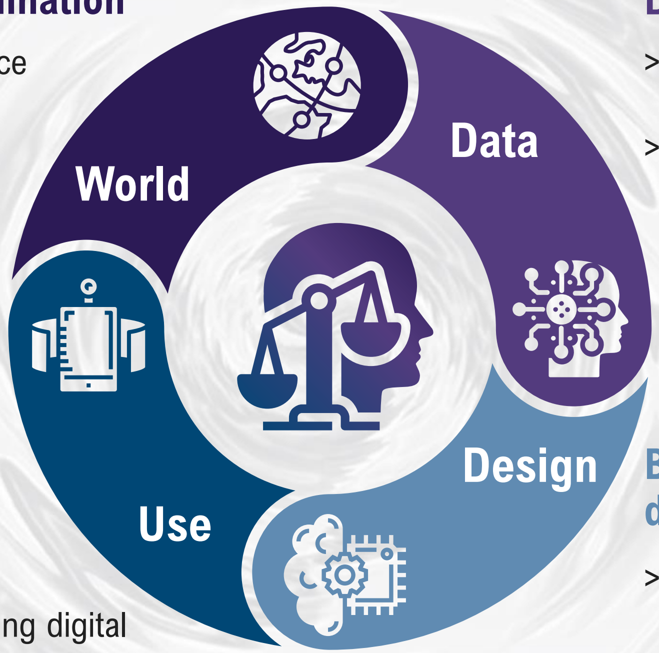
Vicious cycle of discrimination and bias aggravated by AI

Real world patterns of inequality and discrimination

> Unequal access & resource allocation

> Discriminatory processes

> Biased decision making



Discriminatory data

> Sampling biases and lack of representative datasets

> Patterns of bias and discrimination baked into data distributions

Biased AI design and deployment practices

> Power imbalances in agenda setting & problem formulation

> Biased and exclusionary design, model building and testing practices

> Biased deployment

Application injustices

> Disregarding and deepening digital devices

> Exacerbating global inequality & rich-poor gaps

> Hazardous & discriminatory repurposing of biased AI systems

> All societies are afflicted with inequalities and biases; **AI systems adopt these biases** through several ways: the use of discriminatory data stemming from sampling errors or lack of information, or through biased AI design and deployment practices

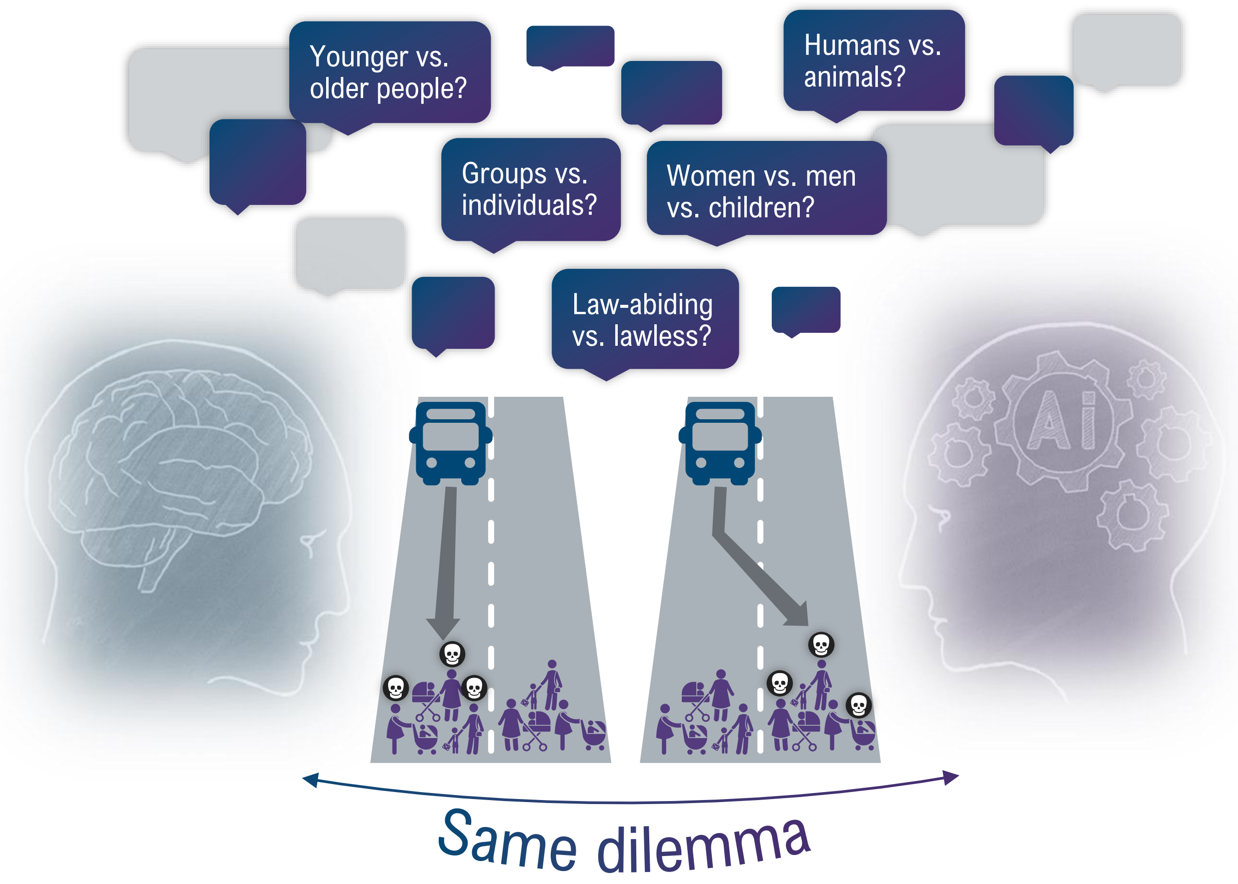
> Applying biased or discriminatory AI to the real world, **enforces a vicious cycle** – as was the case of Amazon and their use of AI to review job applicants' CVs in order to automate the search for talent; the AI deployed turned out to be inherently biased, having been trained to vet applications by observing patterns in resumes submitted to the company over a 10-year period. As most CVs were submitted by men, the system **showed a clear bias toward women applicants**

Sources: British Medical Journal; Reuters; Roland Berger

The morality of AI is under scrutiny as decision making is transferred increasingly to machines – Complex dilemmas and conflicts remain

The Moral Machine – Computing complex and paradox issues

Who should be spared? Example: An imminent car crash

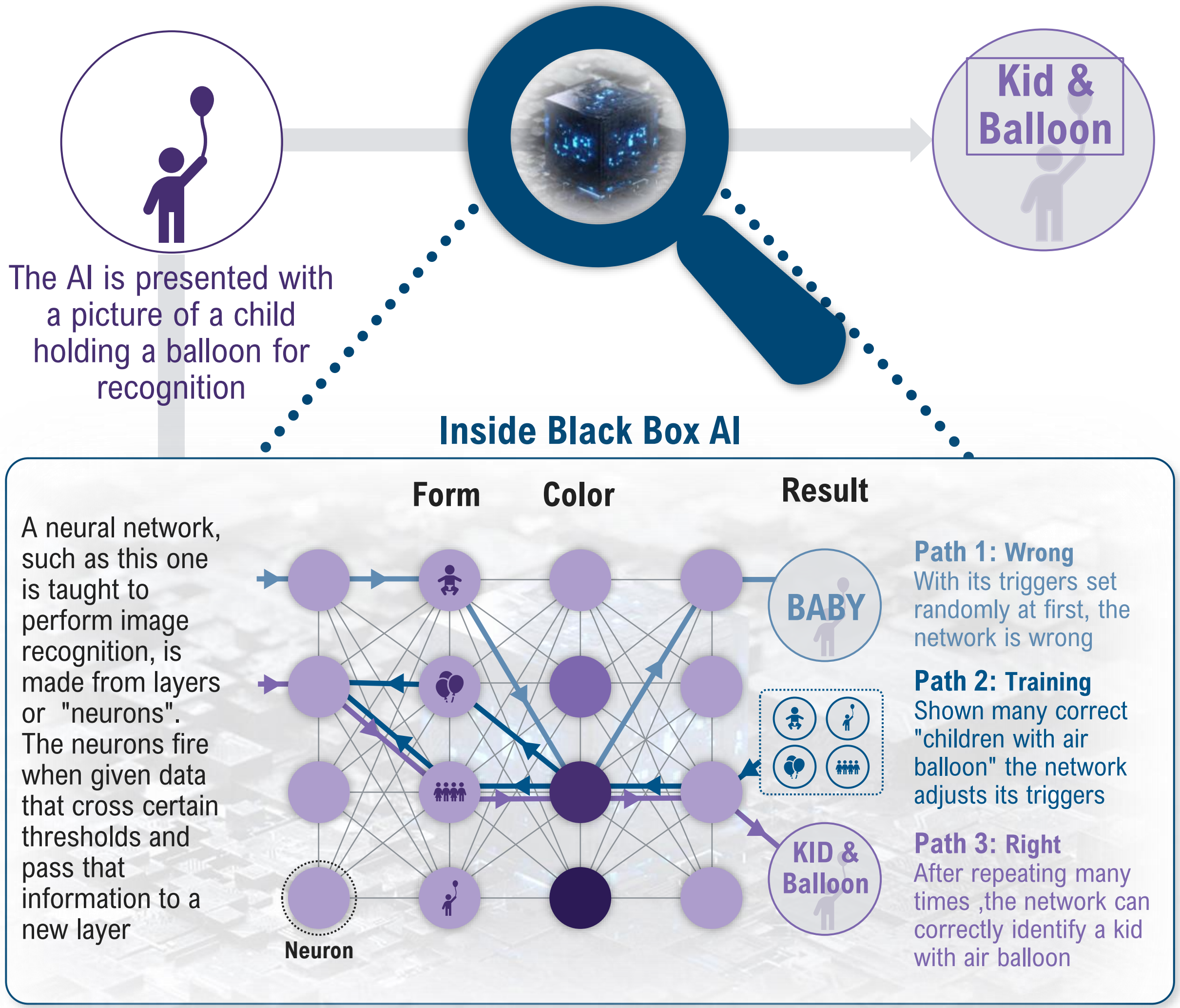


- With the progressive development of AI, today's often **highly individual human-based decision making** (e.g. as a driver of a car whose breaks are failing while approaching a busy crosswalk) **is increasingly shifting towards intelligent machines and AI** (e.g. an autonomous car in the same situation) – the latter being programmed to pursue an optimal goal
- The core of the so-called **"trolley problem"** – a pioneering **moral dilemma** first proposed in 1967 – **is now, in the age of AI, encased in a new layer of complexity:** Beyond the key question faced by an individual (car) driver or AI system of what is considered an **"optimal" outcome** under exceptional circumstances, AI is being tasked to **aggregate and account for varied human behavior patterns, ethical and societal norms across distinct cultures** – and for all cars on the road
- In the case of the car crash dilemma, **thought experiments attest to existing regional differences**: For instance, in Asia and the Middle East, the preference to spare younger rather than older people was less pronounced than elsewhere, reflecting a 'respect your elders' cultural trait
- Other observations attest to more **individualistic versus collectivistic decision-making** depending on region, amongst many other factors. Aggregating these factors would allow the **possibility for AI to evolve as a "moral machine"**

Sources: Moral Machine; Nature; Roland Berger

Shedding light into the AI black box – Greater transparency will improve levels of trust and acceptance between humans and machines

What happens inside an AI black box



> AI doesn't' show its workings – we see its inputs and outputs – but the how and why is opaque. **Black box AI** is built upon **highly complex probabilistic artificial neutral networks**, consisting of hidden layers of nodes processing given input, passing on 'invisible' output to the next layer, based on its learned patterns of recognition. Such AI may thus function in a manner beyond of what its creator could foresee

> For example, an **AI trading program** may be given the goal of maximizing profit, but **how it reaches its trading decisions** – with or without market manipulation, for instance – may be **entirely unclear ex ante** to its creator, **or even ex post** to regulators, due to black box processes

> One way to overcome such issues is the use of **explainable AI (XAI),** a commonly used approach to program an AI: Instead of using probabilistic networks, XAI takes **advantage of families of algorithms** that, for example, belong to **decision trees or rule-based algorithms.** They are much easier understandable for humans

> XAI, however, comes with the **drawback of lesser accuracy** compared to Black box AI, and therefore, is not always an optimal choice

> To **combine both accuracy and transparency**, and in order to gain trust and acceptance with humans, **XAI and Black-box AI can be fused** in a complementary manner

Sources: IEEE; NIST; Roland Berger

Superintelligent AI, autonomous of human control, poses an existential risk to humanity – Or may prompt a technological wave of innovations

Expert opinions on existential risk from superintelligent AI

Studies envisage (probability of 50 %) the occurrence of AI at similar levels to human intelligence by 2040-2050

Superintelligent AI poses an existential threat to humanity – or helps fulfil its potential

Opinions of leading scientists differ

Vincent Müller & Michael Cannon – Eindhoven University of Technology

"Is there a notion of **intelligence** that is 'general enough' to assure existential risk from superintelligence, but 'instrumental enough' to **exclude ethical reflection** on goals by superintelligent systems? **We do not think so.** But if there is no such notion of intelligence with which we can 'have it both ways', then there is **no sound argument for the existential risk from superintelligent AI."**

Nick Bostrom & Eliezer Yudkowsky – Cambridge University

"**Superintelligence is one of several 'existential risks',** […] a risk 'where an adverse outcome would either annihilate Earth-originating intelligent life or permanently and drastically curtail its potential'. **Conversely, a positive outcome for superintelligence could preserve Earth – originating** intelligent life and help fulfill its potential. It is important to emphasize that smarter minds pose great potential benefits as well as risks."

David J. Chalmers – New York University

"If the systems are created in **embodied form,** inhabiting and acting on the same physical environment as us, then the risks are especially significant. Here, there are at least **two worries.** First, **humans and AI may be competing for common physical resources:** space, energy, and so on. Second, embodied **AI systems** will have the **capacity to act physically upon us,** potentially doing us harm."

> AI has undergone profound progress in terms of functionality, tasks and accuracy. However, it is **not yet on a par with human intelligence,** but this is estimated to occur within **two to three decades from now**

> If and when AI surpasses general human intelligence – a moment describes as "**technological singularity**" – a superintelligent AI could innovate by itself, **resulting in a technological wave of innovations** of unknown magnitude and consequence – an innovation explosion

> This evolutionary step carries benefits but also **fears of an existential risk to humanity**, as per definition, intelligence in the field of AI research is concerned with creating optimal algorithms in order to achieve an arbitrary goal – thus **lacking anthropomorphic (moral) traits**

> Issues of **AI control** have shifted the scientific debate to consider superintelligent AI along a spectrum of characteristics, ranging from **general superintelligence,** which is inclusive of a moral mind and self-awareness, to goal-driven **instrumentalized superintelligence,** lacking ethical reflection and awareness of self

Sources: Ratio; Cambridge University Press; Journal of Consciousness Studies; Elsevier; Roland Berger

1 Value of Innovation

2 Frontier Technologies

3 Humans & Machines

Leading firms innovate to sustain competitive advantage – Focus on R&D investment, cooperation and knowledge hubs are key

Actions recommended for companies across all sectors to proactively steer their future

- **Innovations** deliver **long-term value, sustaining growth and profits** – a fundamental truth for companies as much as for economies. An innovation-led company can **capitalize on first mover advantages**. In addition, strengths in innovative technologies can enhance access to funding and capital markets

- In order to innovate new products and services, companies that allocate resources for **partnerships in R&D and innovation,** creating **knowledge spill-overs,** can steer and tap into highly creative and rewarding processes. Companies should seek **diversity of thought** in but also around their core business activities, and partner with suppliers and distributors at home and abroad. Thinking outside the box, companies must also dare to enter cooperation with competitors **(co-opetition)**

- Companies should build up **knowledge hubs** that contribute openly and directly to innovation capabilities. **Collaborations** between such knowledge hubs and **start-ups and/or universities** create innovative business models that can considerably increase work productivity, product and/or service quality, and flow of revenues

Sources: Roland Berger

Frontier technologies are tomorrow's everyday reality – Prepare your company early on

Actions recommended for companies across all sectors to proactively steer their future

- **Awareness of technological trends** and foresightful analyses should be self-evident in a company's **strategic planning.** The goal is to identify impactful innovations early for best possible strategic response and integration. This extends to analyzing and **anticipating competitors' innovation strategies,** identifying potential new market entrants, especially IT/digital companies that could disrupt your market. To stay customer-focused and to **anticipate changing needs and behaviors,** identify technological innovations that your customers are aware of, are seeking out and/or want to use more of – and align your business accordingly

- Be aware that new technologies can also imply **business model innovations** and prepare your company for them. Make sure to **create the right mindset,** capabilities and corporate identity so that you **become the disrupter** and not the disrupted. Identify which new technologies and technology-driven competencies will affect your business model to counteract any surprises

- **Data-driven digitalization is fundamental** to all frontier technologies. Make sure that your company takes a broad approach on digitalization including **infrastructure, processes and systems** – and that data is valued. To be an early adopter, a strong digitalized infrastructure is crucial for further technologically successful, company-wide developments and growth. Depending on use case and company structure, the introduction of innovative new systems in your digitalization strategy may require enhancing existing systems but could also necessitate leap-frogging technologies

Sources: Roland Berger

1 Value of Innovation

2 Frontier Technologies

3 Humans & Machines

New technologies must have inherent human values and skills at their core – Taking the lead benefits business and stakeholders

Actions recommended for companies across all sectors to proactively steer their future

- The future of a company is deeply intertwined with the future of its jobs. A **modern corporate structure** is essential to **enable a workforce** to reach its full potential, benefitting employers and employees. This does not only **require a rethink in corporate management – continuous workforce training** supports socio-technological change

- There is no time like the present: New technology is advancing rapidly requiring **earliest action** including a consensus on standards and frameworks. If governments are dithering, **companies can take the lead** – individually and by **networking and cooperating sector-wide** to help frame the technology-impact debate based on scientific evidence and by displaying best efforts for the sake of social responsibility and future economic progress. In the main, **standards do not slow down innovations** but are helpful in scaling up business

- Companies need to screen **ethical concerns regarding new technologies** from all angles: Internally, companies should raise awareness of new technology implications. Externally, **transparent and coherent positions** must be taken on a broad spectrum of potential moral issues. The inclusion of ethical considerations into corporate culture and decision-making processes translates favorably to a **wider group of stakeholders,** including consumers

Sources: Roland Berger

Main sources

Megatrend "Technology & Innovation"

- **WIPO:** Global Innovation Index 2021. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2021.pdf
- **OECD:** Productivity and economic growth. https://www.oecd-ilibrary.org/sites/f8c31e3c-en/index.html?itemId=/content/component/f8c31e3c-en
- **OECD:** Decoupling of Wages From Productivity: What Implications For Public Policies? https://www.oecd.org/economy/outlook/Decoupling-of-wages-from-productivity-november-2018-OECD-economic-outlook-chapter.pdf
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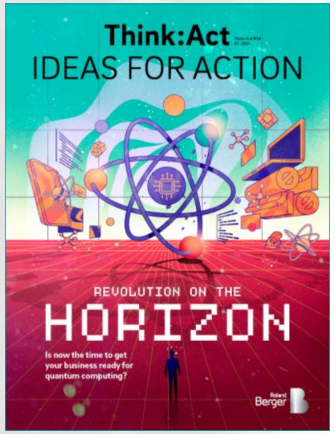
- **Nature:** The Moral Machine experiment. https://www.nature.com/articles/s41586-018-0637-6

Further reading

Think:Act Ideas For Action

Revolution on the Horizon



Authors

Dr. Christian Krys
Senior Expert
Roland Berger Institute
+49 (211) 4389-2917
christian.krys@rolandberger.com

Dr. David Born
Manager
Roland Berger Institute
+49 (69) 29924-6500
david.born@rolandberger.com

Steffen Geering
Specialist
Roland Berger Institute
+49 (211) 4389-2194
steffen.geering@rolandberger.com

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Page 22	Norman Chan/Adobe Stock
Page 24	Blue Planet Studio/Adobe Stock
Page 25/38	putilov_denis/Adobe Stock
Pages 26/36/65	WrightStudio/Adobe Stock
Page 27/55	pickup/Adobe Stock
Page 29	Monster Ztudio/Adobe Stock
Page 30	Production Perig/Adobe Stock
Page 31	Quardia Inc. /Adobe Stock
Page 32	Enzo Wang/Adobe Stock
Page 33	ipopb/Adobe Stock
Page 34	sitthiphong/Adobe Stock
Page 35/51/56	peshkov/Adobe Stock
Page 37	alphaspirit/Adobe Stock
Page 39	Kalawin/Adobe Stock
Page 40	Aania/Adobe Stock
Page 43	arquiplay77/Adobe Stock
Page 44	daizuoxin/Adobe Stock
Pages 45/64	sdecoret/Adobe Stock
Page 47	lev dolgachov/Adobe Stock
Page 50	rgey Nivens/Adobe Stock
Page 52	KanawatTH/Adobe Stock
Page 53	Ivelin Radkov/Adobe Stock
Page 54/69/70	phonlamaiphoto/Adobe Stock; presentationgo
Page 59	alexandra/Adobe Stock
Page 60	ZinetroN/Adobe Stock
Page 61	Sikov/Adobe Stock
Page 62	Igor Stevanovic/Adobe Stock
Page 63	Urupong/Adobe Stock
Page 66	Olga Yastremska/Adobe Stock
Page 67	jijomathai/Adobe Stock
Page 68	Alexander Limbach/Adobe Stock
Page 71	kk-artworks/Adobe Stock
Page 72	Argus/Adobe Stock
Page 73	V. Yakobchuk/Adobe Stock
Pages 76-78	Shuo/Adobe Stock

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