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An OECD Horizon Scan of Megatrends and Technology Trends in the Context of Future Research Policy

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Ministry of Higher Education
and Science
—
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INTRODUCTION

CONSIDERING THE FUTURE

Analysis of future trends, whether derived from extrapolations, simulations, projections or scenarios, can provide important insights for the future. They can offer support and guidance for decision makers and investors, and alert policy makers, the business community, researchers and society more generally to important upcoming issues. Interpretation of future trends, however, always needs to be done with care: they do not foretell the future, they merely indicate how the future might evolve under certain conditions and in a given subject area. A somewhat fuller picture of possible futures can be assembled by bringing together numerous trends from different subject areas. This can strengthen the basis for developing narratives or storylines, which in turn can enrich our view of where the world is heading and what challenges and opportunities may lie on or beyond the longer-term horizon.

In reality, our future is being shaped by a multitude of such powerful, highly complex and interconnected forces, that any attempt to peer into the future seems destined merely to heighten our sense of uncertainty. Yet, seen over a time horizon of say 10-20 years, some of the big trends we see unfolding before us are in fact quite slow-moving. These are **megatrends** – large-scale social, economic, political, environmental or technological changes that are slow to form but which, once they have taken root, exercise a profound and lasting influence on many if not most human activities, processes and perceptions. Examples are global population growth and urbanisation or the ageing of societies in many parts of the world; the warming of the planet and rising sea-levels or the acidification of our oceans and seas; the deepening of globalisation or the growing momentum of digitalisation, big data and bioengineering. Such relative stability in the trajectory of major forces of change allows us to envision at least some elements of our likely medium-to-long term future with some degree of confidence.

What often tends to shake that confidence, at least temporarily, are **disruptive events**. These come in a multitude of forms – from global financial crashes and pandemics to wars and sudden waves of immigration; and from continental-scale natural disasters to sudden shifts in population fertility. Such events are difficult to build into trend projections, and so are often treated in foresight exercises as “wild cards”. Potentially disruptive scientific and technological innovations, on the other hand, frequently find a place in forward trend studies, not least because they often occur as an extension of or as a marked departure from existing science and technology trends. Ultimately, it is how megatrends and disruptive trends – especially in the field of science and technology – interact that will set the scene for the coming decades. It is for governments, business, researchers and citizens in general to reflect on what the interplay of such trends means in terms of opportunities to be seized and challenges to be met.

THE RESEARCH2025 PROCESS

The purpose of this brochure is to provide scene-setting and food for thought in support of the RESEARCH2025 process being launched in February 2016 by the Danish Agency for Science, Technology and Innovation (DASTI). The RESEARCH2025 process is a consultation and co-creation process among a broad range of stakeholders which aims to identify:

- The research needs that flow from the major challenges facing the world and Danish society;
- The opportunities created by future developments anticipated in society, technology and the economy;
- The capabilities of Danish research institutions, enterprises and public organisations to address those needs and opportunities.

The end product of the RESEARCH process will be a catalogue of promising research themes that by 2017 will replace the existing RESEARCH2020 catalogue. The catalogue will constitute a central Danish basis for inspiring and prioritising strategic investments in research. The catalogue is aimed at politicians that allocate national funds for investments in research, the Ministry of Higher Education and Science, Innovation Fund Denmark, and academic and research institutions, among others. Business and interest organisations, ministries, academic and research institutions and many others will contribute to developing the RESEARCH2025 catalogue through a co-creation process. In this way, the catalogue is expected to eventually reflect Danish society's demand for strategic investments in research within areas of great opportunities or challenges.

A key basic assumption in the RESEARCH2025 process is that involved stakeholders are highly knowledgeable about research needs within their own field, but probably less aware of research needs and opportunities elsewhere. The aim of this brochure, therefore, is to provide a horizontal overview of an extensive selection of future global trends that may shape research needs and opportunities for Danish research, industry and society. Its purpose is to inspire stakeholders to look beyond their own primary focus areas, to widen their horizons and alert them to the global trends, challenges and opportunities of the future that could have a bearing on their efforts to identify the most promising Danish research themes for the coming years.

It is important to stress that this brochure is not intended to point out the challenges, opportunities or technologies to be included in the RESEARCH2025 catalogue. Rather the aim is to help and inspire the involved stakeholders to look beyond the existing RESEARCH2020 catalogue and catch sight of global and future opportunities reflected in recent international foresight studies, scenarios and reports. The brochure does not try to relate global future trends to the Danish context, nor does it try to deduce any research implications of the described trends. This is a central task for the Danish stakeholders involved in the RESEARCH2025 process. It is intended and hoped that the stakeholders – continually while reading the brochure – will ask what research implications and opportunities the described trends may offer to Danish businesses and society.

DASTI has not influenced the selection of themes or technologies in the brochure. Nor has the agency swayed the substance of the brochure, which draws upon preparatory work undertaken by the OECD for its forthcoming Science, Technology and Industry Outlook 2016.

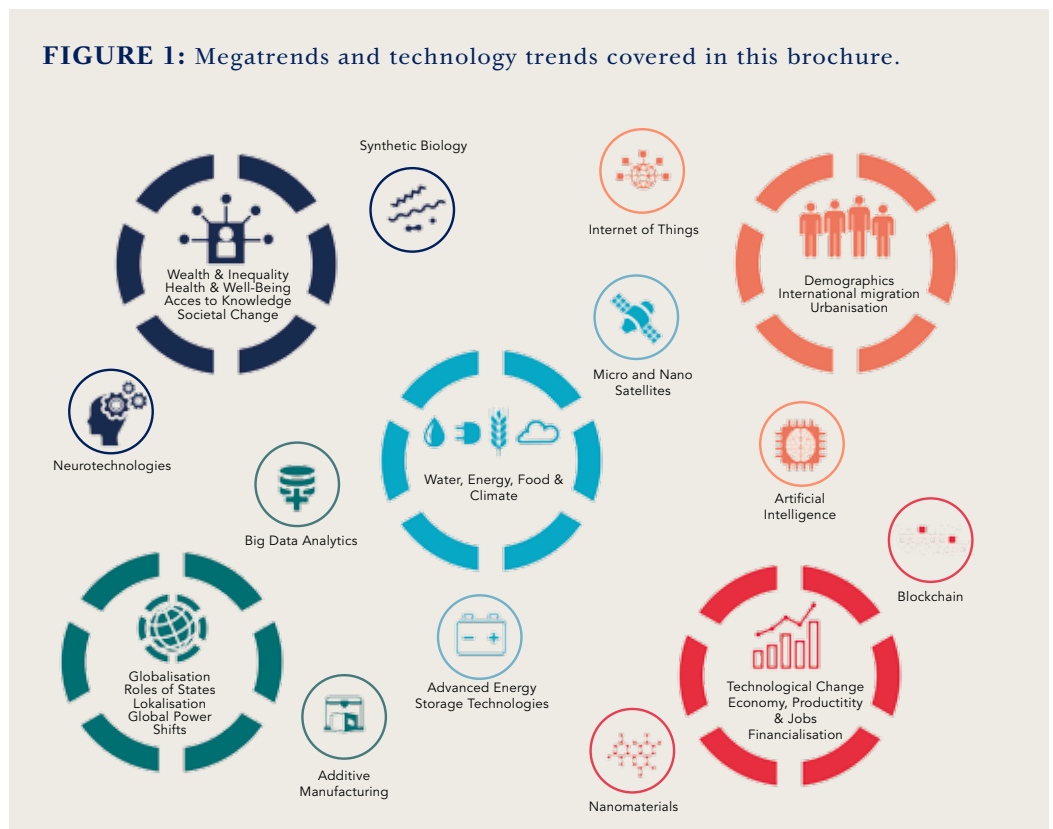
OUTLINE OF THIS BROCHURE

The brochure has three sections. A **first section** deals with the main megatrends that are expected to have significant socio-economic impacts over the next 10-20 years and beyond. The megatrends are clustered under five headings (Figure 1), as follows:

1. *Growing, migrating, and ageing: the 21st century human population* covering demographics, international migration, and urbanisation;
2. *The water, energy, food and climate nexus: time for joined-up thinking* covering water, energy, and food security, and climate change;
3. *The changing geo-economic and geopolitical landscape* covering globalisation, the roles of states, localisation, and global power shifts;
4. *A moving frontier: how digitalisation will drive economies and shape the ways we work* covering technological change, economy, productivity and jobs, and financialisation; and
5. *Wealth, health and knowledge: the great global divide?* covering wealth and inequality, health and well-being, access to knowledge, and societal change.

This clustering of megatrends provides for their integrated analysis and highlights some of the synergies and trade-offs between them. The text avoids making normative or predictive statements on the implications of the megatrends for research. Instead it includes “food for thought” statements that ask thought-provoking questions for the reader to consider. It is not the intention to highlight specific research implications. Rather the statements serve as reminders to the reader to always keep in mind the possible research implications and opportunities for Danish businesses and society. Many other examples of statements could have been chosen. A brief summary of the megatrends is provided in the box below.

FIGURE 1: Megatrends and technology trends covered in this brochure.



SUMMARY OF THE BROCHURE'S MEGATRENDS

The world population will continue to grow in the 21st century and is expected to nudge the 10 billion mark by mid-century. Africa will account for more than half of this growth, which will generate significant youth bulges. Elsewhere, including in many developing countries, populations will significantly age, and those over 80 will account for around 10% of the world's population by 2050. With a declining share of the population in work, ageing countries will face an uphill battle to maintain their living standards. International migration from countries with younger populations could offset this decline. At the same time, technologies that enhance physical and cognitive capacities could allow older people to work longer, while growing automation could reduce the demand for labour.

The global population will be increasingly urban, with 90% of this growth occurring in Asia and Africa. Urbanisation could bring several benefits to developing countries, including better access to electricity, water and sanitation. It could also lead to extensive slum formation with negative consequences for human health and the environment. In more advanced settings, utility and transport networks and systems will become progressively interconnected, leading to 'smart cities' that can use and manage resources more sustainably.

A growing population coupled with economic growth will place considerable burdens on natural resources. Severe water stress is likely in many parts of the world, while food insecurity will persist in many, predominantly poor, regions. Energy consumption will also rise sharply, contributing to further climate change. The extent and impacts of climate change will be considerable, not least on water and food security. Climate change mitigation will require ambitious greenhouse gas emission targets are set and met, implying a major shift towards a low-carbon economy by mid-century. This shift will affect all parts of the economy and society and will be enabled by technological innovation and adoption in developed and developing economies.

The world economy's centre of gravity will continue to shift east and southwards, and new players will wield more power, some of them states, some of them non-state actors (such as multinational enterprises and NGOs) and others newly emerging megacities.

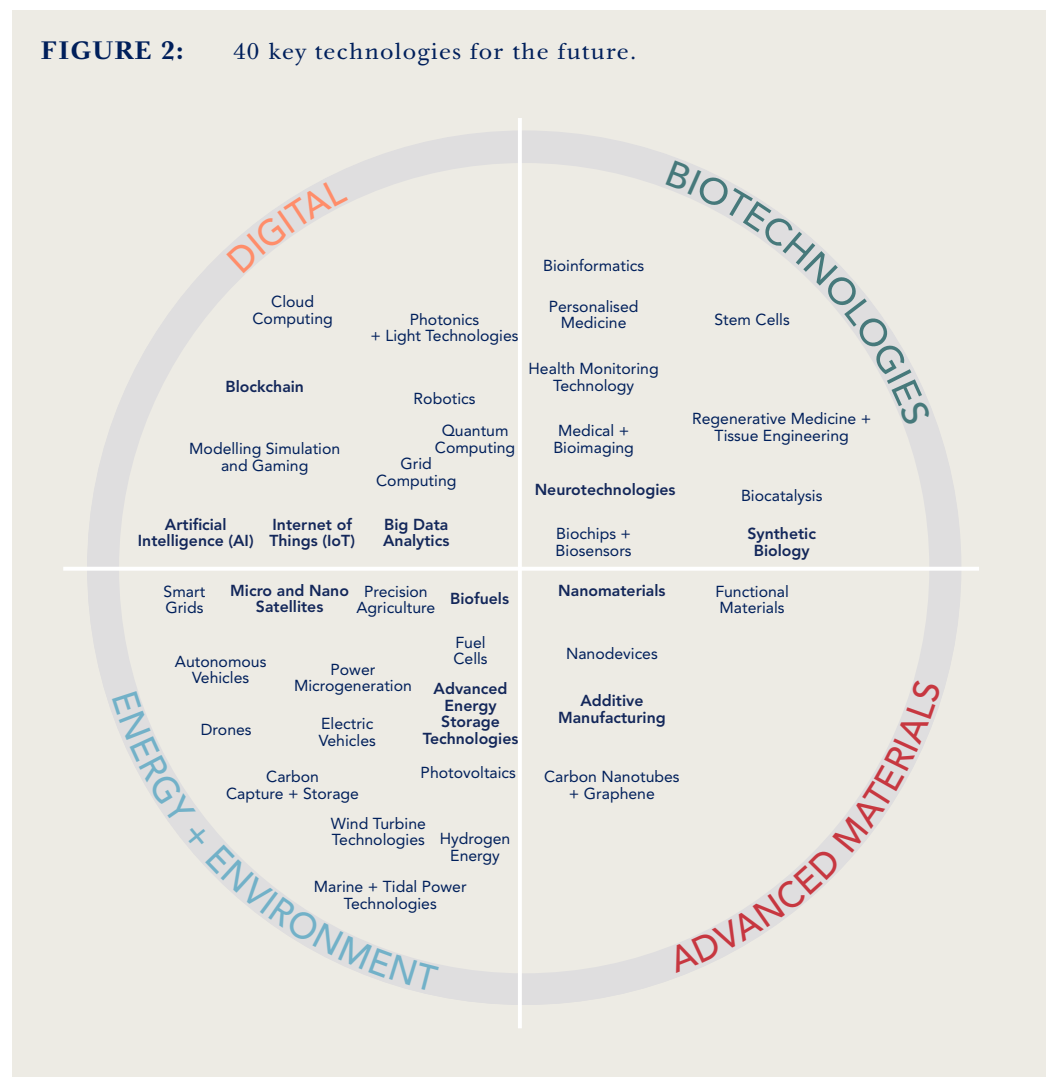
Driving and facilitating many of these shifts in power and influence is globalisation, which operates through flows of goods, services, investment, people and ideas, and is enabled by widespread adoption of digital technologies. But globalisation will inevitably face counter-currents and crosswinds, such as geopolitical instability, armed conflict and new barriers to trade.

Digital technologies will continue to have major impacts on economies and societies. Over the next 15 years, firms will become predominantly digitalised, enabling product design, manufacturing and delivery processes to be highly integrated and efficient. The costs of equipment and computing will continue to fall, while the rise of open source development practices will create further communities of developers. There will be greater opportunity for entrants – including individuals, outsider firms and entrepreneurs – to succeed in new markets. At the same time, the decreasing cost of computing power and advances in machine learning and artificial intelligence will further disrupt labour markets, with perhaps half of total employment at high risk of becoming automated over the next two decades.

While the prosperity gap between rich and poor countries will continue to shrink, it will also tend to widen within developing economies as middle-class spending power gains ground. But inequalities will grow in many developed countries, too, as will poverty rates and the profiles of those at risk of poverty. The future will also see striking changes in family and household structures in OECD countries with significant increases in one-person households and couples without children. Access to education and acquisition of skills will be one of the most important keys to improving life chances. Growth in female enrolment at all levels of education will continue, and will have important implications for labour markets and family life. The growing internationalisation of university education will continue and education at all levels will become increasingly digitalised. The global health divide is also a major concern: infectious diseases affect the developing world disproportionately and their treatment will be further compromised by growing antibacterial resistance. Non-communicable and neurological diseases are projected to increase sharply in line with demographic ageing and globalisation of unhealthy lifestyles.

Many countries periodically conduct foresight exercises that seek to identify promising emerging technologies. Exercises recently carried out in several OECD countries (Canada, Finland, France, Germany, Korea, and the United Kingdom) and by the European Commission have identified well over one hundred such technologies between them – the 40 most commonly-identified technologies are shown in Figure 2. The brochure’s **second section** covers ten of these emerging technologies: *the Internet of Things; Big data analytics; Artificial intelligence; Neurotechnologies; Micro and nano satellites; Nanomaterials; Additive manufacturing; Advanced energy storage technologies; Synthetic biology; and Blockchain*. It is important to stress that this selection does not infer any sort of priority of the chosen technologies. Thus, many of the 30 technologies not chosen are probably closer to Danish positions of strength, societal needs and opportunities and/or political priorities. Nor is it an attempt to derive the most key enabling technologies. Rather, it is intended to provide a sample of emerging technology areas across a broad cross-section of fields and to demonstrate the potential disruption of technological change over the next 10-15 years.

FIGURE 2: 40 key technologies for the future.



The emerging technologies covered are wide-ranging in their origins and potential applications yet show many similarities:

- Emerging technologies are often dependent on other technologies for their future development and exploitation. **Technology convergence** is important and points to a need for cross-disciplinary institutional set-ups – for example, for carrying out R&D work and for offering skills training.
- Emerging technologies are expected to have wide impacts across many fields of application, some of which cannot be anticipated. Furthermore, impacts will be shaped by many non-technological factors (some of these are covered in the earlier section on megatrends). The **unpredictability of technological change** calls for an open perspective that supports a diversity of technology developments and applications and that benefits from regular rounds of anticipatory intelligence gathering and dissemination.
- **Public sector** research has played and continues to play pivotal roles in developing emerging technologies. Public sector research provides new knowledge of phenomena underpinning emerging technologies and often contributes to prototype and demonstrator development. Just as importantly, public sector research nurtures many of the skills needed for further developing and exploiting emerging technologies.
- **Public policy** has important roles to play in funding research and nurturing innovation around emerging technologies. While new firms and entrepreneurs are often at the forefront of developing and exploiting emerging technologies, they are frequently in need of public support, for example, in the form of tax breaks and loans and/or funds for high-risk R&D that sometimes involves co-operation with public sector research organisations. Furthermore, public policy can target promising technologies in their own right or seek to develop technologies within a societal challenge framework.
- Emerging technologies carry several **risks and uncertainties**, and many raise important ethical issues, too. This calls for an inclusive, anticipatory governance of technological change that includes assessment of benefits and costs and an active shaping of future development and exploitation pathways. It also highlights important roles for the social sciences and humanities in developing and exploiting emerging technologies in the future.
- Research and innovation efforts around emerging technologies are increasingly distributed across the world and typically benefit from **international cooperation**. This also means that governing emerging technologies and their use, for example, through regulation and agreements, is increasingly a matter for international coordination.

Research systems and research policy have their own dynamics, driven by developments in science and politics, which deserve attention in their own right. The third and **final section** of the brochure therefore discusses briefly some of the major trends affecting research systems and research policy. These include trends around research funding, future skills needs, where and how research is performed, and the goals of research, among others. These trends are influenced by the megatrends and technological trends covered earlier in the brochure and some of the crossovers are highlighted in this section.

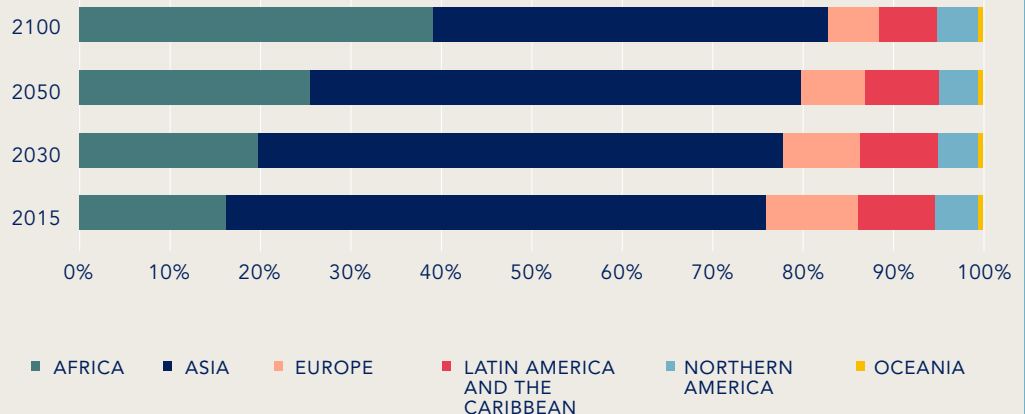
MEGATRENDS

GROWING, MIGRATING, AND AGEING: THE 21ST CENTURY HUMAN POPULATION

A growing world population...

The world's population is expected to grow during the 21st century, though at a slower rate than in the recent past. According to the UN's 2015 medium-variant projection, the global population will reach 8.5 billion by 2030 and 9.7 billion by 2050. Growth will take place almost entirely in less developed countries – for example, **Africa will account for more than half the increase in global population between now and 2050** – while population size in much of the developed world will stabilise or even fall. While today, 60% of the global population lives in Asia (4.4 billion), 16% in Africa (1.2 billion), and 10% in Europe (738 million), by 2050, Asia's share will fall to 54% (5.3 billion), Africa's will increase to 26% (2.5 billion) and Europe's will decline to 7% (707 million) (Figure 3). Africa is projected to be the only region still experiencing substantial population growth after 2050, so that by 2100, it is expected to account for 39% (4.4 billion) of the world's population (UN, 2015a).

FIGURE 3: Population of the World and major areas, 2015, 2030, 2050 and 2100, according to the medium-variant projection. Source: UN, 2015a.

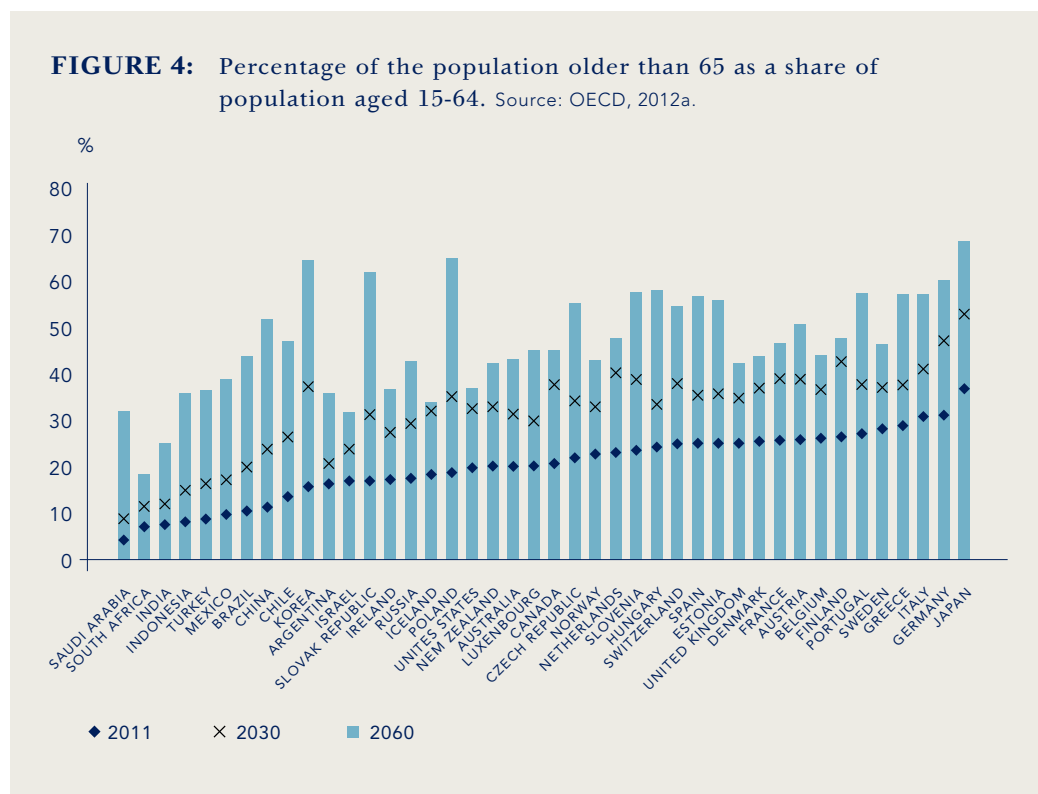


...with significant youth bulges in some developing countries...

Some developing countries will soon experience substantial **youth bulges**. The number of youth aged 15-24 years is growing rapidly in Africa, increasing 42% by 2030 and more than doubling by 2055 (UN, 2015b). A second group of youthful countries is projected to persist in the Middle East. A high proportion of working-age adults could offer these countries an economic boost; on the other hand, these countries are typically among the poorest and already struggle to provide educational and employment opportunities for their young people. A reservoir of disaffected young people with low education and few job opportunities may lead to greater political and social instability.

...and ageing populations in the developed and developing worlds

Low fertility rates across much of the developed and, increasingly, developing world will result in **population decline in many countries**. For some, notably Japan and much of Central and Eastern Europe, populations are expected to fall by more than 15% by 2050. At the same time, life expectancy is projected to reach 83 years in more developed countries by mid-century and 75 years in the less developed regions. The combination of low fertility rates and longer life spans will lead to future ageing in all major regions of the world, so that **by 2050, there will be almost complete global parity between the number of over-60s and the number of children**. This is a significant change from the past and present: while there are around 900 million over-60s in the world today, their number is projected to increase to 1.4 billion by 2030 and 2.1 billion by 2050, and could rise to 3.2 billion by 2100. Europe has the largest proportion of over-60s (24% in 2015), a share that is projected to reach 34% in 2050 (Figure 4). But rapid ageing will occur in other parts of the world as well, particular in Asia, where the over-60s are expected to make up 25% of the population in 2050 (UN, 2015a). **Almost 80% of the world's older population will live in less developed regions:** China will have about 330 million citizens aged 65 or more, India about 230 million, Brazil and Indonesia over 50 million (UN, 2011).



The share of over-80s is set to reach unprecedented levels

The over-80s group accounted for just 1% of the OECD population in 1950, but its share rose to 4% in 2010 and is projected to be close to 10% by 2050; in Germany, Italy, Japan and Korea, the share will likely reach 15% (OECD, 2011a). Globally, the number of over-80s is expected to increase from 125 million in 2015 to 434 million in 2050 and 944 million in 2100. By 2050, just 16% of the over-80s will reside in Europe as the populations of other major areas continue to increase in size and to grow older themselves. **The older population will be predominantly female** if current patterns prevail, with around 60 men per 100 women in the over-80s group (UN, 2015a).

Ageing countries will face an uphill battle to maintain their living standards...

The size of the working-age population (15-64) is currently at an historical peak and will very soon begin to diminish. This means the size of the dependent population (i.e. children under 15 and persons over 65 years of age) relative to the working-age population that provides social and economic support will increase. Without international migration, the working-age population in more developed regions would decline by 77 million or 11% by 2050; the situation in Europe is even more severe, where the size of the working population would decline by 20% (Royal Society, 2012). **Old-age dependency ratios are expected to reach very high levels indeed in some OECD countries** – 70 per 100 in Japan and over 60 in Italy, Korea, Portugal and Spain by 2050 (UN, 2011).

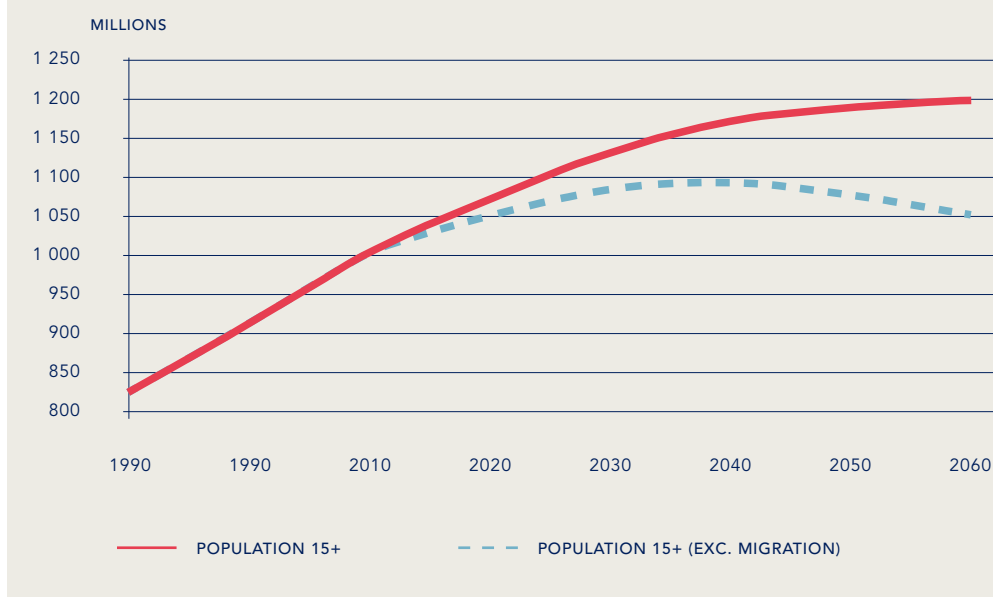
Ageing implies changes in lifestyle and consumption patterns, and this will have significant implications for the types of products and services in demand. At the same time, the prevalence of non-communicable diseases and increased disability among the elderly will place considerable burdens on healthcare and other services, where a more-than-proportional increase in demand can be expected. High old-age dependency ratios will lead to fiscal pressures that raise the risks of inter-generational conflict. In response, governments will likely seek to reduce beneficiaries and benefits, increase workers' contributions, and extend the required number of working years (US National Intelligence Council, 2012).

...leading to growing international migratory pressures...

While the ability of elderly citizens to remain active and continue working beyond official retirement age is set to increase, this alone is expected to be insufficient to meet workforce shortages. The central scenario in the OECD's long-term growth projection assumes that **inflows of migrant workers will be an important factor to mitigate ageing in most OECD economies** (Westmore, 2014) (Figure 5), heralding a new age of international migration. It is difficult to measure and estimate reliably future changes in levels of international migration – the movement of people across international boundaries, which is often a response to changing socio-economic, political and environmental forces, is subject to significant volatility (UN, 2012). Looking back over the period 1960-2010, international migration stocks grew both in real numbers and as a percentage of the world's population (from 2% in 1960 to 3.1% in 2010). Even if the stock of international migrants is assumed to remain at around 3% of the world's population, this implies a growth to around 250 million by 2030 (UK Foresight, 2011). Other estimates put the flow of international migrants from developing to developed countries at 96 million during 2010-50, with the US, Canada, the UK and Australia the largest net receivers (UK Ministry of Defence, 2014). However, **developing Asia, particularly China, could become a major area of destination by 2050**, and a growing number of migrants will probably move between and within Asia and Africa as countries in these regions develop economically.

FIGURE 5: Population and migration 2010-2060 in OECD countries.

Source: Westmore, 2014.



Estimations of future workforce shortages should consider technological change as an important determining factor, particularly the **impacts of robotics and artificial intelligence**, which may reduce the demand for migrant workers' labour and skills. Technologies such as these and others (e.g. neurotechnologies) may also enhance physical and cognitive capacities, allowing people to work longer in their lives. Nevertheless, on the supply side, youth bulges in some parts of the developing world are creating conditions ripe for outward migration: a likely lack of employment opportunities and growing risks of internal conflict will force many to seek better lives and safety elsewhere. Climate change may also have more of an influence on future international migration flows (European Environment Agency, 2015). And existing diasporas in developed countries will continue to facilitate migration and settlement of friends and family from the less developed world (EUISS and ESPAS, 2012).

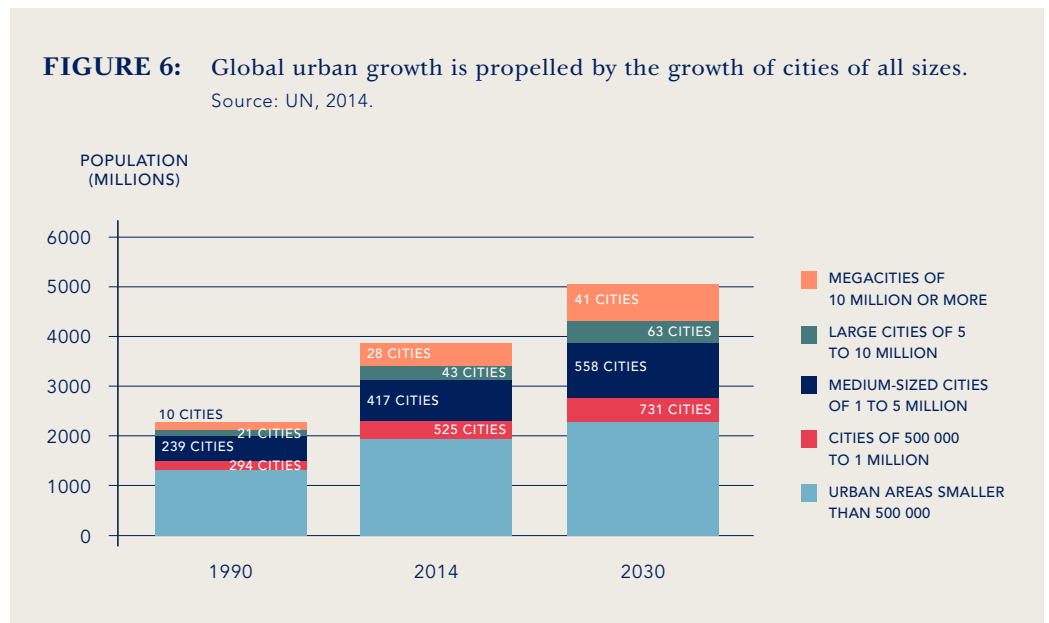
...and challenges

International migration, while potentially solving anticipated labour and skills shortages in receiving countries, will see the size and importance of ethnic minority communities grow. Some of these may be poorly integrated and economically disadvantaged, which may lead to tensions and instability (UK Ministry of Defence, 2014). This may make it more difficult for governments to win support for more open and forward-looking immigration policies (ESPAS, 2015). Immigration will also be challenged by inequalities: in societies with a shrinking middle class, openness is likely to be perceived as a threat to well-being and job security. Rising populism could also see governments use migrants as scapegoats for existing social problems (EUISS, 2010).

The largest migratory flows are within states, from rural to urban areas

By 2050, the urban population is expected to surpass 6 billion – up from less than 1 billion in 1950. By 2100, it is likely to reach somewhere around nine billion, corresponding to close to 85% of the projected global population (OECD, 2015a). This growth in city populations will be spread unevenly across the globe: **almost all urban population growth will occur in cities in developing countries, with nearly 90% occurring in Asia and Africa.** With 73% of its population living in urban areas today, Europe is expected to be over 80% urban by 2050. In a few countries, e.g. Japan and the Russian Federation, the urban population will decrease in line with falling overall population numbers (UN, 2014).

The number of “megacities” of 10 million or more inhabitants has almost tripled over the last 25 years, and they now account for 12% of the world’s urban population. Forty or so such cities will exist by 2030 (Figure 6). Still, around half of the world’s urban population resides in relatively small cities of less than half a million inhabitants, and **cities of less than 1 million inhabitants are expected to be the fastest-growing agglomerations in the future** (UN, 2014). At the same time, some cities will shrink in size as residents move to other locales seeking work and a better life; if left unmanaged, this process will create swathes of urban decay (Martinez-Fernandez et al., forthcoming).



Urbanisation brings several benefits...

High fertility rates combined with limited job prospects in many rural areas are important drivers of urbanisation, as cities typically offer better jobs and educational opportunities. Indeed, **urbanisation can be an important dynamo of economic growth:** cities generally provide easier access to modern and efficient infrastructure – for example, public transportation, housing, electricity, water and sanitation – for large numbers of people in an economically efficient manner (OECD, 2012b; UN, 2014). In emerging economies such as China, cities have been the main sources of domestic demand, through higher consumption of a growing affluent middle class and very high spending on infrastructure, a dynamic that is expected to continue (EUISS and ESPAS, 2012).

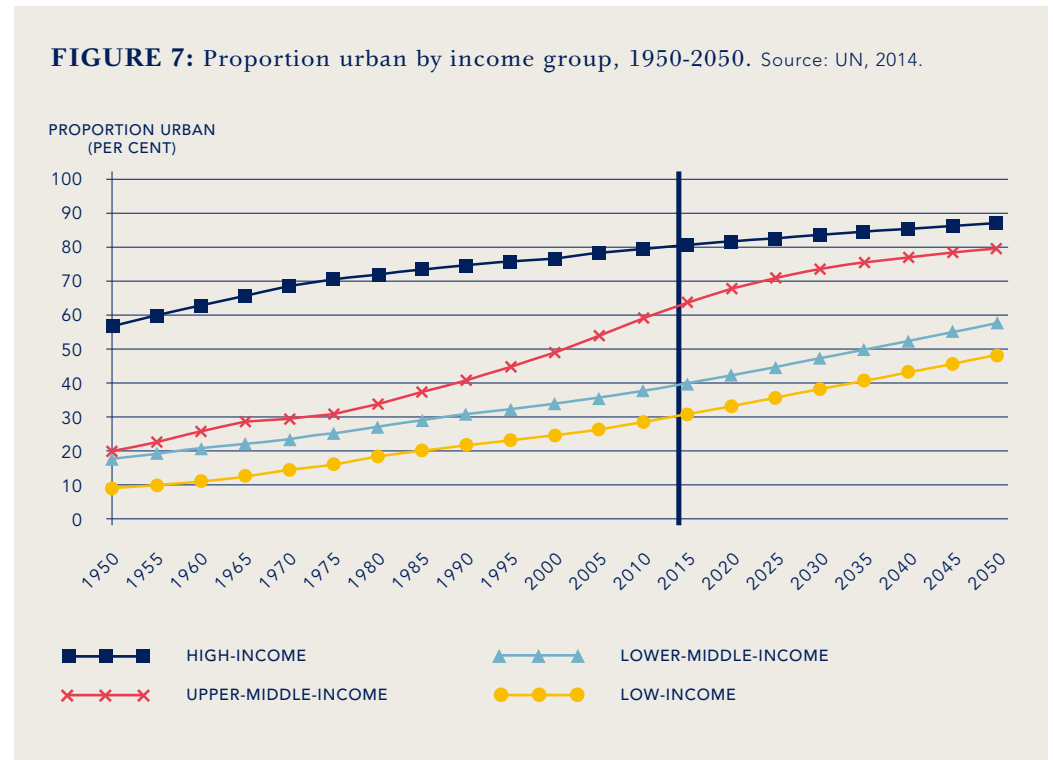
Building on advances in sensors and their connectivity through high-performance computing – the so-called Internet of Things – urban areas in more advanced economies will increasingly become “**smart cities**”. Various utility and transport networks and systems will become progressively interconnected, thereby supporting more sustainable use and management of resources (EC, 2014a).

...but also has its costs

While cities will make it easier to provide modern energy and water infrastructures to a growing number of people, air pollution and unmanaged waste will be major concerns for public health in many urban areas (OECD, 2012b). Climate change will see storm surges and rising sea levels increase over the next decades, which will have major impacts on low-lying coastal cities, especially in Asia, where so much of the world’s urban population lives. Extreme weather events will also disrupt complex urban systems (OECD, 2014a) and will have major impacts on the insurance industry in developed countries.

The economic benefits of urbanisation seen in countries such as China may not materialise in other parts of the world, particularly in sub-Saharan Africa and some parts of Asia. Inadequate education and physical infrastructure, combined with poor governance, have so far constrained the efficient use of productive resources and the industrial development that might have come with it (OECD, 2015a). A growing proportion of low-income groups will become urbanised over the next decades (Figure 7) so that **in some regions, urban growth will become virtually synonymous with slum formation**. Urban slums suffer from substandard housing and inadequate water, sanitation and waste management services, all of which have negative consequences for human health and the environment (OECD, 2012b). Such areas are also more likely prone to conflict and social unrest (UK Ministry of Defence, 2014).

FIGURE 7: Proportion urban by income group, 1950-2050. Source: UN, 2014.



FOOD FOR THOUGHT 1: As populations expand and contract across different parts of the world, the location and types of demand for products and services will shift substantially. How is this likely to affect the location and orientation of business innovation activities and the research communities that support them?

FOOD FOR THOUGHT 2: Ageing in developed and many developing countries will shape the types of innovation societies' demand. Likewise, technological innovation could transform the lives of elderly citizens, extending working lives and improving overall quality of life. How might ageing societies and the products and services they demand affect research agendas in both developed and developing countries?

FOOD FOR THOUGHT 3: In the absence of substantial improvements in urban governance capacities, urbanisation in much of the developing world will lead to extensive slum formation over the next decades. What roles could technological and social innovation play to improve these capacities and, by extension, the living conditions of inhabitants and the sustainability of cities more generally?

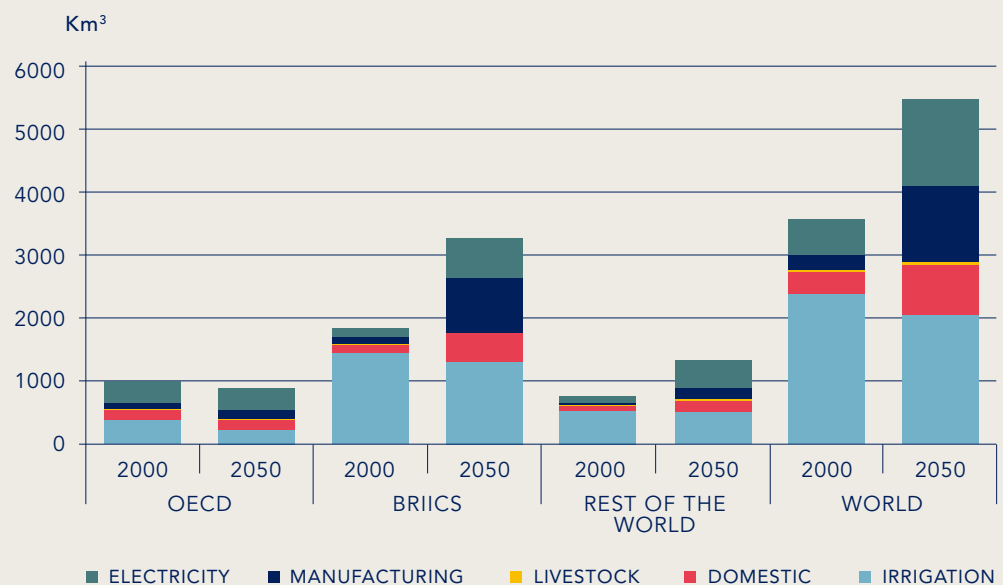
THE WATER, ENERGY, FOOD AND CLIMATE NEXUS: TIME FOR JOINED-UP THINKING

A growing world population and increasing economic development will enlarge global demand for water, food and energy, putting further pressures on the natural environment. Continued degradation and erosion of the natural environment is expected to occur over the coming decades, which, when taken together with climate change, raises the risk of irreversible changes that could endanger two centuries of rising living standards. These environmental challenges will need to be systemically addressed in the context of other global challenges, notably water, food and energy security (OECD, 2012b).

Severe water stress is likely in many parts of the world

Water demand outpaced population growth by a factor of more than two during the twentieth century. Based on continuing socio-economic trends and no new policies to improve water management (a baseline scenario), **water demand is projected to increase by 55% globally between 2000 and 2050**. Agriculture will remain the largest consumer of water, but sharp increases in demand are expected from manufacturing (+400%), electricity generation (+140%) and domestic use (+130%). This growth is driven by increased demand from OECD non-member economies; by contrast, water demand across the OECD area is expected to fall in line with continuing efficiency improvement in agriculture and investments in wastewater treatment (Figure 8) (OECD, 2012b).

FIGURE 8: Global water demand in 2000 and 2050 based on an OECD baseline scenario. Source: OECD, 2012b.



Note: The BRIICS region covers Brazil, Russia, India, Indonesia, China and Southern Africa. In the model used, India means "India region", which also includes Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan and Sri Lanka. Similarly, the Southern Africa region includes ten other countries in this geographical area, including the Republic of South Africa. The OECD Environmental Outlook's baseline scenario presents stylised projections of what the world could look like in 2050 if current socio-economic and environmental trends and existing policies are maintained, but no new policies are introduced to protect the environment. The baseline scenario does not reflect major future developments in policies that affect either the drivers of environmental change or environmental pressures. It should be stressed that the baseline scenario is not supposed to be a prediction of what the world will look like (as it is likely that new policies will be introduced in the coming decades), but rather a hypothetical projection forward of current trends without new policies.

Groundwater is being exploited faster than it can be replenished across many parts of the world – the depletion rate more than doubled between 1960 and 2000 – and is also becoming increasingly polluted. By 2050, **groundwater depletion may become the greatest threat to agriculture and urban water supplies in several regions**. The quality of surface water in many OECD non-member economies is also expected to deteriorate, through nutrient flows from agriculture and poor wastewater treatment. The consequences will be increased eutrophication, biodiversity loss and disease (OECD, 2012b).

Some 3.9 billion people – over 40% of the world’s population – are likely to live in river basins under severe water stress by 2050, especially in northern and southern Africa, and South and Central Asia. At the same time, 1.6 billion people – almost 20% of the world’s population – are projected to be at **risk from floods**. The economic value of assets at risk is expected to be around USD 45 trillion by 2050, a growth of over 340% from 2010 (OECD, 2012b).

Food insecurity will persist in many, predominantly poor, regions

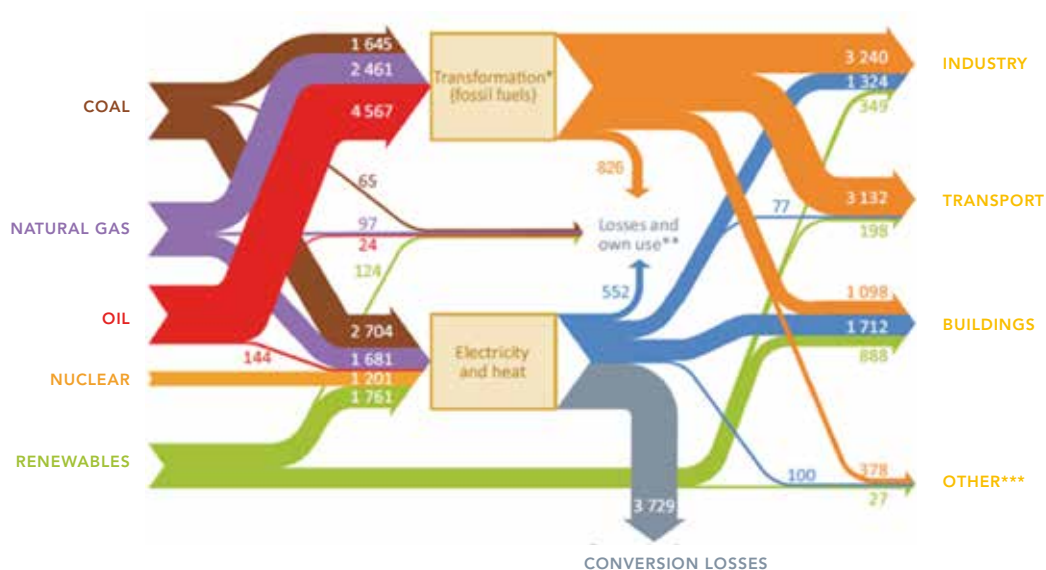
It is estimated that **60% more food will be required to feed the world population by 2050** (OECD, 2013a). Furthermore, changing diets, driven by a growing middle class, will lead to additional demand for more resource-intensive types of food, such as meat. On a global level, food production should be able to support a population of 9-10 billion in 2050. However, food and nutritional insecurity will persist in many, predominantly poor, regions (FAO and WWC, 2015). An increasing number of regions will face water scarcity, and the competition for scarce water resources could lead to internal and international conflict (WWAP, 2015). **Soil degradation** will affect the amount of land available for productive agriculture: around half of the world’s agricultural land is already affected by moderate to severe degradation and around 12 million hectares of productive land become barren annually due to desertification and drought. If no significant improvements are achieved in production practices, the loss of yield may be as high as 50% in some African countries by 2050 (UNCCD, 2014). The situation in most OECD and BRIICS countries is less severe, as continuing yield improvements will lead to more efficient use of land. Instead of agricultural land expansion, land abandonment is planned in many countries, which will allow ecosystems to partially recover and regenerate (OECD, 2012b).

Energy consumption will rise sharply, driven by population and economic growth...

Based on existing and planned government policies (the International Energy Agency’s [IEA] so-called “New Policies Scenario”), **global primary energy demand is set to increase** by 37% between 2012 and 2040. Most of this increased demand can be ascribed to economic growth in non-OECD countries, particularly in Asia, which will account for around 60% of global energy consumption. Under this scenario, growth in global demand is expected to slow down from over 2% per year in the last two decades to 1% per year after 2025. This is a result of price and policy effects, as well as structural shifts in the global economy towards services and lighter industrial sectors (IEA, 2014a).

Industry will remain the largest consumer of energy in 2040 (Figure 9), by which time its energy demand is expected to have risen by about 40%. Manufacturing in the OECD has gradually shifted away from coal and oil over recent decades, a trend that is projected to continue: while in 1990, coal and oil accounted for nearly half of heavy industry’s fuel, they are expected to decline to just 15% of the fuel mix by 2040. China’s fuel mix will also “lighten-up” by this time. This will lead to a fall in the average amount of industrial energy demand per unit of economic output worldwide. Future energy demand growth varies by industry sub-sector, however, with the chemical sector seeing the largest growth as the demand for plastics and other chemicals increases (ExxonMobil, 2015).

FIGURE 9: World energy demand by fuel and sector in the IEA's New Policies Scenario, 2040 (Million Tonnes of Oil Equivalent). Source: IEA, 2015a.



* Transformation of fossil fuels (e.g. oil refining) into a form that can be used in the final consuming sectors. This excludes energy demand in blast furnaces and coke ovens, which is attributed to industry.

** Includes fuel consumed in oil and gas production, transformation losses and own use (except blast furnaces and coke ovens), generation lost or consumed in the process of electricity production, and T&D losses.

*** Other includes agriculture and other non-energy use (mainly asphalt and lubricants).

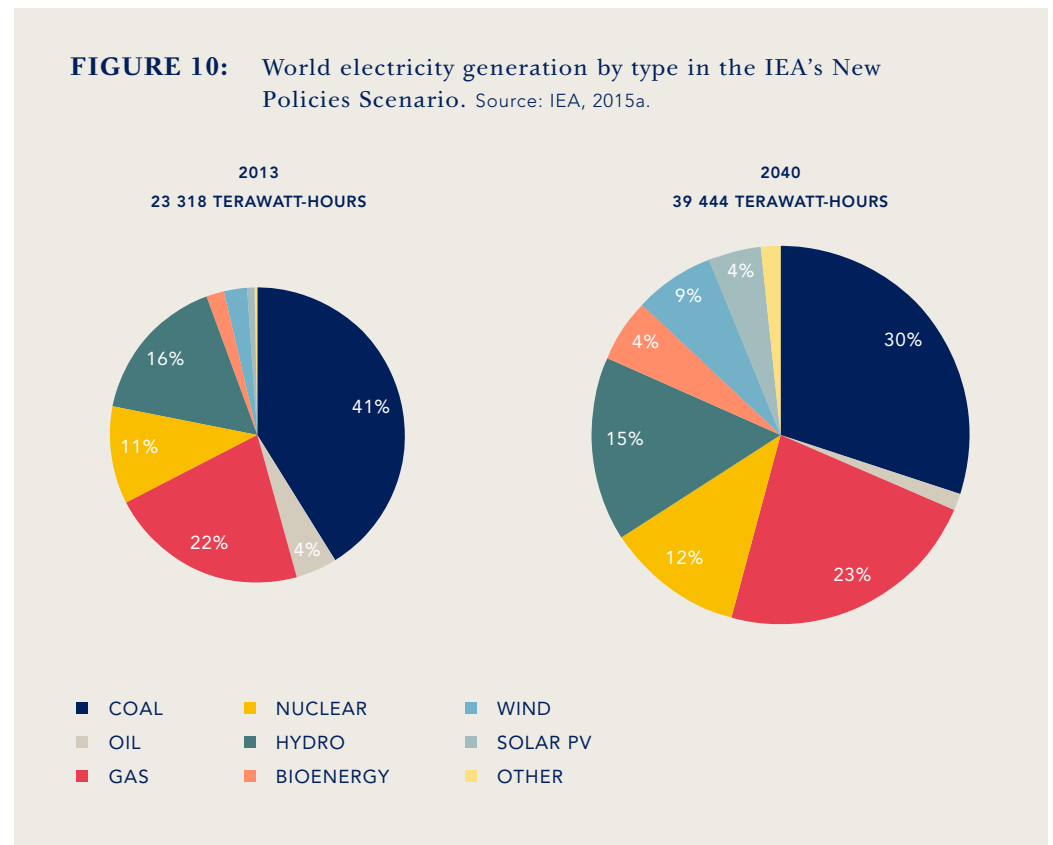
Transportation will be the second largest consumer of energy in 2040. While car numbers are projected to expand with a growing global middle class, fuel efficiency improvements mean energy demand from cars will rise only slightly. Hybrid vehicles could account for nearly 50% of new-car sales by 2040, compared with just 1% in 2010 (ExxonMobil, 2015). This effect will be especially noticeable in Europe, where liquid fuels consumption is expected to decline (EIA, 2014). Commercial transport – including airplanes, shipping, trains and trucks – will account for virtually all of the growth in energy demand from transportation. Most of this demand growth will be met by oil (ExxonMobil, 2015).

The third largest consumer of energy in 2040 will be commercial and residential buildings. Worldwide, households will increasingly shift towards cleaner fuels and will rely more on electricity than primary fuels as domestic appliances and electronics become more widely available (ExxonMobil, 2015). Nearly 1 billion people will newly gain access to electricity by 2040, but more than half a billion will remain without it (IEA, 2014a).

...though with a changing fuel mix

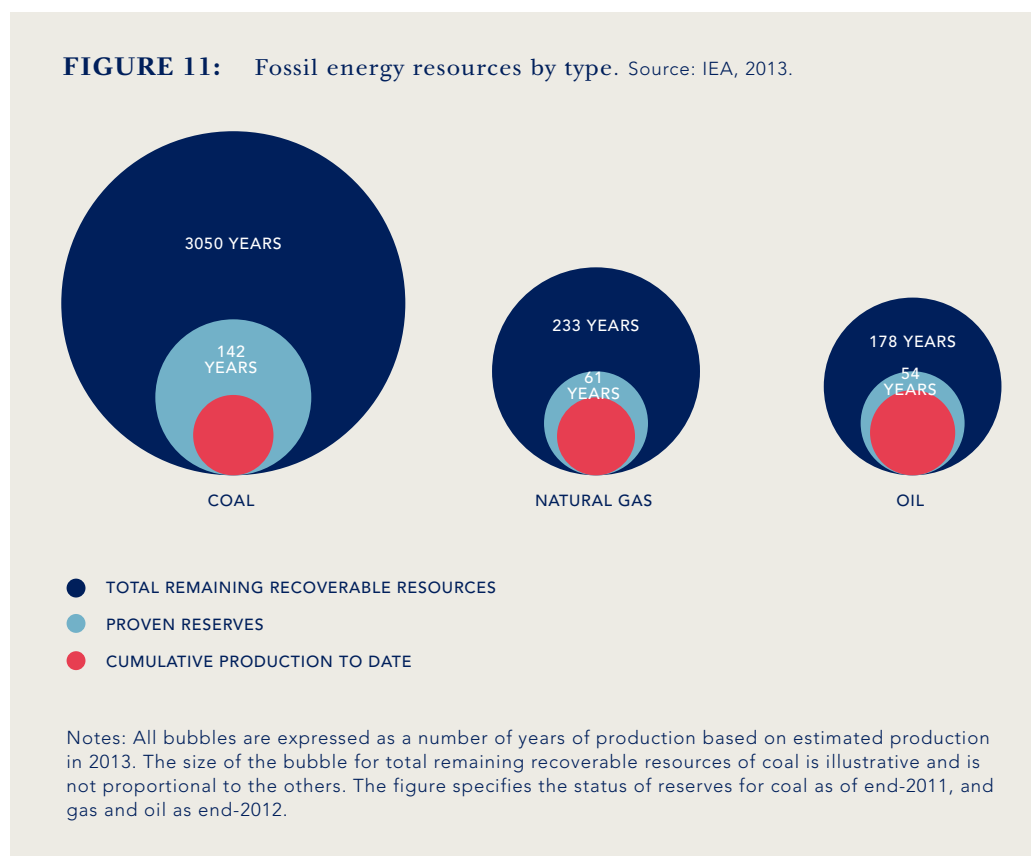
In the IEA's New Policies Scenario, **demand for fossil fuels will grow by 2040**, though their share in the global energy mix is set to decline. This is mainly because of greater use of renewables in the production of electricity (Figure 10). Worldwide, the largest share of growth in renewables-based generation will be from wind power (34%), followed by hydropower (30%) and solar technologies (18%) (IEA, 2014a). At the same

time, biofuels may provide up to 27% of the world’s transportation fuel by 2050, up from the current level of 2% (IEA, 2011), though with uncertain consequences for food security. Nuclear power capacity is set to rise by almost 60% over the same period, but its share in global electricity generation will increase by just one percentage point to 12%. China will account for almost half the expected growth, with India, Korea and Russia collectively making-up a further 30%. Almost 200 operational reactors (out of 434 operating in 2013) will have been decommissioned by 2040, mostly in Europe, the United States, Russia and Japan. The cost of decommissioning is estimated at more than USD 100 billion (IEA, 2014a).



The growth in renewables-based generation will mean oil, gas, coal and low-carbon sources will make up almost-equal parts in the world’s energy supply mix by 2040 (IEA, 2014a). Without more stringent climate change mitigation policies, **fossil fuels will continue to dominate the fuel mix**, not least because of the enormous quantity of their reserves (Figure 11). The IEA (2014) projects world oil supply to rise to 104 million barrels per day in 2040 and estimates this will require some USD 900 billion per year of investment in upstream oil and gas development by the 2030s. The Middle East and the Russia/Caspian region will likely remain the largest oil exporters over the next decades, while Asia Pacific and Europe will remain the largest importers. The situation in North America is somewhat different, as strong growth in tight oil, oil sands and natural gas liquids could see the region emerge as a net liquids exporter (ExxonMobil, 2015).

FIGURE 11: Fossil energy resources by type. Source: IEA, 2013.



Demand for natural gas will grow by more than half, the fastest growth rate of all fossil fuels (IEA, 2014a). A significant proportion of this growth is set to come from unconventional sources, such as shale gas produced in North America (ExxonMobil, 2015). Furthermore, an increasingly flexible global trade in liquefied natural gas will offer some protection against the risk of supply disruptions. Global coal demand will grow by 15% to 2040; around two-thirds of this increase will occur over the next decade, mainly in non-OECD countries like China, after which growth is set to slow considerably (IEA, 2014a).

Climate change is ongoing

Global land and ocean surface temperature data show an averaged combined warming of 0.85°C over the period 1880 to 2012. The greatest warming over the past century has occurred at high latitudes, with a large portion of the Arctic having experienced warming of more than 2°C. The last 30 years were likely the warmest of the last 1 400 years in the northern hemisphere (IPCC, 2014). Anthropogenic greenhouse gas (GHG) emissions are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. Atmospheric concentrations of carbon dioxide (CO₂), methane and nitrous oxide are unprecedented in at least the last 800 000 years (IPCC, 2014). CO₂ emissions account for around 75% of global GHG emissions, with most coming from energy production – **fossil fuel combustion represents two-thirds of global CO₂ emissions** (OECD, 2012b). Around half of the anthropogenic CO₂ emissions since 1750 have occurred in the last 40 years (IPCC, 2014). Agriculture is a major emitter of the more powerful greenhouse gases of methane and nitrous oxide.

There is a strong, consistent, almost linear relationship between cumulative CO₂ emissions and projected global temperature change during the 21st century (IPCC, 2014). Further warming over the next few decades is now inevitable, based on recent rises in atmospheric CO₂ levels, and **the global mean surface temperature change for the period 2016-35 relative to 1986-2005 will likely be in the range 0.3°C to 0.7°C**. Heat waves will likely occur more often and last longer, while extreme precipitation events will become more intense and frequent in many regions. Rainfall will most likely increase in the tropics and higher latitudes, but decrease in drier areas. The oceans will continue to warm and acidify, strongly affecting marine ecosystems. The global mean sea level will continue to rise at an even higher rate than during the last four decades. The Arctic region will continue to warm more rapidly than the global mean, leading to further glacier melt and permafrost thawing. However, while the Atlantic Meridional Overturning Circulation will most likely weaken over the 21st century, an abrupt transition or collapse is not expected (IPCC, 2014).

Climate change will have profound impacts on water and food security

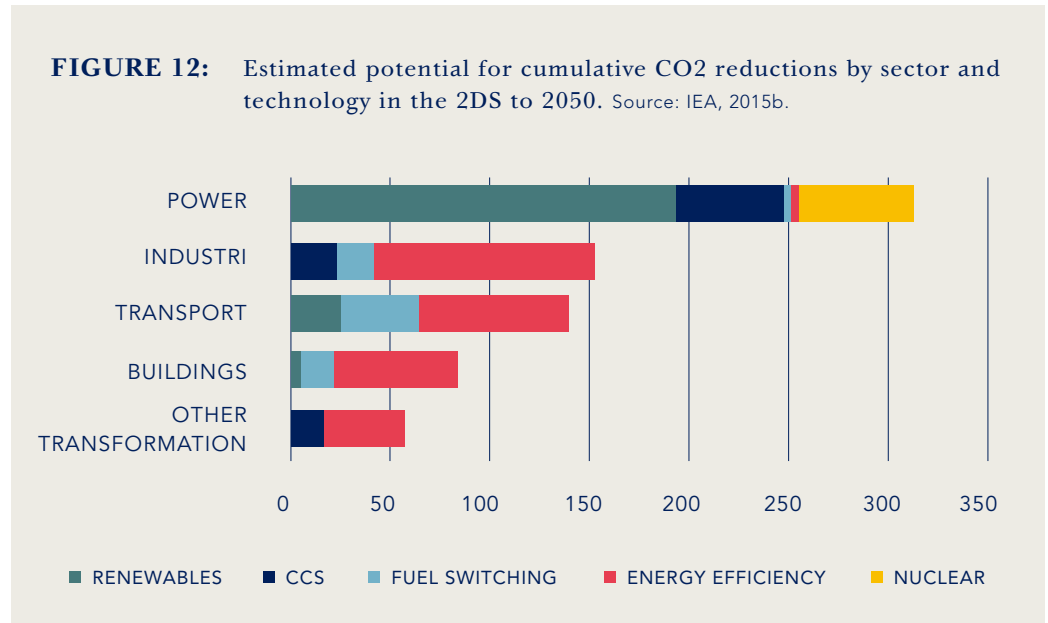
These climatic changes increase the risk of severe and possibly irreversible detrimental impacts at regional and global levels. **Extreme and variable rainfall** will have major impacts on water availability and supply, food security, and agricultural incomes, and will lead to shifts in the production areas of food and non-food crops around the world (IPCC, 2014). The impacts of climate change on yields of the major crops (wheat, rice and maize) will be negative for most countries and commodities, though are likely to affect the poorest populations the most (Ignaciuk and Mason-D'Croz, 2014). They will likely reduce renewable surface water and groundwater resources in most dry subtropical regions, intensifying competition for water among different sectors (IPCC, 2014).

Climate change mitigation requires much more ambitious GHG emission targets

Reducing and managing the risks of climate change will require a mixed strategy of mitigation and adaptation. The extent of mitigation efforts will determine levels of future GHG emissions: without additional efforts beyond those already in place today, warming by the end of the 21st century will lead to a high risk of severe, widespread and irreversible impacts globally, even with adaptation (IPCC, 2014). The IEA's New Policies Scenario, discussed above, is consistent with a long-term temperature rise of 4°C. In many respects, this is already an ambitious scenario that requires significant changes in policy and technologies, but will still lead to dangerous levels of climate change. A more stringent mitigation scenario that leads to CO₂-equivalent concentrations of about 450 parts per million in 2100 would meet the 2°C targets agreed at the recent Paris climate conference. This **2°C Scenario (2DS) is characterised by 40-70% reductions in global GHG emissions by 2050 compared with 2010**. It will mean increasing the share of low-carbon electricity supply from the current share of approximately 30% to more than 80% by 2050 (IPCC, 2014).

Energy technology innovation will be key in achieving the 2DS. Support for a portfolio of low-carbon technologies across all energy sectors (Figure 12) will provide the greatest potential to ensure uptake of immediately available solutions that keep climate goals achievable while also stimulating the initial development of more complex solutions needed for long-term deep decarbonisation (IEA, 2015b). Some solutions will be broadly applicable, while others will target specific sectors. In the power sector, while onshore wind and solar PV are ready to be mainstreamed in many energy systems, very high levels of deployment will require further innovation in enabling technologies – for example, in energy storage and smart grid infrastructure – to manage their variability and increase the flexibility of power systems (IEA, 2015b). Carbon capture

and storage (CCS) technologies are projected to play an important role, though require considerable further technical and market development before they can be extensively implemented. In other energy sectors – including industry, transport and buildings – energy efficiency technologies are expected to play a leading role in achieving the 2DS.



Emerging economies are projected to account for most of the increase in GHG emissions over the coming decades. Their uptake of innovative low-carbon technologies accounts for almost three-quarters of worldwide CO2 emissions reduction in 2050 in the 2DS. While rapid economic development holds significant potential to deploy the latest low-carbon technologies across all energy sectors, this will depend on international co-operation that supports technology and knowledge transfer. Furthermore, emerging economies will need to accumulate the necessary domestic skills and organisational capabilities if technology adoption, adaptation and development are to succeed (IEA, 2015b).

FOOD FOR THOUGHT 1: Future water and food security are inextricably tied to climate change, which in turn is heavily influenced by GHG emissions from the energy and agriculture sectors. What are the research implications of “joining-up the dots” among water, food, energy and climate and adopting a systems approach to policy and analysis?

FOOD FOR THOUGHT 2: Fossil fuel use is set to increase over the next few decades, contributing to CO2 emissions and the risk of future climate change. To stay within the limits of the 2DS, wholesale decarbonisation of the economy, including the energy sector, will be required. How can business, government and research prepare for and effect a “system transition” to a low-carbon economy?

FOOD FOR THOUGHT 3: Emerging economies account for most of the potential GHG emissions increases over the next few decades and will need to deploy new low-carbon technologies if the world is to stave off the risk of severe climate change. How can research and innovation system actors in the more technologically-advanced OECD countries better support adoption and adaptation of advanced technologies in emerging and developing country contexts?

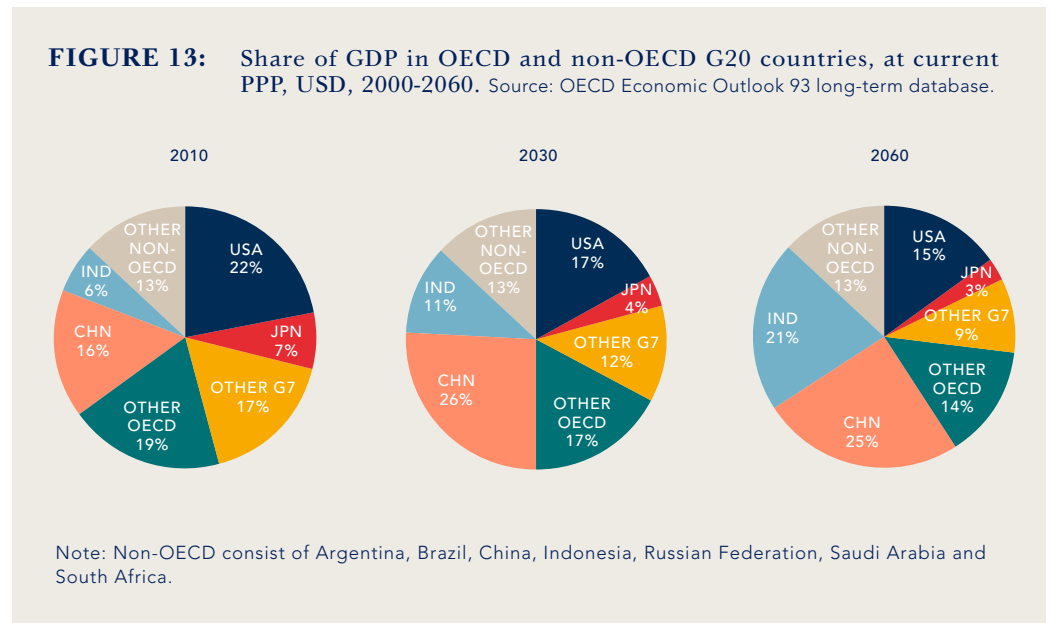
THE CHANGING GEO-ECONOMIC AND GEOPOLITICAL LANDSCAPE

The shift we are observing today, from a hegemonic to a multipolar world of economic and political power, is of long standing. Indeed, the gradual transition was noted at least as far back as the 1980s (OECD, 1987) as the new contours of an increasingly interdependent and interconnected world came into sharper focus. Thirty years on, the dynamics of change are as strong as ever, paving the way for a further significant transformation of the global landscape in the decades ahead.

The centre of gravity of the world economy is shifting east- and southwards...

The next 50 years will see the centre of gravity of the world economy shift east and south. By 2030, developing countries are expected to contribute two-thirds of global growth and half of global output, and will be the main destinations of world trade. Simultaneously, **considerable changes will take place in the relative size of the world's major economies** (Figure 13). Fast growth in China and India will see their combined GDP surpass that of the Group of Seven (G7) economies fairly soon and overtake that of the entire current OECD membership by 2060 (Johansson et al., 2012). The top economies in 2030 are widely expected to be the United States and China, with a race for third place between the European Union and India (Gros and Alcidi, 2013; Economist Intelligence Unit, 2015).

FIGURE 13: Share of GDP in OECD and non-OECD G20 countries, at current PPP, USD, 2000-2060. Source: OECD Economic Outlook 93 long-term database.



Several new emerging countries will appear on the scene by 2030, since economic progress is accelerating in many states. New large economies in 2030 (measured in total GDP at purchasing power parity [PPP]) will include Mexico, Indonesia, Turkey, Nigeria and Viet Nam, their eventual success depending largely on the quality of their governance and of their economic policy, their demographic profile and the level of education they provide to their citizens (ESPAS, 2015).

...and new players are wielding more power, some of them states...

As the new geographic diffusion of power has changed, so too have many of the features of power. A growing list of emerging states will be looking to translate their economic gains into more meaningful global influence. **Global governance structures will evolve further** as key groupings take on board the growing presence of some of the new vibrant economies, perhaps following the example set by the G7/G8, which scaled up to the G20 as a reflection of those new realities. In so doing, a delicate balance will need to be struck between the necessary engagement of such countries in international economic governance and the challenge of co-ordinating the growing number and diversity of participants.

...some of them non-state actors...

Non-state actors such as multinational businesses, non-governmental organisations, sovereign wealth funds, major cities, academic institutions and foundations endowed with global reach are all expected to play increasingly influential roles in the coming decades. In some cases they may even prove instrumental in the creation of new alliances and coalitions that have the wide public support to tackle some of the global challenges facing the planet – poverty, environment, security, etc. (NIC, 2012).

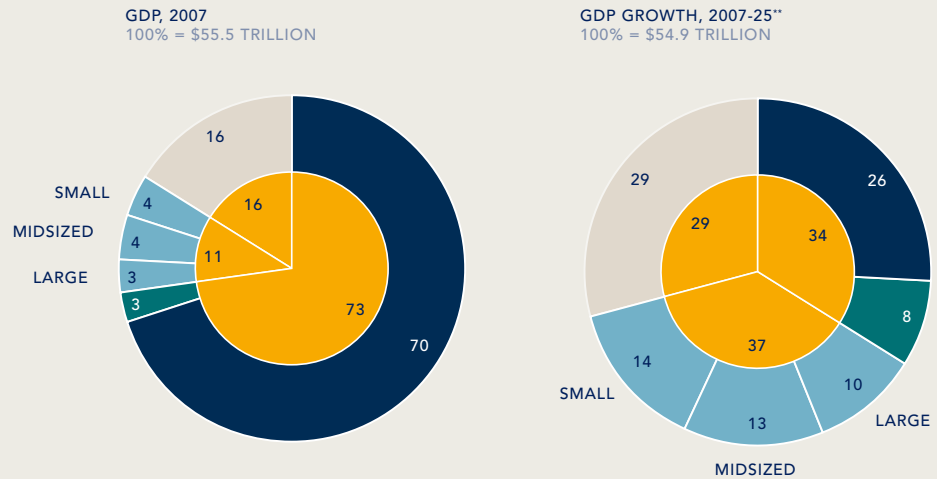
...and others newly emerging megacities

Cities, and in particular megacities, stand out as one of the increasingly powerful subnational actors. Metropolitan areas are the prime engine of growth. In the OECD area, more than half of economic growth and job creation occurred in the 275 metropolitan areas with over 500 000 inhabitants (OECD, 2013b). Megacities (populations over 10 million) in the developed world and in the emerging economies have until now been very much the centre of attention for business and policy makers alike – small wonder, since together they account for more than 70% of world GDP. This looks set to change, however, as **interest switches to the growth of medium-sized cities** (below 10 million inhabitants) especially in emerging and developing economies (Figure 14). Emerging-market mega- and middleweight cities together (with their high and growing concentration of middle-class households) are likely to contribute more than 45% of global economic growth from 2007 to 2025. Business opportunities, it is suggested, are less likely to be realised through gaining share in existing urban markets; it is the fast-growing “middleweights” that will increasingly attract interest (MGI, 2011a).

FIGURE 14: Growth of medium-sized cities to 2025. Contribution to GDP and GDP growth by type of city. Source: MGI, 2011a.

Middleweight cities in emerging markets are poised to deliver nearly 40 percent of global growth by 2025, more than the entire developed world and emerging market megacities combined*

- DEVELOPED ECONOMIES
- EMERGING MARKET MIDDLEWEIGHT CITIES
- EMERGING MARKET MEGACITIES
- EMERGING MARKET SMALL CITIES AND RURAL AREAS



* Megacities are defined as metropolitan areas with ten million or more inhabitants. Middleweight are cities with populations of between 150000 and ten million inhabitants.
 ** Real exchange rate (RER) for 2007 is the market exchange rate. RER for 2025 was predicted from differences in the per capita GDP growth rates of countries relative to the United States.

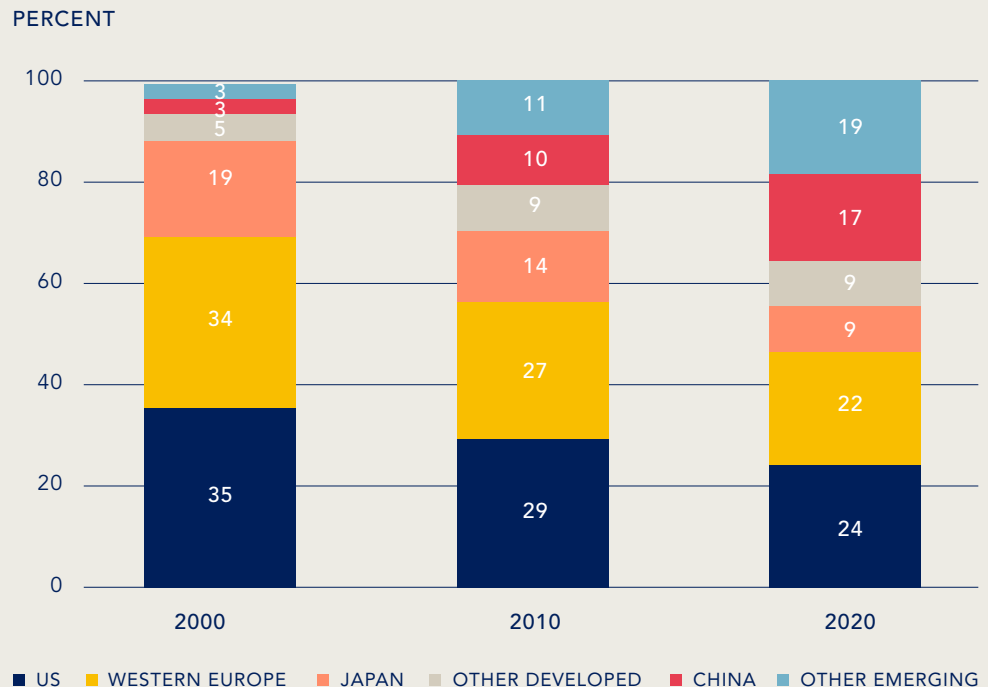
Driving and facilitating many of these shifts in power and influence is globalisation...

Global trade integration is expected to continue, albeit at a slightly slower rate than seen during recent decades. The shift in global economic weight will be reflected in trade patterns, with exports from OECD non-member economies rising from 35% of world exports in 2012 to 56% in 2060 (Braconier, Nicoletti and Westmore, 2014). The increasing role of the developing world in trade, coupled with rapid advances in communication and technology, will see **further fragmentation of supply chains**, so that the import content of exports will rise from around 40% today to 60% in 2030 (WTO, 2013), aided by the continuing decline in global transport costs.

...operating through flows of goods, services, investment and people ...

Trade in services is expected to continue to expand faster than trade in goods, due partly to the continuing liberalisation of the sector, and partly to the increasing share of GDP accounted for by services. And on the financial front, the expectation is that outward flows of foreign direct investment will have more than doubled by 2030 (Roland Berger, 2014a). Already by 2020 emerging economies are likely to be in possession of almost 40% of global financial assets, doubling their share since 2010 (Figure 15) (MGI, 2011b).

FIGURE 15: By 2020, emerging markets' share of financial assets is projected to almost double*. Source: MGI, 2011b.



* Assumes consensus GDP forecast for individual countries and that emerging markets' currencies appreciate vis-a-vis the US dollar.

Skills are increasingly internationally mobile, too. For example, reflecting the recent growth in university enrolment around the world, more than 4 million students were studying abroad in 2012, more than double the figure in 2000. Traditional destination countries, such as the United States, remain strong magnets for students seeking a high-quality education, although new destination countries and regional hubs are competing for a share of the revenue and intellectual capital of internationally mobile students (UIS, 2014). **By 2025, the total number of students seeking to study abroad could double to 8 million**, with demand growing fastest in Africa, the Middle East, Asia, Central America and South America (Goddard, 2012).

A key, much more significant factor driving globalisation is migratory flows. There are roughly 230 million migrants in the world today, moving in search of better lives and better jobs, fleeing from wars and civil strife, and/or reuniting with their families. Migratory movements show no sign of slacking, as the long drawn-out conflicts among other places in North and sub-Saharan Africa and the Middle East drive people to seek safe havens in Europe, and income and wealth disparities across the globe continue to attract people from poorer to more prosperous countries. Many, of course, bring qualifications and skills with them. In the decade to 2010/11, for example, the number of tertiary educated immigrants in the OECD increased by 70%, to reach 27 million (OECD, 2013b). All the signs point to a further strengthening of factors pushing and pulling migratory flows in the decades to come.

...as well as information technology

Underpinning much of the globalisation phenomenon is information and communications technology. Internet penetration for example has been growing quickly, helped considerably by mobile broadband. But it now seems to be slowing and it is considered unlikely that the milestone of 4 billion Internet users can be achieved before 2020 (Figure 16) (ITU and UNESCO, 2015). For the developing world, it is estimated that over the seven-year period from 2014 to 2020, an additional 1.1 billion new individuals will acquire a mobile phone for the first time, or 155 million per year. Moreover, 3G and 4G penetration is expected to double in the developing markets by 2018, with some operators planning to leapfrog 3G technology and launch 4G networks (Figure 17) (GSMA Intelligence, 2014). However, **a new digital divide is looming on the horizon.** The next phase of Internet development will be marked by a growing number of connected devices. North America, for example, is likely to have almost 12 devices per capita connected by 2019, Western Europe around 8. This will be in stark contrast to Latin America's 2.9 and Africa's 1.4, suggesting big differences in how societies will be utilising, and benefiting from, the Internet (ITU and UNESCO, 2015).

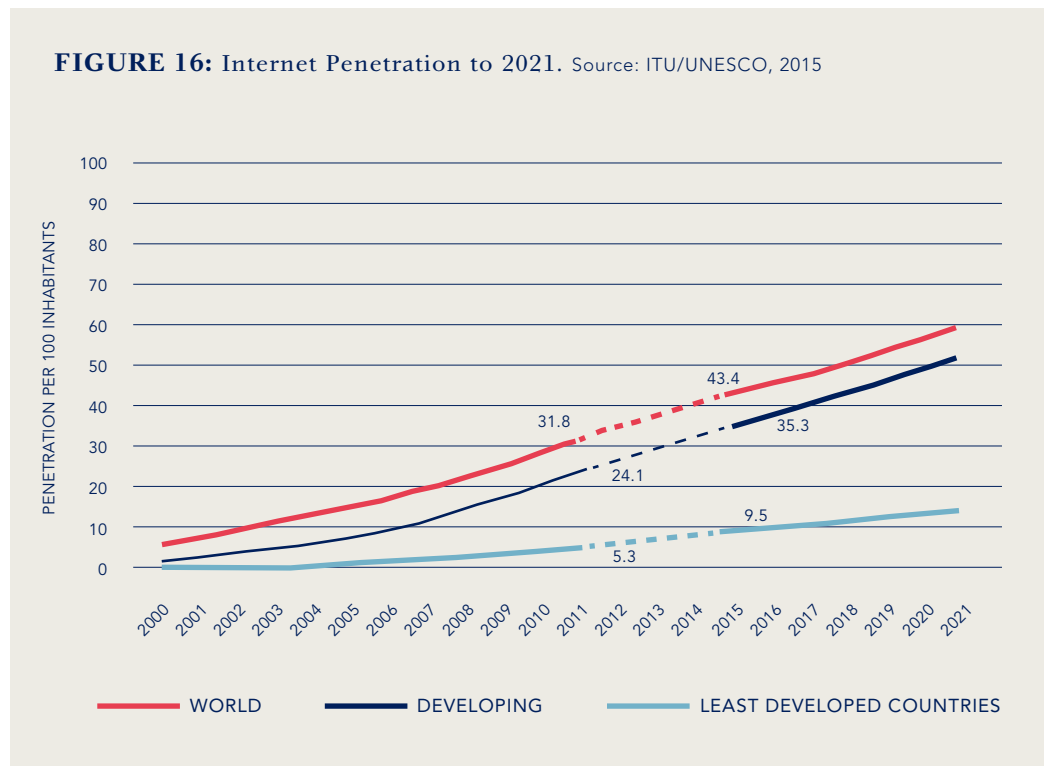
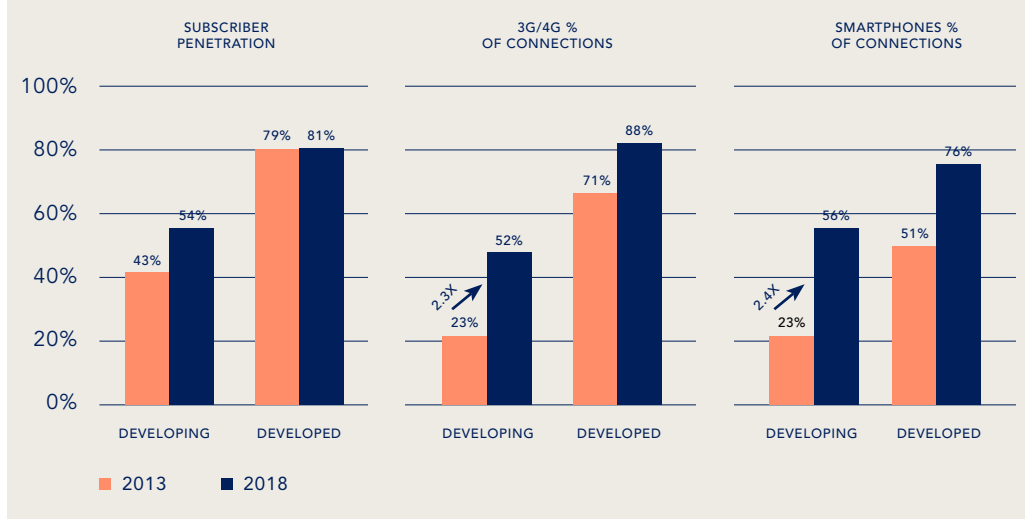


FIGURE 17: Outlook for growth in network and device technology in the developing world. Source: GSMA Intelligence, 2014.



Apart from moves by some governments to limit citizens' access to Internet content through controls (the "walled garden" phenomenon), a further obstacle to the global spread of information technology and its multiple applications and connectivity potential could be the lack of local language in Internet use. While it is true that English serves as a common Internet language for millions of people, the flip side is that **millions of people have no access because they speak no English. Around 55% of websites around the world use English** as the primary language, yet only 5% of the global population (335 million) speak English as their first language. Chinese on the other hand (including all dialects) is the first language of over 1.1 billion people (17% of the global population), yet only 3% of websites are written in Chinese. This trend continues in many non-English-speaking countries throughout the developing world, where very little Internet content exists in languages such as Arabic, Hindi and Bengali (GSMA Intelligence, 2014).

But globalisation will inevitably face counter-currents and crosswinds, such as...

The momentum behind globalisation is enormous, and the most plausible forecast for the next few decades is that globalisation will continue to advance. This is not to say that there will be no setbacks on the way. Three such counter-currents are explored below: the impacts of armed conflict, localisation barriers and the progression to a circular economy.

...geopolitical instability and armed conflict...

Looking back, **the last two decades have witnessed a gradual decline in the number (and severity) of internal armed conflicts worldwide** – from a peak in 1994 when almost a quarter of the world's countries were embroiled in civil conflict, to less than 15% today. This has been much the result of widespread improvements in factors such as levels of education, economic diversification and more favourable demographic developments (Hegre and Nygard, 2014). The number of interstate conflicts, while fluctuating somewhat, has also been on a declining trajectory (Pettersen and Wallenstein, 2015), thanks mainly to a rising body of global norms against such warfare and the deepening economic and financial linkages among countries.

Unsurprisingly, when it comes to forecasting the longer-term outlook for armed conflict, views diverge. Hegre and Nygard (2014), for example, forecast that this downward trend will continue, with the share of countries involved in internal armed struggles falling from 15% now to 12% in 2030, and 10% in 2050, and with conflicts concentrated mainly in sub-Saharan Africa and South Asia. Others are somewhat less sanguine. The US National Intelligence Council (NIC, 2012) states that the risks of interstate conflict are on the rise owing to changes in the international system, but does not foresee conflict on the level of a world war involving all major powers.

New developments might be expected at the crossroads of intra- and interstate armed conflict, as internal tensions spill across frontiers, generating **“internationalised” intrastate conflict**. Outstanding features of the recent wave of warfare include the extreme fragmentation of armed groups and the decentralised multiplication of fronts and factions engaged in conflict. For Briscoe (2014), three particular risks stand out for the international community: the intractability of conflict, with trouble tending increasingly to re-emerge in territories that have already been affected by warfare; unpredictable suicide attacks on major cities and infrastructures that lead to vulnerable states backing proxy groups and exacerbating cross-border civil war; and doubts about the capacity of current institutional mechanisms to deal with such fragmented and internationalised internal conflicts.

There are of course **important economic implications** both for the countries involved in conflict and for their trading partners. The fact that armed conflict can impact negatively on openness to trade and investment seems intuitively obvious, and yet the matter has attracted little attention from economic research until fairly recently. Work by Kamin (2015), for example, suggests that major conflicts can indeed reduce trade flows (by up to two-thirds). The impacts tend to be asymmetrical, affecting the exporter side more than the importer side, and depend to some extent on the nature of the conflict and the number of conflicts a country is involved in (Kamin, 2015). For exporting nations, understanding and anticipating the risks and the nature of these economic impacts will be an important part of conducting business in an increasingly complex geopolitical future.

...localisation barriers to trade...

Despite moves to foster more open multilateral trade (such as the Transatlantic Trade and Investment Partnership), **new trade barriers have been applied with increasing frequency since the onset of recession**. Between October 2008 and May 2014, well over 1 000 such measures (originally meant to be temporary) had been implemented, but only one-fifth of them removed. The low removal rate and the accumulation of new restrictions have seen the world’s stock of trade-restricting measures climb relentlessly upwards (World Bank Group, 2015). Just in the six months between November 2013 and May 2014, G20 countries implemented an additional 112 new trade-restrictive measures affecting 0.5% of world imports (WTO, OECD and UNCTAD, 2014). This is raising concerns among the business community and trade policy makers alike, and has led the G20 to call on the OECD, WTO and UNCTAD to monitor such trends on a regular basis. A significant share of these measures can be characterised as localisation barriers – measures that favour domestic industry at the expense of foreign competitors. The fastest-growing of these instruments are **local content requirements** (LCRs). A minimum level of locally produced – as opposed to imported – materials, parts, etc. is sometimes required under trade laws when giving foreign companies the right to manufacture in a particular place.

LCRs, especially those applied in the technology sector, have attracted considerable attention with studies by, for example, The Peterson Institute (Hufbauer et al., 2013), and the number of studies addressing concerns about government procurement LCRs and localisation of data has increased rapidly (Stone, Messent and Flaig, 2015). Trade-related LCRs reduce overall trade flows, even in those economies not even implementing such measures. OECD analysis suggests that the net impact of even a small number of LCRs (8% of the measures examined in the report) is to reduce world imports by USD 12 billion and world exports by nearly USD 11 billion. Four-fifths of the decline in trade occurs in intermediate goods and is considered particularly alarming in the context of global value chains (GVCs). The results imply that LCRs can lead to increasing economic isolation, undercutting important gains made from the rise of GVC activity. Declining trade volumes in intermediates threatens to reduce connectivity across the globe and potentially reverse the trend to greater economic integration (Stone Messent and Flaig, 2015).

Similar concerns are being expressed about government procurement LCRs as well as efforts by countries to control flows of data generated by firms offering a host of data storage, transfer and data mining services within and across borders. In light of current trends, the medium- to long-term impacts of LCRs, government procurement LCRs and data localisation on trade flows, technology transfer and innovation, as well as on investment (more substantially affected by LCRs than trade), will be an important area of research for the business community and policy makers alike.

...and unintended side effects of the circular economy.

A perceptible shift is under way towards the “circular economy”, although the world still has a very long way to go to the resource revolution aspired to in many quarters. OECD countries are stepping up efforts to move to a more resource-efficient economy, and are showing signs of decoupling material consumption from economic growth. Indeed, GDP per material input has increased by about 30% since 2000; municipal waste has decreased by almost 4% over the past decade; recycling rates are increasing (by up to 80% in some cases) for materials such as glass, steel, aluminium, paper and plastics. However, despite the progress, global material consumption is continuing to increase in line with world GDP due to higher material use in emerging economies (OECD, 2015b).

While the concept of the circular economy means different things to different people, many would nonetheless agree that it **implies a systemic change**, moving to a zero- or at least low- waste, resource-efficient society and involving big changes to our methods of both production and consumption. Looking beyond the potential for materials savings and a smaller footprint on the environment that a move away from the established “take, make and dispose” model could bring, a circular economy would create huge economic opportunities as new services and business models emerge and the relationship between producer and consumer, and between a product and its user, undergoes radical transformation. Repair, re-use, re-distribution and re-manufacture would increase, as well as recycling rates; materials technology would evolve and enable a move from non-renewable materials to the production and use of high levels of renewable materials in finished products (Waste Management World, 2015). This scaling up of the shift to a circular economy promises to deliver substantial macroeconomic as well as corporate benefits. The materials savings potential alone is thought to be over a trillion dollars annually (WEF, 2014; McKinsey Centre for Business and Environment and The Ellen MacArthur Foundation, 2015).

Yet an implicit consequence of this change in economic model could well be to focus efforts on circulation within the national or regional level economy rather than on a wider geographic scale. By way of example, one might see countries creating their own markets for the secondary materials they produce, rather than relying on export markets to satisfy demand. The broader point here, however, is that the business and policy-making communities will themselves need to gear up for the challenge in the coming years, yet have little or no knowledge of the trade, investment, technological and wider economic implications of the advent of the circular economy to guide them.

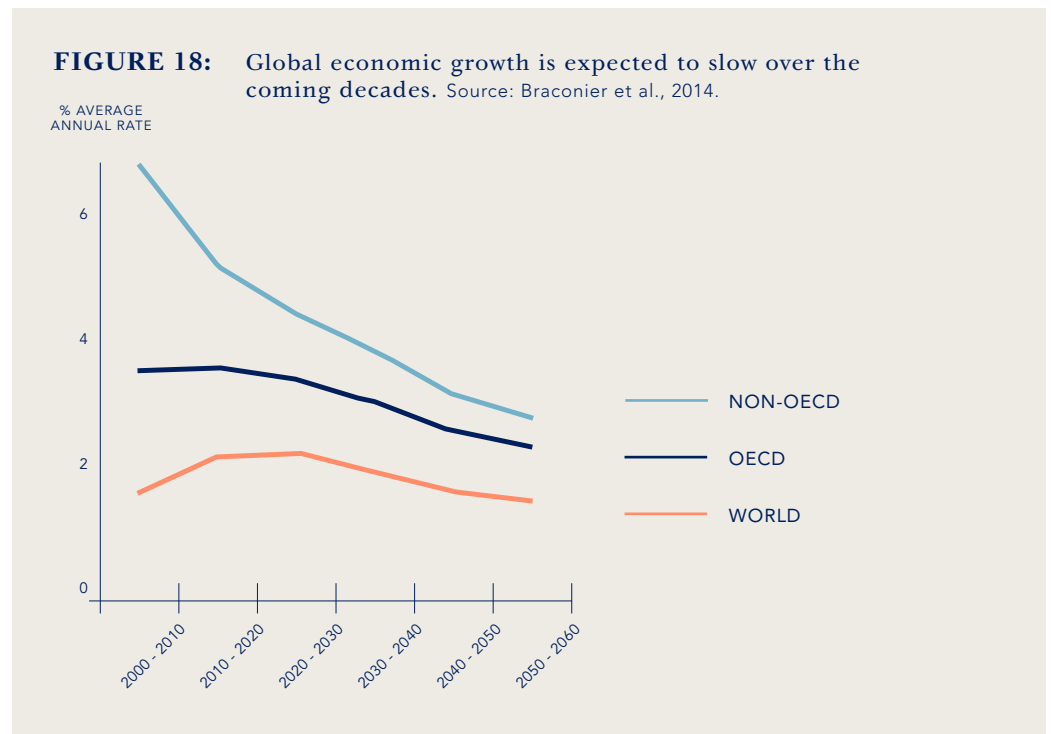
FOOD FOR THOUGHT 1: The next decades will see the emergence of many rapidly growing middle-sized cities in the developing world. What knowledge is needed to ensure smart and sustainable urban development?

FOOD FOR THOUGHT 2: Understanding and anticipating the nature and risks of the impacts of armed conflict – including economic and migration impacts – will be an increasingly important matter for policy makers and businesses alike. What are the research implications of this growing necessity?

FOOD FOR THOUGHT 3: The advent of the circular economy may be slow, but it is gathering momentum across the world in both developed and emerging economies. How can business, government and research effectively prepare for the inevitable long-term changes in mindsets, policy approaches, business opportunities and business models?

A MOVING FRONTIER: HOW DIGITALISATION WILL DRIVE ECONOMIES AND SHAPE THE WAYS WE WORK

The OECD estimates that global growth will slow from 3.6% in 2010-20 to 2.4% in 2050-60 (Figure 18) and will be increasingly driven by innovation and investment in skills (Braconier et al., 2014; Adalet McGowan et al., 2015). At the same time, production in OECD countries will shift from energy-intensive physical assets to intangible assets (i.e. knowledge-based capital). This transformation, which is already well underway, is being largely driven by widespread digitalisation of economies and societies.

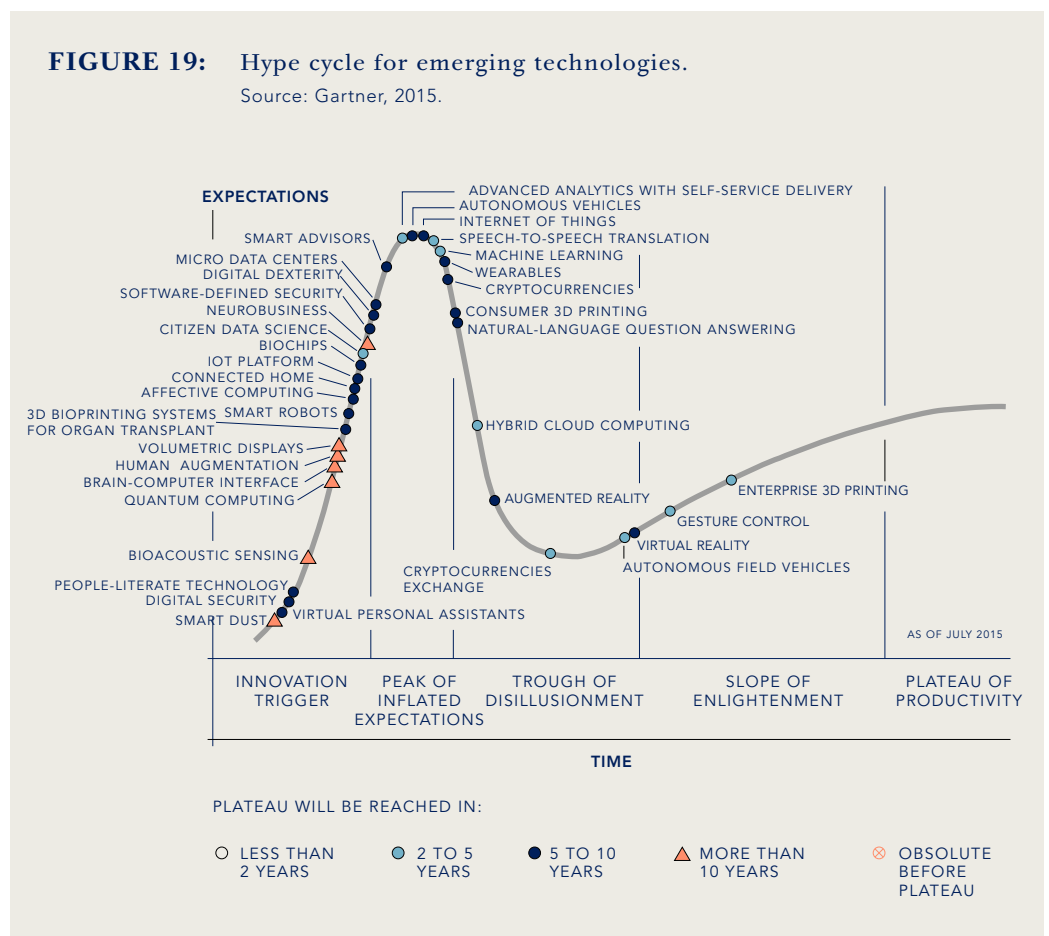


DIGITAL TECHNOLOGIES HOLD GREAT PROMISE

The **growing maturity and convergence of digital technologies** are likely to have far-reaching impacts on productivity, income distribution, well-being and the environment by 2030. These impacts will vary across industries, countries and sections of the workforce. Given how ICTs are in different stages of maturity and evolve at different paces and with different uncertainties, it is difficult to forecast with precision when and how impacts will come. Expectations of technologies often tend to be exaggerated well in advance of their eventual adoption and dissemination (Figure 19). In fact, the impacts of digital technologies on productivity gains so far fall short of those seen in earlier industrial revolutions (Gordon, 2012; Cowen, 2011). But this is likely to change over the next 10 to 15 years, as big data and processing power improve real-time measurement of business activities, lower equipment costs bring faster and cheaper business experimentation, and digitalisation enables innovations to be replicated with greater speed and fidelity (Brynjolfsson and McAfee, 2011).

FIGURE 19: Hype cycle for emerging technologies.

Source: Gartner, 2015.



By 2030, firms will be predominantly digitalised, enabling product design, manufacturing and delivery processes to be highly integrated and efficient. Additive manufacturing technologies will allow certain products to be tailored to specific user needs using computer-assisted drawing software. Placing an order will be a matter of uploading a file providing the desired specifications, which will trigger automated manufacturing and delivery processes, possibly involving different companies that can more easily coordinate thanks to digital technologies. The Internet of Things, big data analytics, artificial intelligence and machine learning tools will enable the emergence of smart machines that will be increasingly adjustable through sensor technologies, cheap computing power and the real-time use of algorithms (OECD, 2015ca). Some of these digital technologies are described in more detail in the Technology Trends section.

Digitalisation could promote greater entrepreneurship

The costs of equipment and computing will continue to fall, while the rise of open source development practices will create further communities of developers, not only in software but also in hardware and “wetware”, e.g. in do-it-yourself synthetic biology. There will be **greater opportunity for entrants** – including individuals, outsider firms and entrepreneurs – to succeed in new markets. Pattern-recognition technologies, such as big data and machine learning, will enhance capabilities for assessing user needs and overall demand for innovation. The risks and time-spans in product development and market launch are expected to decrease, spurring additional developments. Innovation-related production costs will fall in key industries, with cloud computing and 3D printing services providing platforms for new firms. Product distribution costs will continue to fall, reducing the cost of launching new products and services (OECD, 2015d). These developments could also provide emerging economies with opportunities to accelerate technological catch-up, possibly allowing them to leapfrog to productivity levels closer to those observed in OECD countries.

Digital technologies will make the services sector a more dynamic part of the economy

The services sector has already become a dynamic part of the economy, enabled by digital technologies that have helped to create new and more efficient businesses, boosted productivity growth, and facilitated international trade in services. Manufacturing in OECD economies increasingly thrives on services inputs for value creation, and **the differences between manufacturing and services have become increasingly blurred**. A large part of future growth in production is expected to come from so-called “manu-services”, which involve combining advanced manufacturing with a range of different services. The growing and complex interactions between manufacturing and services will call for a more integrated view on manufacturing and services in company strategies, as well as in policy discussions (OECD, 2015c).

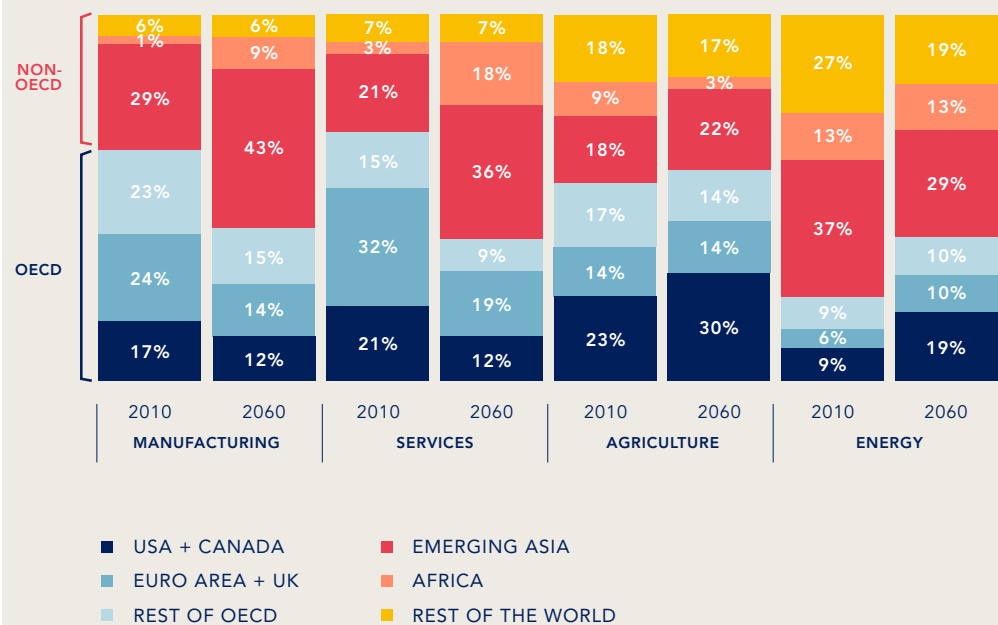
Digitalisation will further deepen the international fragmentation of production

Without digital technologies, the increasing international fragmentation of production in “**global value chains**” (GVCs) would not have been possible: manufacturing GVCs cannot function as efficiently without digitally-enabled logistics, telecommunications, and business services. Within these GVCs, more labour-intensive activities have typically been offshored from OECD economies to economies with low cost labour. But the extent to which this will continue in the future is uncertain. Wage increases, e.g. in Eastern China, are quickly eroding the labour cost advantage of emerging economies, while long and complex GVCs have exposed companies to a growing degree of supply risk in case of adverse shocks. In addition, management, logistical and opera-

tional problems, including the protection of IPR, resulted often in significant ‘hidden’ costs (i.e. costs that were not taken into account in the decision to offshore) and have in some cases made offshoring less or not profitable (OECD, 2015c). Taken together, these supply-side factors may motivate some companies in some industries to “re-shore” activities closer to their main markets in OECD countries.

Still, in addition to their lower labour costs, emerging economies such as China and India are the world’s most populous countries and have high GDP growth, which make them increasingly important markets for firms in many industries. A new middle class is fast-emerging that will lead to a rise in consumption of basic consumer products and other product categories. **These demand-side factors mean emerging economies are likely to remain favoured locations for production activities**, reducing the likelihood of widespread re-shoring to OECD economies (OECD, 2015c). Furthermore, income gains and changing consumption patterns mean that manufacturing exports from China, India and other Asian economies are expected to climb up the global value-added ladder, while significant shifts towards services will see China and other emerging economies gain large shares in services trade at the expense of OECD economies in the long-run (Figure 20) (Johansson and Olaberria, 2014).

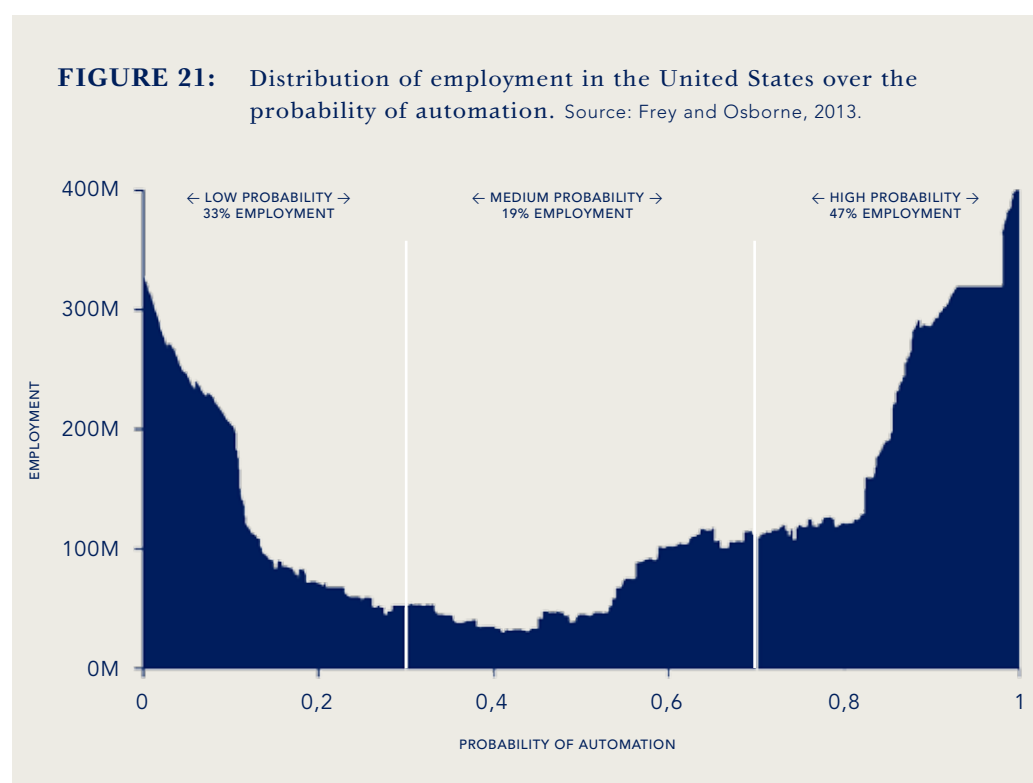
FIGURE 20: Gross exports as a share of world exports by industry, 2010 and 2060 %. Source: Johansson and Olaberria, 2014.



Manufacturing includes chemicals, rubber and plastic, electronics, food, iron and steel, metal products, other manufacturing, other metals, other minerals, paper and wood, textiles, transport equipment. Service includes business service, transport service, wholesale and retail, public administration and other services. Agriculture includes livestock, rice and crops, other agriculture and other mining. Energy includes coal, crude oil, electricity, gas and refined oil.

Digitalisation will redefine the role of labour in pervasive ways with disruptive effects

The decreasing cost of computing power and other advances in digital technologies are already disrupting labour markets and making workers redundant (see Brynjolfsson and McAfee, 2011). Computers have begun displacing labour when it comes to explicit (codifiable) routine tasks that follow precise and well-understood procedures such as clerical work (e.g. accounting) and some physical operations in production lines. For the time being, tasks that are hard to describe as a set of steps and are bounded to particular circumstances remain impervious to automation (Autor, 2015). These tasks are more abstract in nature and often involve problem-solving capabilities, intuition, creativity and persuasion. However, advances in machine learning and artificial intelligence are expected to expand the capabilities of task automation. Recent research suggests that **almost half of total employment could be at high risk (with a probability of more than 70%) of becoming automated over the next two decades** (Frey and Osborne, 2013) (Figure 21). This probability is based on the degree to which the job requires social intelligence, creativity, and perception and manipulation skills.



If these predictions prove correct, then a large portion of the workforce will need to be retrained. Depending on how quickly economies are able to create new jobs to replace those that have been lost, there may still be too few jobs, perhaps on a permanent basis (**technological unemployment**). Greater work-sharing and a reduced working week could help distribute work more evenly, but would need to guarantee a living wage (Skidelsky, 2013). Work may also become more fragmented, with an increasing number of workers doing lots of different part-time jobs – the rise of the so-called **“gig economy”**. The growth of online platforms that link a vast pool of freelancers, who are physically based in different parts of the world, with companies inviting them

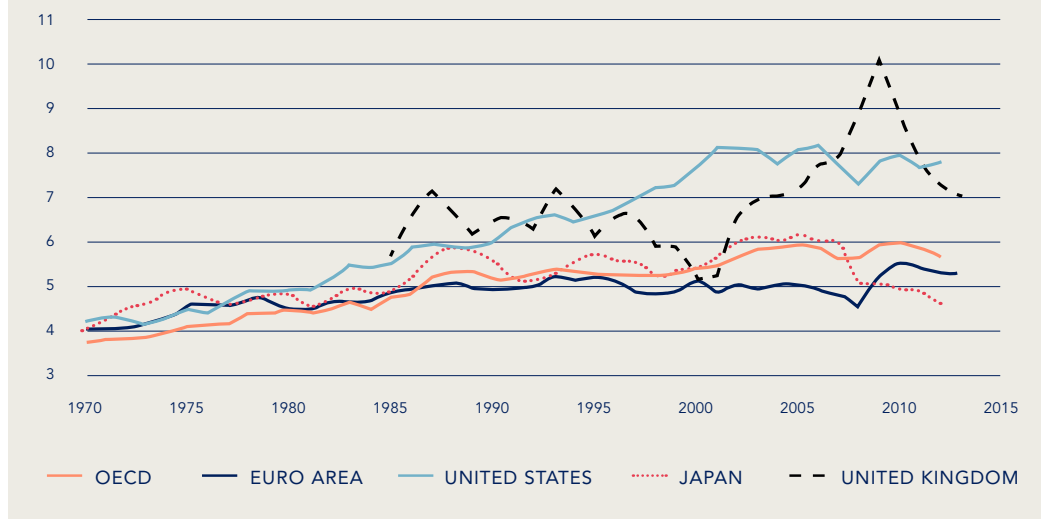
to bid to work on a wide variety of tasks, is enabling this trend. While such platforms offer flexibility to workers and companies, they raise some difficult questions about workplace protections and what a good job will look like in the future (Sundararajan, 2015). Furthermore, two of the biggest markets for these platforms are India and the Philippines, where lower costs of living allow workers there to undercut their peers in OECD economies. This could trigger a “race to the bottom”, driving down real wages and increasing inequality in OECD countries (Fox and O’Connor, 2015).

Digitalisation will continue to disrupt the financial sector

OECD countries have experienced an **upwards trend in the value-added share of the financial sector in GDP over the past half-century** (Figure 22), which has coincided with the sector’s growing influence on the overall economy and society (Mukunda, 2014). The sector’s rising profit share is considerably higher compared with the rest of the economy and its high wages have attracted some of the best talent, possibly at the expense of sectors with greater potential for productive innovation (Cournède et al, 2015; Cecchetti and Kharroubi, 2015). Banks and other lenders represent the largest component of the financial sector and have expanded at broadly similar rates. Intermediated credit and stock market capitalisation have also increased. While these trends may hold over the next 10 to 15 years, if not intensify as financial services further develop in emerging economies, digitalisation promises to disrupt the sector considerably. For instance, banks’ lending role will be increasingly challenged by digitally-enabled peer-to-peer lending platforms, while equity crowdfunding is also expected to grow (OECD, 2015e). Online payment systems (such as PayPal) and cryptocurrencies (such as bitcoin) are also forecast to proliferate. Other innovations leveraging the blockchain will lower transaction costs and provide computationally inexpensive methods for securely transferring value. This is expected to disrupt those institutions, like banks, whose *raison-d’être* lies in the centralised provision of trust behind transactions.

FIGURE 22: Value added by the financial sector, % of GDP.

Source: Cournède et al., 2015.



Long-term investment plays a key role in promoting innovation-based growth and job creation. Yet **high-frequency computer trading and a disproportionate focus on quarterly earnings will likely continue to bias capital markets towards short-termism**. A key policy challenge will therefore be to establish long-term investment incentives that offset tendencies in the financial system to measure profit margins on a short-term basis (WEF, 2011). Institutional investors with a longer-term return horizon, such as pension funds, sovereign wealth funds, or foundations, could help counterbalance this trend, particularly if a larger proportion of their investment portfolios could be targeted at financing innovative young firms.

FOOD FOR THOUGHT 1: Over the next 10 to 15 years, GDP growth in OECD countries will progressively rely on productivity gains through innovation, especially investments in knowledge-based capital. Consumer surplus will increase in ways not captured by traditional metrics such as GDP. What other metrics could capture with more accuracy the well-being generated by the knowledge-based capital economy?

FOOD FOR THOUGHT 2: Automation is set to further disrupt labour markets, creating jobs in some industries but displacing workers in others, including in the world of research. How is automation expected to affect the demand for researchers, the tasks they carry out as part of their research work and their training needs?

FOOD FOR THOUGHT 3: The recent financial crisis and economic slowdown it unleashed have drawn greater attention to the workings of the financial sector and its regulation. What further opportunities, risks and uncertainties does digitalisation bring to the sector, and what impacts might these have on the future funding of research and innovation activities?

WEALTH, HEALTH AND KNOWLEDGE: THE GREAT GLOBAL DIVIDE?

Barring major global catastrophes, and despite slowing global growth rates, the world is very likely to be a much richer place by mid-century. World GDP is expected to more than triple by 2060, per capita incomes are also set to rise rapidly, and wealth accumulation is anticipated to continue apace. However, whether this will also be a better world depends very much on how incomes and wealth will be distributed across the globe and within countries.

While the prosperity gap between rich and poor countries is shrinking...

At present, the prosperity gulf between developed and developing economies is wide. But the future promises convergence. Over the next half century, **disparities in GDP per capita are expected to narrow across countries**; per capita income levels of the currently poorest economies will more than quadruple (in 2005 purchasing power parity terms), whereas they will only double in the richest economies; China and India will experience more than a sevenfold increase of their income per capita by 2060. Nonetheless, significant gaps in living standards will remain between advanced and emerging economies as well as between them and the least developed countries.

...it is tending to widen within developing economies...

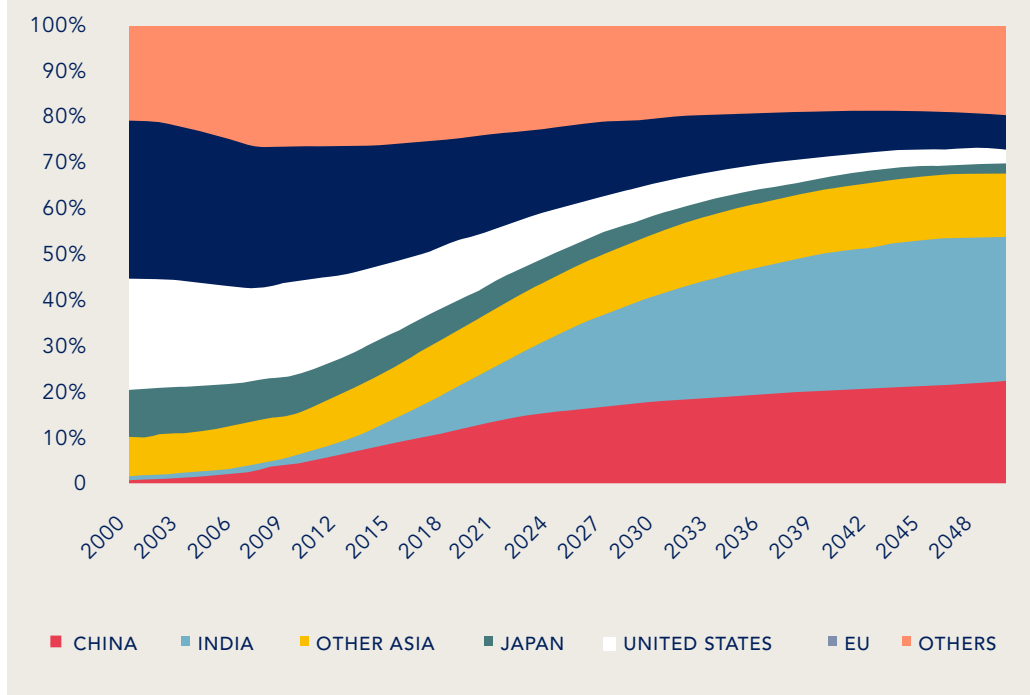
Inequalities within countries will pose major political, social and economic risks in the coming years. Over two-thirds of emerging and poor countries, encompassing 86% of the population of the developing world, will experience growing inequalities. For many, the prospects of long-term help are particularly gloomy: by 2030, some two-thirds of the world's poor could be living in "fragile" states – in other words, in countries where there is no government that could effectively constitute a counterpart for foreign aid agencies (ESPAS, 2015).

...as middle-class spending power gains ground

Rising wealth and income in the developing economies of the world is progressing hand in hand with the emergence of a global middle class. By current projections, the global economy's middle class is expected to more than double between 2009 and 2030, from 1.8 billion to almost 5.0 billion, accounting for about 60% of the world population. Some **two-thirds of those middle-class citizens are expected to be found in Asia** (Gros and Alcidi, 2013). Of course, the number of people in the middle class does not properly capture its spending power. Given the broad range of expenditures that fall within the middle-class definition, some countries have more affluent middle classes than others. Today's middle class in Europe and North America make up just over half of the global total in terms of number of people, but they account for almost two-thirds of total spending by the world's middle class. This is about to change. Asia's share of global middle-class expenditure is expected to climb from around one-quarter today to almost 60% in 2030, bringing about a huge shift from spending on necessities such as food and clothing to choice-based spending on categories such as household appliances and restaurants (Figure 23) (Kharas and Gertz, 2010).

FIGURE 23: Shares of Global Middle Class Consumption, 2000-2050.

Source: Kharas and Gertz, 2010.



But inequalities are growing in many developed countries too...

Growing income and wealth inequalities are not the preserve of the developing world. In the vast majority of advanced countries, **the gap between rich and poor** has reached its highest level for three decades. Today, the richest 10% of the population in the OECD area earn nearly 10 times the income of the poorest 10%, up from 7 times in the 1980s. However, the ratio does vary widely across OECD countries. In Nordic and many Continental European countries, the ratio is significantly lower than the average, but in Italy, Japan, Korea, Portugal and the United Kingdom it is closer to 10 to 1, between 13 and 16 to 1 in Greece, Israel, Turkey and the United States, and as high as between 27 and 30 to 1 in Mexico and Chile (OECD, 2015f).

...as are poverty rates and the profiles of those at risk of poverty

Importantly, however, the rise in overall income inequality in OECD countries is not only about the top income bracket. The evidence suggests that what matters most is the gap between low-income households and the rest of the population. Indeed, over the last 30 years, incomes at the low end of the scale often grew much more slowly during the prosperous years and decreased during downturns. Unsurprisingly perhaps, for the vast majority of developed countries for which data are available, poverty rates increased from the mid-1990s to the 2010s, pushing up rates for the OECD area as a whole by 1.5 percentage points. Over the last couple of decades the risk of poverty has shifted markedly away from the elderly towards families with children. Hence, large families with three or more children also tend to have higher levels of poverty risk. Moreover, **child poverty is seen to be increasing in almost all OECD and EU countries**. On average across the OECD, the child poverty rate increased from 12.2% in 2000 to 13.2% in 2010 (OECD, 2013c).

Also at risk are young adults, who make up an increasing share of the poor. The increase in youth poverty is to be found particularly among youngsters not in education, employment or training who run a greater than average chance of unemployment, lower wages, poorer health and therefore a greater risk of long-term “scarring”. In many countries, migrant families and their children are also at risk. Within Europe, this is particularly true of non-EU immigrant families and their offspring (Jokinen and Kuronen, 2011). And finally, there are those families facing persistent poverty. These are most likely to be older people, single people (especially women both with and without children) and jobless households.

The future will see striking changes in family and household structures in OECD countries ...

Such phenomena are closely (but not exclusively) associated with changing family and household structures. In recent decades families in the OECD area have undergone significant transformation. **The extended family has almost disappeared in many countries**, and the traditional family consisting of a married couple with children has become much less widespread as divorce rates, cohabitation, couples “living together apart”, single parenthood and same-sex partnerships have all increased. With rising migration, cultures and values have become more diverse, more women have taken up work, more young people are spending more time in education and training, and the elderly are living longer and increasingly alone (OECD, 2011b).

The expectation is that these trends will continue over the coming decades, with significant increases in many OECD countries in: one-person households (reaching 30-40% of all households by 2025-30 in many countries), single-parent households (30-40% of all households with children by 2025-30 in some countries) (Figure 24), and couples without children. A priori, and if the underlying associations continue to apply, the projected changes in household and family structure suggest quite significant challenges in the future. For example: The expected increase in single-parent families (Figure 25), the numbers of cohabiting couples and reconstituted families could lead to more such families facing **a higher risk of poverty**; the rising number of single-adult households coupled with growing numbers of elderly people implies that the significant proportion of elderly people among society’s poor will persist in coming years; the increase in childless couple households, divorce rates, remarriages and step-families may weaken family ties **and undermine capacity for informal family care**; and the growing numbers of single-adult households will put **increased pressure on housing** (OECD, 2011b).

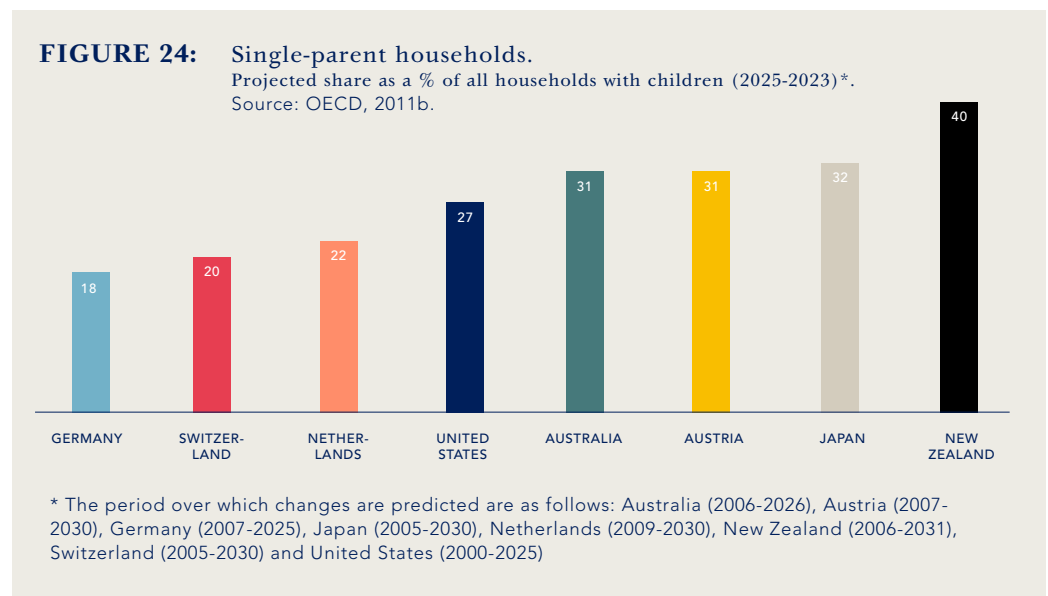
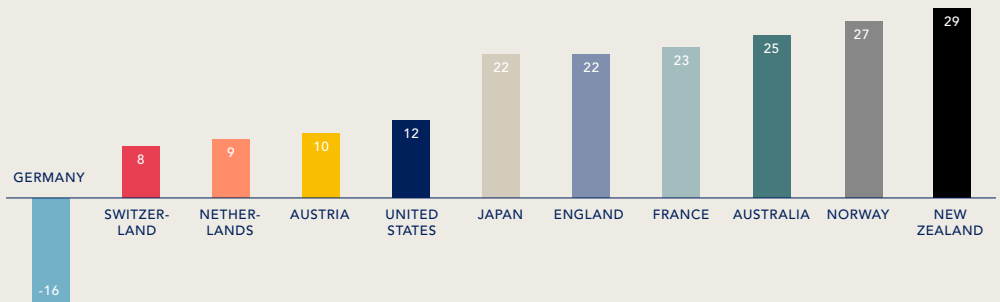


FIGURE 25: Single-parent families.
 Projected % increase in selected OECD member countries
 (early-mid-2000s to 2025-2030*). Source: OECD, 2011b.

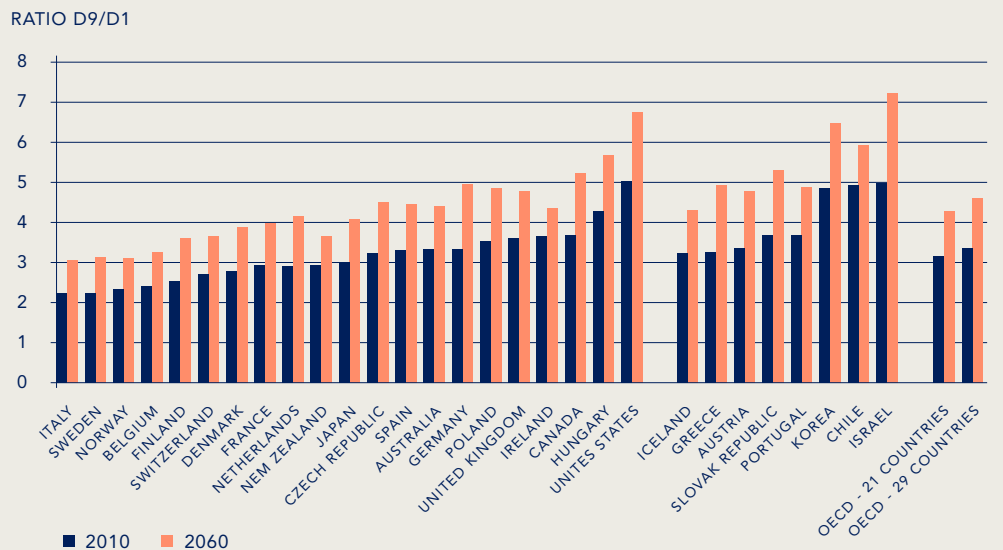


* The periods over which changes are predicted are as follows: Australia (2006 to 2026), Austria (2007 to 2030), France (2005 to 2030), Germany (2003 to 2025), Japan (2005 to 2030), Netherlands (2009 to 2030), New Zealand (2006 to 2031), Norway (2002-2030), Switzerland (2005 to 2030), United Kingdom (2006 to 2031), United States (2000/2025)

...with important implications for education and access to knowledge...

Such projections do not bode well for the future. Recent analysis (e.g. Piketty and Zucman, 2013; Braconier et al., 2014) suggests that the trend towards increasing inequality in incomes and wealth will very likely continue for many years to come. Indeed, based on current trends, **earnings inequality in an average OECD country could rise by more than 30% by mid-century**, bringing OECD economies as a whole to the same level of inequality experienced in the United States (Braconier et al., 2014) (Figure 26).

FIGURE 26: Gross earnings inequality (D9/D1) 2010 and 2060.
 Ratio of the 10% best-paid workers to that of the least-paid workers (D9/D1 ratio).
 Source: Braconier et al., 2014.



The reasons, it is suggested, are to be found primarily in human capital accumulation theory: **inequality undermines education opportunities for the disadvantaged**, which in turn reduces social mobility, leading to a slowing of human capital accumulation. Survey results tend to support this theoretical approach. The OECD's Adult Skills Survey (PIAAC) demonstrates that widening income disparities hamper the development of skills among those segments of the population with poorer educational background. For OECD countries, virtually all increases in earnings dispersion would take place between high- and medium-income earners, in line with recent evidence suggesting that technology increasingly replaces medium-skilled jobs, leading to earnings polarisation (Braconier et al., 2014).

Clearly, then, access to education and the acquisition of knowledge and skills will be one of the most important keys to improving life chances – not only in the advanced economies, but also and especially in the developing world. The International Institute for Applied Systems Analysis policy-driven fast-track scenario for world educational attainment, for example, assumes lower secondary schooling to reach 50% of each cohort by 2030, and 90% by 2050. Tertiary education attainment is assumed to reach 60% by 2050 (KC et al., 2010). On current evidence, the scenario may prove somewhat optimistic still, since the UN's target of getting every child in the world into school by 2015 has been missed. Nonetheless, the long-term trends are favourable. By 2050 there will be more people than today having completed secondary education, and a large increase in numbers of people having obtained degrees (Nagdy and Roser, 2015). **The average level of educational attainment is set to rise more quickly in developing countries than in advanced economies, shrinking the gap between the two.** The number of students around the globe enrolled in higher education is forecast to more than double to 262 million by 2025. Nearly all of this growth will be in the developing world, with more than half in China and India alone. As a result, by mid-century, it is possible that a majority of the world's children will have had a university or higher-level education. In almost all OECD countries, the proportion of the population who will be graduates in 2025 is likely to increase, in some cases very significantly (OECD, 2008).

What stands out among these future education trends are three things: the growing share of female enrolment; the accelerating internationalisation of university education; and the widening use of digital technology in teaching and learning.

...especially for women

Through concerted efforts by governments, civil society and the development community, **girls' enrolment at all levels of schooling in the developing world has risen significantly over the last two decades.** Most low-income countries, for example, made substantial progress during the 1990s in achieving gender parity in both primary school enrolments and literacy. Although many parts of Africa are improving only slowly, South Asia, which lagged behind sub-Saharan Africa in 1999 at the primary school level, reached the UN's 2015 target as early as 2010. Even the Middle East, where traditional religious prejudices often prevent girls going to school, has made substantial progress (The Economist, 2013). There is a good deal of optimism therefore that by mid-century, global gender gaps at the primary school level are likely to have largely disappeared, although girls are likely to remain under-educated in many of the world's most intractably poor countries (UK Ministry of Defence, 2014). At the higher education level, too, gender equality is making significant inroads. In most OECD countries, women already account for at least 50% of tertiary education enrolments. That proportion could increase yet further through 2025 – to over 70% in Austria and the United Kingdom, and well over 60% in North America and parts of Scandinavia (OECD, 2008). It goes without saying that the emergence of such strongly qualified female cohorts has important implications for economic growth, labour markets, family life, patterns of childcare and elderly care.

Opportunities are expanding rapidly via the internationalisation of university education...

The internationalisation of university education has already begun. There has been more than a fivefold increase in foreign students since the mid-1970s. The number stood at around 0.8 million worldwide in 1975 and had risen to an estimated 4.1 million by 2010. Foreign students are highly concentrated in a few countries, as almost half go to the top five destination countries (the United States, the United Kingdom, Germany, France and Australia). Nevertheless, the fastest-growing destination regions are Latin America and the Caribbean, Oceania and Asia, reflecting university internationalisation in a growing set of countries (OECD, 2012c). Looking ahead, **the number of students seeking study abroad could double to 8 million by 2025**. Average annual growth in demand for international higher education between 2005 and 2025 is expected to exceed 3% in Africa, the Middle East, Asia, Central America and South America (Goddard, 2012). The top sending countries for international students in 2025 will be China, India, Germany, South Korea, Saudi Arabia, Nigeria, Turkey, Pakistan, France and Kazakhstan, and students from China and India are predicted to make up roughly one-third of the total number (British Council, 2013). Yet internationalisation is posing growing challenges to the institutions involved: competitive pressures from globalisation; a shift from co-operation to competition among institutions; struggle for funding; and increased privatisation of international higher education through revenue generation (European Parliament, 2015).

...and the digitisation of education at all levels

As digital technologies make ever-deeper inroads into education, and in particular at university level, learning methods and strategies will change. The scope for personalisation is already expanding, as the capabilities and the willingness to use digital resources help create bespoke pathways for learning, for example by breaking the courses into modules and enabling students and instructors to re-configure the modules to suit the learning situation. Then there is analysis and use of “big data”, which offers more nuanced and timely insights into all kinds of learning processes and tailoring of content to specific learning contexts. Nonetheless, far from placing the technology and the IT infrastructure in the foreground, the focus is expected to continue to shift toward conceiving it as a **digital learning environment** (Brown, 2015).

Access to education, of course, is not necessarily access to knowledge. The future is on a course that will increasingly thrive on ubiquitous access to ever-growing volumes of information and data in contexts other than those of a structured learning/teaching environment. The keys are the growing penetration of the Internet and mobile technology. According to the latest data from the International Telecommunication Union (ITU), 43% of the world's population is now online with some form of regular access to the Internet, and the figure is growing by the day. However, the digital divide is proving stubbornly persistent in terms of access to broadband Internet, including the challenge of extending last-mile access to infrastructure to remote and rural communities. There are as yet 4.2 billion or 57% of the world's people who still do not enjoy regular access to the Internet (ITU, 2015). For some observers, however, **the digital divide may soon be bridged, namely by mobile technology** (ITU, 2015). The total number of unique mobile subscribers is between 3.7 billion and 5 billion people (depending on source). According to Ericsson (2015), mobile broadband subscriptions will reach 7.7 billion globally by 2020. They already account for an overwhelming share of all broadband subscriptions, and it is expected that while mobile broadband will only complement fixed broadband in some segments, it will become the dominant form of access in others (Ericsson, 2015).

But other digital divides may be waiting around the corner. It is not just the humans who are getting connected. Many analysts agree that the Internet of Things (IoT) is now coming of age, and foresee strong growth in the IoT in their predictions. There are currently five connected devices for every person connected with the Internet. However, looking forward, machine-to-machine is expected to show strong growth driven by new use cases, e.g. in cars, machines and utility metering. Paradoxically perhaps, the growth of the IoT may even introduce a new form of the digital divide, in terms of who has access to which connected devices (ITU and UNESCO, 2015).

The global health divide is also a major concern, in respect to infectious diseases...

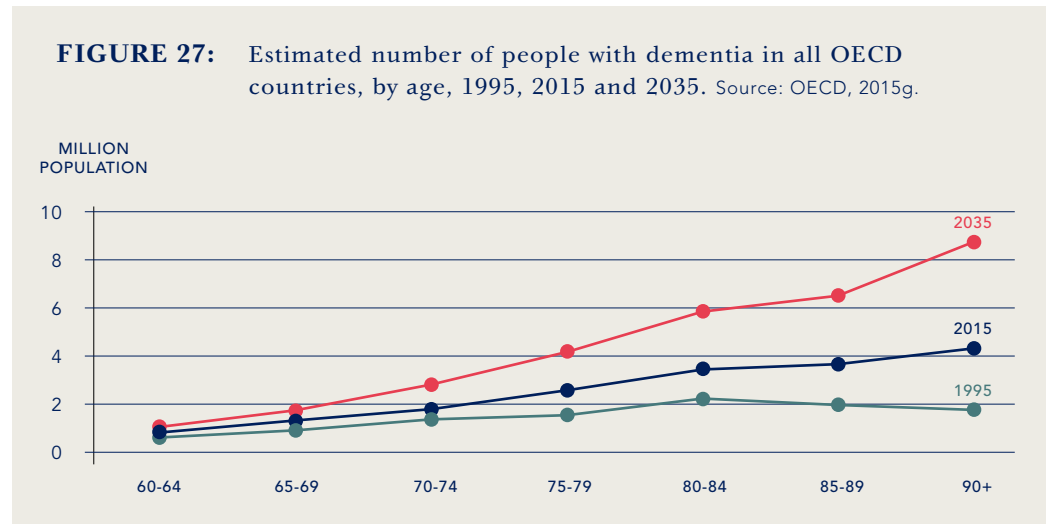
Deep dividing lines may persist for some time to come not only in respect to technology, education, income and wealth, but also and especially with regard to health. The healthcare systems of the future will have to face a growing spectrum of challenges, not least from a rapidly changing world panorama of disease. **Progress has been made in the battle against some infectious diseases** such as tuberculosis (TB), HIV/AIDS and malaria. HIV/AIDS mortality has fallen quite dramatically in recent years, and deaths from TB (95% of which occur in low- and middle-income countries) are declining, albeit very slowly (WHO, 2014a). Approximately half of the world's population is at risk of malaria (with 90% of malaria deaths occurring in Africa). However, between 2000 and 2013, an expansion of malaria interventions helped to reduce malaria incidence by 30% globally, and by 34% in Africa. During the same period, malaria mortality rates decreased by an estimated 47% worldwide and by 54% in Africa (WHO, 2015). However, **trends are at work in society that suggest that future progress in countering infectious diseases may become harder to achieve.** Urbanisation is continuing to gather pace in the developing world; climate change is influencing geographic patterns of human and animal infections (e.g. malaria); international tourism is growing; global migration levels are unlikely to abate; and excessive current use of antibiotics is set to reduce the future effectiveness of drugs against some communicable diseases (e.g. TB).

...non-communicable and neurological diseases ...

While the annual number of deaths due to infectious disease is projected to decline, the total annual number of deaths from non-communicable diseases (NCDs) is projected to increase from 38 million in 2012 to 52 million by 2030. This **epidemic of NCDs is being driven by powerful forces such as demographic ageing, rapid unplanned urbanisation, and the globalisation of unhealthy lifestyles.** While many chronic conditions develop only slowly, changes in lifestyles and behaviours are occurring rapidly and pervasively. The leading causes of NCD deaths in 2012 were cardiovascular diseases, cancers, respiratory diseases and diabetes. These four major NCDs were responsible for 82% of NCD deaths. Going forward, annual cardiovascular disease mortality is projected to increase from 17.5 million in 2012 to 22.2 million in 2030, and annual cancer deaths from 8.2 million to 12.6 million (WHO, 2014b). The prevalence of diabetes has been increasing globally in recent decades, and WHO projects that it will be the seventh-leading cause of death in 2030. NCDs already disproportionately affect low- and middle-income countries, and current projections indicate that by 2020 the largest increases in NCD mortality will occur in Africa and other low- and middle-income countries (WHO, 2011).

Cases of **neurological disease**, spurred in particular by rising longevity and the anticipated rapid ageing of societies in the coming decades, are expected to multiply (Figure 27). Alzheimer's Disease International (ADI), for example, estimates that 46.8 million people worldwide are living with dementia in 2015, and that the number will almost double every 20 years, reaching 74.7 million in 2030 and 131.5 million in 2050. Fifty-eight percent of all people with dementia live in countries currently classified by the World Bank as low- or middle-income countries. This proportion is estimated to

increase to 63% in 2030 and 68% in 2050. Between 2015 and 2050, the number of older people living in high-income countries is forecast to increase by 56%, compared with 138% in upper-middle-income countries, 185% in lower-middle-income countries, and by 239% in low-income countries (ADI, 2015).



...and antibacterial resistance

Finally, as noted earlier, use of antibacterial drugs has become widespread over several decades (although equitable access to antibacterial drugs is far from being available worldwide). These drugs have been extensively misused in both humans and food-producing animals in ways that favour the selection and spread of resistant bacteria. Consequently, **antibacterial drugs have become less effective** or even ineffective, resulting in an accelerating global health security emergency that is rapidly outpacing available treatment options (WHO, 2014c).

The health challenges are therefore considerable, but so too are the opportunities

The global health challenges for the next decades are immense. But the very scale of those challenges across the developing world and the advanced economies offers vast opportunities for established and novel medical procedures, specialised treatments, new medicines and technological solutions, as well as for the development and implementation of innovative systems of health provision and care co-ordination and management. Unfortunately, at the present time the resources devoted to preventing, mitigating and curing disease, as well as to people's access to those resources, are also unevenly distributed. Evidence to date indicates that access to good health care correlates quite strongly with income level, educational level and access to knowledge. Thus, as incomes and educational levels rise across much of the globe, even in poorer countries, and the middle classes in emerging and developing economies gain ground, the prospects for sustainable **health markets** in those parts of the world are expected to brighten considerably.

FOOD FOR THOUGHT 1: Family structures in OECD economies are undergoing very significant changes – more single parents, more single-person households, more patchwork families, more elderly living alone, more families with migrant backgrounds, etc. – changes that are very likely to continue into the future. But what do we know about the future implications of these changing family structures for housing, transport, health and social services, schooling needs, and so on?

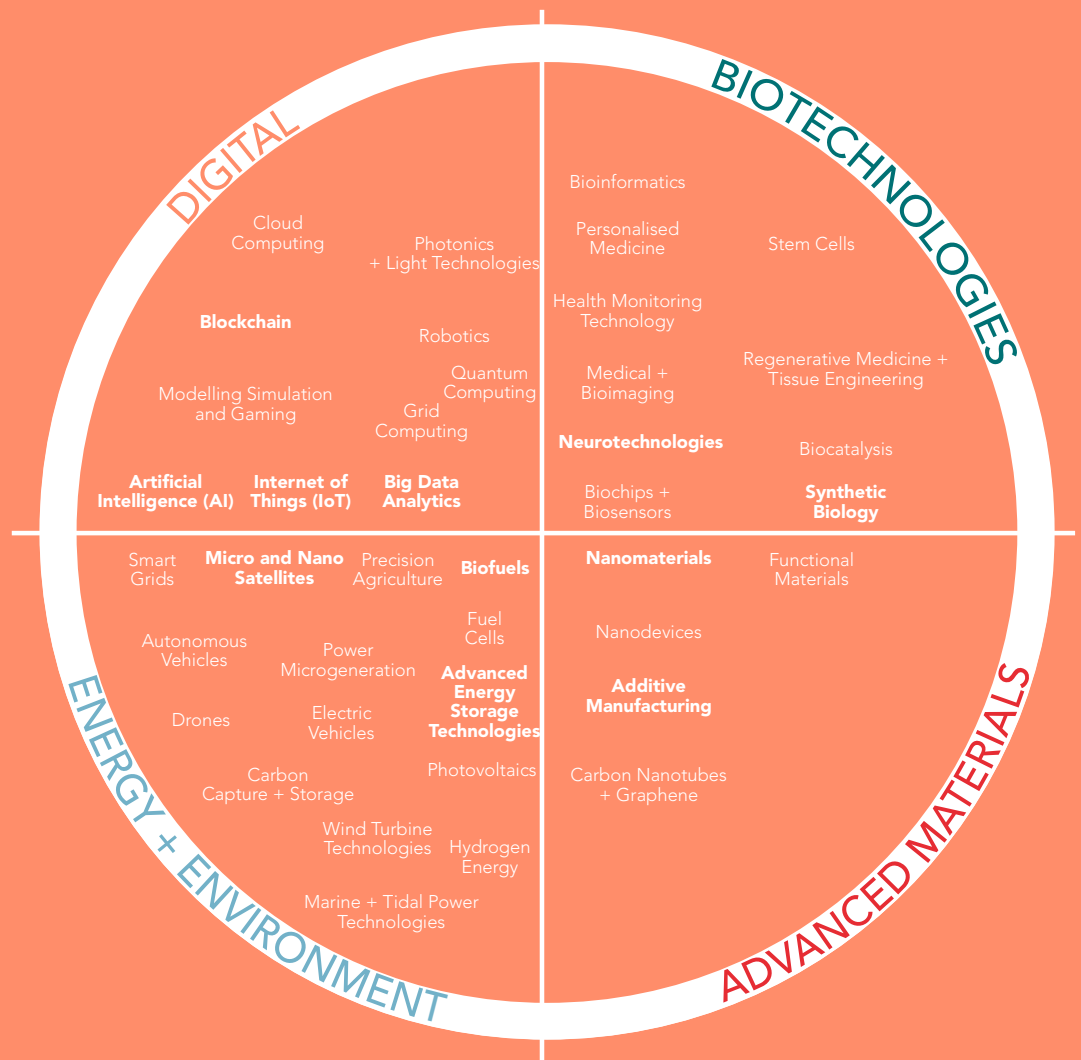
FOOD FOR THOUGHT 2: In the developed world, women are outpacing men in terms of participation in higher education, and trends suggest that the gap will widen in the coming years. How is this likely to affect some of the key dynamics of our societies such as marriage, labour market participation, and early childhood education?

FOOD FOR THOUGHT 3: In the not-too-distant future, several seemingly unconnected developments – such as climate change, growing migratory flows, rapid expansion of international tourism and mounting antibacterial resistance – could combine to significantly re-shape the disease landscape, not least in the advanced economies. How can research help better identify and anticipate the risks not just to the health sector but to society and the economy more broadly, and improve the general level of readiness?

TECHNOLOGY TRENDS

The brochure's second section covers ten (highlighted in bold) of the 40 most commonly-identified technologies shown in Figure 28.

FIGURE 28: 40 key technologies for the future.





THE INTERNET OF THINGS

The Internet of Things promises a hyper-connected and ultra-digitally responsive society that supports human, societal and environmental developments. However, several safeguards need to be put in place to ensure data protection and security.

The Internet of everything...

The Internet of Things (IoT) is defined as the connection over time of almost any object and device to the Internet's network of networks (OECD, 2015h). In the public space, at the workplace and at home all kinds of objects and sensors will gather data and exchange these with one another and with humans. The IoT is really an Internet of everything, since in addition to connecting things, it also enables digital connections among other elements in the physical world, such as humans, animals, air and water. The networked sensors and actuators in the IoT allow monitoring of the environment, status reporting, receiving of instructions, and sometimes even automated actions (MGI, 2013).

...is spreading at exponential speed...

The number of connected devices in and around people's homes in OECD member countries will probably increase from 1 billion today to 14 billion by 2022 (OECD, 2015h). By 2030, it is estimated that 8 billion people and maybe 25 billion active "smart" devices will be interconnected and interwoven by one single huge information network (OECD 2015i). Other estimates indicate a number of 50 to 100 billion connected devices in and outside people's homes by 2020 (Evans, 2011; MGI, 2013; Perera et al., 2015). The result is the emergence of a gigantic, powerful "superorganism", in which the Internet represents the "global digital nervous system" (OECD, 2015i).

...and presaging transformational impacts on our societies

The IoT is set to enable a hyper-connected and ultra-digitally responsive society. Its economic impact is estimated between USD 2.7 trillion and USD 6.2 trillion annually by 2025 (MGI, 2013). While the IoT has profound implications for all aspects and sectors of the economy, the largest impacts are expected in the healthcare sector, network industries and the manufacturing sector.

Health and healthcare

The IoT provides opportunities to improve people's health and provide better healthcare by connecting inner and outer bodily sensors to both personal health monitoring devices and professional health care systems. An Internet of bio-nano things monitoring and managing internal and external health hazards may be emerging (Akyldiz et al., 2015). The treatment of chronically ill patients in particular is expected to become more efficient (MGI, 2013).

Energy systems

IoT-enabled smart grids with smart energy meters allow for two-way communication between homes/organisations and the energy grid (OECD, 2015h). Consumer awareness about energy consumption will rise, potentially reducing energy consumption as a result. In addition, smart grids help cut utility operating costs and reduce power outages and electricity waste by providing real-time information about the state of the grid (MGI, 2013).

Transport systems

The IoT holds great promises for the improvement of transport management and road safety. Sensors attached to vehicles and elements of the road infrastructure may become interconnected, thereby generating information on traffic flows, the technical status of vehicles and the status of the road infrastructure itself. Traffic lights and road toll systems may be adapted to the actual road usage, emergency services can be triggered automatically, and car theft protection may be enhanced (OECD, 2015h).

Smart cities and urban infrastructures

The IoT also holds promise for other efficiency gains in the functioning of cities. Embedded sensors in waste containers and water infrastructure management enable the streamlining of garbage collection and may improve water management (MGI, 2013). Furthermore, location-based services that citizens may use on their mobile phones can give city planners new insights into the usage of the public road infrastructure (OECD, 2015h).

Smart manufacturing

The IoT will also impact manufacturing by improving factory operations and managing risk in the supply chain (OECD, 2015h). Existing business processes, such as product logistics, inventory management and maintenance of machines will change radically. Waste and loss could be significantly reduced by using sensors and circuit breakers. The IoT offers data and tools to create comprehensive supply-chain intelligence.

Further developments are challenged by high ICT-related costs and emerging skills needs...

How fast and how effectively the IoT will evolve over the next 15 years depends to a large extent on the roll-out of fixed and mobile broadband and the decreasing cost of devices (OECD, 2015h). In addition, in order to optimise the potential of the IoT, business and governments will have to build capacity to process the large amounts and variety of data that are produced. Skills for data analysis are a key asset for the future, and inequity is likely to enlarge as the gap between those who can and cannot keep up with IoT developments widens as well (Policy Horizons Canada, 2013).

...persisting technological uncertainties...

Intertwined developments in the areas of big data, the cloud, machine-to-machine communication and sensors underpin the rise of the IoT. The impact of the IoT depends in particular on new and emerging technological developments in two key areas: big data analytics and artificial intelligence. In addition, the interoperability among sensors, computers, and actuators is an important issue for the IoT to succeed (MGI, 2013).

...and, at the core of all concerns, an issue of trust

Security and privacy are considered the most important risks relating to the IoT. Hackers may be able to remotely take over connected objects such as the electricity grid and driverless cars or manipulate IoT-generated data. The reliability of the network is a major issue, since human lives may depend on successful, sometimes real-time transfers of data. The key issue of consent and perhaps the notion of privacy itself are also challenged by the near-continuous flow of sensitive data that the billions of ubiquitous sensors will produce (OECD, 2015h). Furthermore, artefacts in the IoT can become extensions of the human body and mind. Human autonomy and agency may be shifted or delegated to the IoT, with potential risks for users' privacy and security (IERC, 2015).

Conflicts with existing regulation and regulatory uncertainty may act as bottlenecks when rolling out IoT services nationwide (OECD, 2015h). The international dimension of the IoT adds further to the complexity, since objects and artefacts could be controlled remotely from abroad while litigation is treated under national legal frameworks.



BIG DATA ANALYTICS

To reap the promises of big data, analytics tools and techniques are needed. The socio-economic implications are tremendous, but a major policy challenge will be to balance the need for openness with the threats an extreme “datafication” of social life could raise for privacy, security, equity and integrity.

Making sense and value of big data will bring tremendous opportunities

Big data analytics is defined as a set of techniques and tools used to process and interpret big data that are generated by the increasing digitisation of content, greater monitoring of human activities and the spread of the Internet of Things (IoT) (OECD, 2015i). Big data analytics is associated with data mining, profiling, business intelligence, machine or statistical learning and visual analytics. It can be used to infer relationships, establish dependencies, and perform predictions of outcomes and behaviours (Helbing, 2015; Kuusi and Vasamo, 2014).

Big data analytics offers opportunities to boost productivity, foster a more inclusive growth, and contribute to citizens’ well-being (OECD, 2015i). Big data analytics should help firms, governments and consumers/citizens access an unprecedented amount of data (volume), increasingly inform their decision-making with real-time data (velocity) and combine a new range of information from structured and unstructured sources (variety), generating disruptive impacts on all human activities (value). The IoT and the acceleration in both the volume and velocity of open data that are accessible and exploitable will further increase the needs for big data analytics and enhance the strategic value of big data.

The exploitation of big data will become a key determinant of innovation and a competition factor for individual firms (MGI, 2011c). Data-driven governance offers significant room for improving public administration efficiency (MGI, 2011c). Big data analytics represents a key opportunity to rebuild public trust through greater openness, transparency, responsiveness and accountability of the public sector (Ubaldi, 2013). Consumers and citizens could be better informed and participate more closely in public affairs; they will enjoy and expect more personalised products and service.

Research systems are set to benefit...

Increasing access to public science has the potential to make the entire research system more effective and productive by reducing duplication and the costs of creating, transferring, and re-using data; by allowing the same data to generate more research, including in the business sector; and by multiplying opportunities for domestic and global participation in the research process (OECD, 2014b). The rise of open data and open access policies and infrastructures is already making isolated scientific datasets and results part of big data. The number of stakeholders involved in research practices and policy design will continue to increase, making science a citizen endeavour, reinforcing a more entrepreneurial approach to research and encouraging more responsible research policies.

...and the healthcare sector as well

Big data analytics may trigger some substantial changes in healthcare systems by enabling a shift from a reactive set-up that focuses on disease to a preventive setup that focuses on quality of life and well-being (OECD, 2013d). Sharing health data, through

electronic health record systems, for example, can increase efficient access to health-care and provide novel insights into innovative health products and services (OECD 2013e). Diagnosis, treatment and monitoring of patients may become a joint venture of analytical software and physicians. Clinical care may even become preventive in nature as big data analytics help discover pathologies before symptoms occur. On top of open research data, the connection of smart applications through the IoT will enable the gathering of a wealth of health-related records, being self-reported or automatically tracked, on both sick and healthy people. New potential clinical trial participants will be more easily in reach. Broad data on exposures, outcomes and healthcare utilisation could be put together with deep clinical and biological data, opening new avenues to advance common knowledge, for instance on ageing-related diseases, or to support interdisciplinary research, for instance on combined effects of cure and care (Anderson and Oderkirk, 2015).

Gaps in IT, skills and legal infrastructures still need to be filled

The rise of big data analytics poses major challenges to skills and employment policies (OECD, 2015i). The demand for data specialist skills will exceed the current supply of the labour market and the current capacity of education and training systems, requiring rapid adjustments in curricula and the skill sets of teachers and on-the-job workers. Big data is also expected to increase the need for a fast, widespread and open Internet (including the IoT), new supercomputing powers and large storage facilities, which current IT infrastructures cannot fully support. Legal institutions must also evolve to better promote a seamless flow of data across nations, sectors and organisations. There are growing concerns about how to define and appropriate open access rights, while maintaining publishers' and researchers' incentives to keep publishing and performing research. International co-operation will be key in that respect.

There is risk of enlarging social inequalities

Growing social inequalities will result not only from job destruction and employment polarisation that will inevitably come along with the structural shift in skills, but also from weaker social mobility and a persisting digital divide. Discrimination enabled by data analytics may result in greater efficiencies, but may also limit an individual's ability to modify path-dependent trajectories and escape socio-economic lock-ins. In addition, a new digital divide is arising from growing information asymmetries and related power shifts from individuals to organisations, from traditional businesses to data-driven businesses, and from government to data-driven businesses (OECD, 2015i). Social cohesion and economic resilience could be undermined, especially in developing economies.

Privacy, security and integrity are at stake

Big data analytics may enable a massive brewing of personal data that become accessible to a large number of actors (everyone?) in a way that is unpredictable and could become uncontrollable, as the volume, velocity and variety of data increase. For instance, patients sharing sensitive health data may support medical research and benefit from preferential medical treatment. Yet medical data made accessible to business interests (e.g. insurance companies and employers) raises a major issue of privacy and equity. Privacy is also endangered if these data are not well protected and if hacking or misuse could result from breaches in security.

Big data analytics offers a unique possibility to combine personal data with pattern recognition programmes, enabling the generation of new information and knowledge about people (ITF, 2014). However, the same data and same programmes could serve to manipulate people, distort their perception of reality and influence their choices (Glancy, 2012; Helbing, 2015; IERC, 2015; Piniewski et al., 2011). Individual autonomy, free thinking and free will would be challenged, potentially undermining the foundations of modern democratic societies.



ARTIFICIAL INTELLIGENCE

Artificial intelligence offers unique opportunities to improve human lives and to address major societal challenges. While their full impact remains difficult to appraise, intelligent devices and systems are likely to drive irreversible changes in our societies.

When machines start thinking

Artificial intelligence (AI) is defined as the ability of machines and systems to acquire and apply knowledge and to simulate intelligent behaviour. This means performing a broad variety of human tasks, e.g. sensing, processing oral language, reasoning, learning, making decisions, and demonstrating ability to move and manipulate objects accordingly. Intelligent systems use a combination of big data analytics, cloud computing, machine-to-machine communication, and the Internet of Things (IoT) to operate and learn (OECD, 2015h).

The rise of intelligent machines...

It is only a matter of time before machines become as smart as humans (Helbing, 2015). AI abilities are likely to reach those of the human brain within the next few decades. Robotics will be one of the technological fields that benefits most from AI developments, as AI will enable robots to adapt to new working environments with no reprogramming (OECD, 2015c). Advanced robots could generate substantial savings on labour costs and productivity gains. AI also holds great promises for safety, by physically replacing humans, reducing work accidents and enhancing decision-making in hazardous and dangerous situations.

...may deeply disrupt industry...

All economic sectors will be affected by AI developments, some more than others. AI and advanced robots will become increasingly central to manufacturing. Sectors that are likely to experience a new production revolution and full transformation include agriculture, chemicals, oil and coal, rubber and plastics, shoe and textile, transport, construction, defence, and surveillance and security (López Pelaez and Kyriakou, 2008; ITF, 2015; Roland Berger, 2014b; ESPAS, 2015; MGI, 2013; UK Government Office for Science, 2012).

AI opens new business opportunities in robotics manufacturing, whose current global market is estimated at USD 26 billion (Goldin and Pitt, 2014). China is expected to account for more than one-third of the industrial robots installed worldwide in 2018 (IFR, 2015) and should be one of the fastest-growing markets for advanced robotics as domestic salaries increase, global quality standards rise and new technologies alter industrial processes at the core of China's economy (e.g. electronics, ICTs, etc.).

...and revolutionise a broad range of services

AI-enhanced systems are expected to form an integral part of everyday life by 2030. Services robots may change households and personal assistance services (ESPAS, 2015; MGI, 2013). In sectors where interpersonal skills are key (e.g. tourism and restaurants) robots could act like humans (López Pelaez and Kyriakou, 2008). AI will be increasingly deployed in education, medicine, law, marketing, and finance. In the health sector, for instance, surgery robots are already in use and further automation of health-related

tasks are highly probable (López Pelaez and Kyriakou, 2008). Diagnostics could also evolve with AI-enabled analysis of medical databases (MGI, 2013). As their performance improves, especially their anthropomorphist capacity, AI may increasingly perform social tasks. “Social robots” may help address the needs of ageing society by assisting humans physically and psychologically, artificially acting as companions and diminishing social isolation of the elderly (IERC, 2015).

AI augurs massive job destruction

AI will have high impact on employment although its scale and nature are still uncertain. It is estimated that up to 47% of US jobs and 36% of UK jobs may disappear due to future technology advances (Brynjolfsson and McAfee, 2014). In France, it is estimated that 42% of jobs are likely to be automated in the next 20 years (Roland Berger, 2014b). Humans will most likely be substituted by AI-enabled robots in “dirty, dangerous, and demanding” jobs, as well as in those that are repetitive and labour-intensive. But advances in smart systems will also enable automation of some knowledge work. For the first time, automation will no longer depend on a differentiation between manual and intellectual tasks but on some routine features of the jobs. Middle income classes may be under particular pressure, as an increasing number of administrative, cognitive and analytical jobs may be performed by data- and AI-empowered applications.

AI challenges the socio-economic foundations of post WWII societies

As smart machines replace human workers in jobs, reproducible goods and services could be produced at lower marginal cost and become almost free. Productivity gains and economic growth could thus be disconnected from job creation and well-being. However, a no-job growth jeopardises public budgets and social safety net systems. A drop in employment would be echoed by a proportional drop in the tax base and government revenues. Social contributions and personal tax income accounted for an average 18% of OECD GDP in 2013 (OECD, 2015j). Likewise, employment-based pension systems are threatened. As workers may be left without salary, income redistribution policies will become more central to future social cohesion. The challenge could be of an unprecedented scale to avoid growing inequality.

Reaping the benefits of AI depends on several framework conditions being in place

An essential factor for reaping the benefits of AI is the provision of reliable transport, energy and communication networks, including the IoT (OECD, 2015h). AI can make mistakes, resulting in possibly serious damages (e.g. wrong patient diagnosis). AI decisions may also be subject to misunderstanding, criticism or rejection (e.g. loan refusal). AI may ultimately become uncontrollable. The imperfect and unpredictable nature of AI questions the principles of legal responsibility and how liability should be shared among AI itself, AI constructors, programmers, owners, etc. Another legal dimension of AI is related to the intellectual property (IP) of inventions enabled by AI, and how IP rights and revenues should be shared. Legal considerations will have major consequences on insurance markets and IP systems.

New skills needs are expected to emerge. Demand for knowledge workers who are able to develop AI or to perform AI-enabled tasks will increase. Creative or tacit-knowledge, which are less codifiable, or skills requiring social interactions or physical dexterity, which are less easily automatable, are likely to remain in human hands over the next few decades (López Pelaez and Kyriakou, 2008; Brynjolfsson and McAfee, 2015). Today’s education systems should ensure that young people are equipped with the right skills to perform in tomorrow’s AI-enhanced environment. Training systems will help smooth the transition and ensure people can follow the unpredictable learning curve of AI.

AI may change humans

The integration of smart robots into the private sphere will increase emotional attachment in relation to AI machines and alter human behaviours. Some argue that behavioural differentiation between AI and non-AI machines may justify providing social robots with legal rights and that their protection could serve as a guide to broader regulation of socially desirable behaviours (Darling, 2012). Others consider that social relationships between humans and robots should be reflected in moral obligation (Coeckelbergh, 2010). More broadly, the use of AI for all human purposes raises several ethical and philosophical issues around human life, the possible de-humanisation of society, the role humans may play in a new AI-enhanced society, and a new human relation to time, for instance through a rebalancing of work and free time.



NEUROTECHNOLOGIES

Advances in neurotechnologies could influence many aspects of human life, for example, enabling us to control environments through our thoughts. Still, there remain few practical applications outside of the lab, though this will likely change over the coming decade.

Neurotechnologies for human enhancement and repair

Neurotechnology is defined as any artificial means to interact with the brain and nervous system in order to investigate, assess, access and manipulate the structure and function of neural systems (Giordano, 2012). This encompasses brain research itself, surgical interventions in the brain to implant electronic devices that can repair or substitute brain functions, the treatment of brain diseases and conditions through methods such as external brain stimulation, and the use of neuro-prostheses through brain-computer interfaces.

Neurotechnologies promise to help better understand the natural processes of the brain, to study and treat neurological disorders and injuries, and to enhance neural capabilities, resulting in increased human intelligence and efficiency. Advances in neurotechnology are expected to impact many different fields, including medicine, defence and intelligence agency operations, the justice system, advertising, business, communications, and even politics (Potomac Institute, 2015).

Neurotechnologies bring together and combine expertise from neuroscience, microsystems engineering, computer science, clinical neurology and neurosurgery. The field is converging with other fields in order to advance. The synergistic nature of these advances means that new paradigms and technologies for enhancing humans are likely to develop rapidly. The way ahead will be transformed by advances in nanotechnologies, big data analytics and neuroscience, among others.

Neurotechnologies could be widely applied in medicine

Neurotechnologies could provide effective treatments for many serious neurological and mental health disorders. For example, they could be used to retard disease progression and potentially cure those suffering from Parkinson's disease; and they could improve the quality of life for people suffering from depression, migraines and other psychiatric conditions (Nuffield Council on Bioethics, 2013). The best-known novel neurotechnologies in the medical field are as follows:

Transcranial brain stimulation is a non-invasive procedure used to stimulate the brain. While it is regularly used as a research tool, therapeutic applications are being increasingly explored, specifically in treating drug-resistant depression.

— Deep brain stimulation is an invasive procedure requiring brain surgery to place electrodes in a specific region deep within the brain. Its therapeutic uses include treating movement disorders (such as those associated with Parkinson's disease) and neuropathic pain. There is also considerable research activity exploring its use to treat a wide range of psychiatric disorders such as epilepsy, dystonia, Tourette's syndrome, depression, obsessive-compulsive disorder and cluster headaches (Nuffield Council on Bioethics, 2013; OECD, 2014c).

- Brain-computer interfaces (BCIs) may or may not be invasive and work by acquiring brain signals, analysing them, and translating them into commands that are relayed to output devices (e.g. computers and robotics) that carry out desired actions (Shih et al, 2012). Such applications can be further enhanced by incorporating artificial sensory systems that provide environmental feedback to the brain. BCIs have vast implications for those who have neurological disabilities. For example, they can be used to replace or restore useful function to people disabled by neuromuscular disorders, to improve cognitive functions, and to communicate thoughts and intentions when normal capabilities are impaired (Wolpaw and Wolpaw, 2012; Policy Horizons Canada, 2013).

Neurotechnologies have many potential applications outside the medical field

Beyond clinical applications, BCIs could be widely applied in fields such as entertainment, defence, finance, human computer interaction, education and home automation; the most promising areas are assistive technologies and gaming. BCIs are also being used for reaction and evaluation monitoring in fields such as marketing and ergonomics. BCIs can also enable hands-free device control and user-state monitoring, which can be useful for automobile drivers, pilots, astronauts and others engaged in focus-demanding tasks (Potomac Institute, 2015).

More speculatively, BCIs could be used to enhance baseline intelligence, allowing multiple brains to cooperate on tasks and enhance performance. They could also be used to develop new senses for human beings, such as the ability to sense magnetic fields or infrared or radio waves. Neuroimaging could be used to document and share dreams, ideas, and abstract concepts. Users would be able not only to control machines with their minds but also to mentally share thoughts (Potomac Institute, 2015).

There is a boom in neurotechnology innovation

Beyond the clinical applications, the automobile, advertising and defence industries have invested in neurotechnology and will likely increase investments as the potential of such technologies grows. Innovation in the field is booming, with the number of patents filed at the United States Patent and Trademark Office doubling from around 800 in 2010 to more than 1 600 in 2014. There are currently over 8 000 active patents and more than 1 500 pending applications (Potomac Institute, 2015). Patents have been awarded to firms well beyond those in the medical field, such as those working on video game control systems based on brain waves.

Neurotechnologies carry risks and raise important ethical questions

Invasive neurotechnologies requiring neurosurgery risk potential unintended physiological and functional changes in the brain resulting from the implanted electrodes or stem cells, as well as infection and bleeding associated with surgery itself. Non-invasive neurotechnologies pose fewer risks, although their long-term use may lead to negative consequences on brain structure and functioning (Mak and Wolpaw, 2009; Wolpaw, 2010; Nuffield Council on Bioethics, 2013) and may also be associated with complex unintended effects on mood, cognition and behaviour (Nijboer et al, 2013).

There are ethical considerations for BCI technologies that relate to its potential to change some central concepts and categories used to understand and observe the set of values, norms and rules that involve the human moral status. The blurring distinction between man and machine makes it more difficult to assess the limits of the human body and raises questions concerning free will and moral responsibility (Schermer, 2009).



MICRO AND NANO SATELLITES

As increasing use is made of small and very small satellites with more capabilities, policy makers will have at their disposal an impressive spectrum of sophisticated tools to address “grand” challenges related to, for example, the environment, climate and food production.

Ever smaller, cheaper and faster

The last few years have witnessed the start of a revolution in the design and deployment of satellites. Small satellites have become very popular. The different families of small satellites are distinguished by their weight –less than 500 kg . Nano- and micro-satellites weigh between 1 and 50 kg. CubeSats are miniaturised satellites whose original models measured 10x10x10 cm and weighed 1 kg (also known as “1 Unit”). Satellite units can then be combined to create larger CubeSats.

The smaller the satellite, the cheaper it is to build and launch. A nano- or microsatellite can be built for EUR 200-300K. Small satellites are becoming much more affordable, as off-the-shelf components are now commonly used to build satellite platforms and support mass production. Most of the electronics and subsystems required to construct a nano-satellite in-house can be bought online (OECD, 2014d). The main cost barrier remains access to space. Small satellites can be launched as secondary payloads for less than EUR 100K. They can also be deployed from the International Space Station, after having been transported there as cargo. It is expected that between 2014 and 2020 more than 2 000 nano- and microsatellites will require launching worldwide (SpaceWorks, 2014).

Small satellites offer vast opportunities in terms of speed and flexibility of construction. Whereas conventional large satellites may take years if not decades to move from drawing board to operational mission, very small satellites can be built very quickly. By way of illustration, it took Planet Labs just nine days to build two CubeSats in early 2015.

Interest in small satellites continues to grow...

Small satellites are finding use across a wide range of applications – from Earth observation and communications to scientific research, technology demonstration and education, as well as defence. The fast deployment of small satellites is taking place as technology for traditional, much larger multifunctional satellites keep evolving. Since the launch of the first CubeSat in 2002, the number of very small satellites in operation has increased at a remarkable rate. In 2014, 158 nano- and microsatellites were launched, i.e. an increase of 72% compared to the previous year (FAA, 2015).

Creating new commercial ventures

The increased use of off-the-shelf components as opposed to more expensive space-qualified products is creating a new world market for space systems and services. Developers are increasingly turning to complex system architectures, to get small satellites to interact in constellations. In 2013, the firm Skybox Imaging launched its first high resolution imagery satellite as part of a planned constellation of 24 small satellites to provide continuously updated and cheaper satellite imagery. Likewise, Planet Labs launched the “Flock 1” constellation with 28 nano-satellites early 2014.

Pushing knowledge frontiers

CubeSats are very popular in universities, as technology demonstrators. They emerge as low-cost educational satellite platforms and have gradually become the standard for most university satellites. As of spring 2014, almost a hundred universities worldwide

are pursuing CubeSat developments (OECD, 2014d). At the educational level, university small satellites can help students put into practice their engineering and scientific competences much faster.

Monitoring lands and oceans

Although large satellites in geostationary orbits remain key pillars for the telecommunications and meteorological infrastructure, small satellites used in large constellations in lower orbits promise ground-breaking improvements, for example in Earth observation. Microsatellites provide the capacity for around-the-clock observation. A case in point is the monitoring of the health of oceans and inland waters. Satellite constellations can be used for monitoring illegal fishing and improving marine domain awareness to combat criminal activities. Similarly on land, constellations could contribute to monitor agricultural crops, improve crop productivity, and keep track of deforestation.

Opening space to all

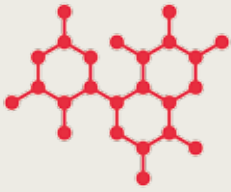
Small satellites have become very attractive in the past five years, due to their lower development costs and shorter production lead times. Small satellites are thus attracting a lot of interest around the world, and many countries have decided to fund their first space programmes with the development of small satellites. Over the last decade, the Ukrainian launcher Dnepr has launched 29% of satellites of 11-50 kgs, ahead of India's Polar Satellite Launch Vehicle.

...but further expansion of the small satellites industry faces several challenges

A perennial trade-off between size and functionality: The smaller the satellite, the fewer instruments it can carry and the shorter its life expectancy because of the smaller amount of on-board fuel. Larger satellites still have a major role to play, as they carry more instruments and have longer life-times, which allows important commercial and governmental missions to be carried out. However recent advances, both in miniaturisation and satellite integration technologies, have dramatically reduced the scale of the trade-off (NASA, 2014).

Dealing with high business risk: Increasingly, nano- and microsatellites are being launched in large clusters, and a single failure (at launch or on deployment) can lead to substantial losses. A recent failed Antares rocket launch led to the loss of over 30 satellites (SpaceWorks, 2015).

Debris and collisions: the growing environmental threat: The main environmental concern is that fast deployment of small satellites will heighten the risk of collision in some already crowded orbits, creating a cascading effect as more debris generates ever greater risk of further collisions. According to international guidelines on space debris, most satellites should either move to a 'graveyard' orbit or re-enter the atmosphere when they reach their end-of-life operations. However, by construction, very small satellites do not have the on-board fuel for deorbit manoeuvres.



NANOMATERIALS

Nanomaterials display unique optical, magnetic and electrical properties that can be exploited in various fields from healthcare to energy technologies. However, technical constraints and uncertainties over toxicity to humans and the environment continue to hinder their widespread application.

Nanomaterials are defined as a material with any external dimensions in the nano-scale (10⁻⁹ metre) or having internal structure or surface structure in the nanoscale that represents a range from approximately 1 nanometre (nm) to 100 nm (ISO, 2012). Nanomaterials can be either natural, incidental or artificially manufactured / engineered. Nanomaterials include carbon based products; nanostructured metals, alloys, and semiconductors; ceramic nanoparticles; polymers; nanocomposites; and sintering and bio-based materials (VDI Technologiezentrum GmbH, 2015). Among carbon based materials, nanotube technologies and graphene are of particular interest for industry and research purposes. Among other materials that currently attract most attention are nano-titanium dioxide, nano-zinc oxide, graphite, aerogels and nano-silver (EC, 2014a).

Nanomaterials have unique properties...

Nanomaterials are expected to have considerable impact on materials science due to their unique mechanical, magnetic and electric characteristics that cannot be generated at milli- or micro-scale. This is because nanomaterials, in contrast to macroscopic materials, show a high ratio of surface atoms to core atoms. Their behaviour is mainly dominated by surface chemistry. The higher surface proportion increases the surface energy of the particles, causing the melting point to sink and the chemical reactivity to increase. Unique optical, magnetic, electrical and other properties emerge at this scale by exploiting quantum effects.

...that are expected to have many areas of application

The current market value of nanomaterials is around EUR 20 billion (EC, 2014a) and the spectrum of commercially viable applications is expected to increase over the next few years. Although marketed in small quantities in absolute figures, applications such as carbon black and amorphous silica have reached a level of maturity and already represent high volumes of the nanomaterials market. Areas of application already encompass medicine, imaging, energy and hydrogen storage, catalysis, lightweight construction, and UV protection (VDI Technologiezentrum GmbH, 2015; Tsuzuki, 2009).

One of the most promising application areas for nanomaterials is in medicine, which currently accounts for the highest share of applied nanoproducts (Vance et al., 2015). Nanomaterials are expected to enhance diagnostics in several ways, e.g. increases in sensitivity of diagnostics chips (lab-on-a-chip) will enable earlier diagnosis of cancer; robust fluorescent markers using nanomaterials are likely to increase reliability of in-vitro diagnostics (VDI Technologiezentrum GmbH, 2015); and tagged gold nanoparticles will boost the development of molecular imaging and can also be used for rapid screening of cancer drugs that require less special equipment than traditional methods (University of Massachusetts Amherst, 2014). Nanomaterials are also expected to enhance medical treatment, e.g. biocompatible nano-cellulose could be applied in treating burns.

Outside of the medical field, nanomaterials will be increasingly used in everyday items. For example, nanofibres have enabled development of textiles that are water-, wrinkle-, and stain-resistant or, if intended, selectively permeable. Combined

with e-textiles, they could contribute to the development of smart fabrics / functional textiles (VDI Technologiezentrum GmbH, 2015; EC, 2014), which may also be used in military and emergency response applications to increase the safety of individuals. Nanomaterials are also likely to facilitate development of functional building materials such as self-cleaning concretes. In the energy and environment area, smart polymeric nanomaterials have expected uses in biodegradable packaging and hydrogels, while silicon nanocrystals are used already in photovoltaic cells (OECD, 2011c).

Private sector research activities are dominated by multinational enterprises

Industrial research on nanomaterials is dominated by multinational enterprises from a variety of sectors. BASF is one of the leading companies in the fields of chemical nanotechnology, nanostructured materials, nanoparticles, and safety of nanomaterials. For instance, the company is a global leader in research on metallic organic frameworks applied in energy and environment industries (BASF, 2015). L'Oréal is among the largest nanotechnology patent holders in the United States, and has used polymer nanocapsules to deliver active ingredients into deeper layers of the skin (Nanowerk, 2015). Beyond the multinationals, an increasing number of technology start-ups are exploiting nanomaterials in specific niche areas. For example, a promising application area for nanomaterials is waste-water treatment by individuals in less-developed parts of the world. One start-up has developed a cost-effective water filtration membrane based on titanium dioxide nanoparticles that are able to filter dirt and bacteria (Nanowerk, 2014), while another has designed an open-source 3D-printable water filter prototype that uses activated carbon and nanomembrane technology and that can be integrated into a water bottle cap (Faircap, 2014).

Outstanding technical and environmental concerns restrict the application of nanomaterials

Nanomaterials face several challenges if they are to find widespread commercial applications. On a technical level, signal transmission between the nanoscale and the macroscopic world remains problematic, as does controlling mechanical responses at the nanoscale (Fahlman, 2011). These technical restrictions continue to hinder development of cost-effective, large-scale commercial applications of nanomaterials.

There are also questions around unintended hazards (toxic effects) to humans and the environment. While particle size alone is insufficient to account for toxicity (SCENIHR, 2009), using nanomaterials in some specific environments may need to be regulated (OECD, 2015k). For example, due to their small size, nanoparticles can permeate cell membranes (via skin absorption, ingestion, inhalation) and travel to places in the body where larger particles cannot physically reach (Suran, 2014). The same risk has to be considered for the use of nanoparticles in agriculture (Das et al, 2015). Risk assessment is still confronted with a considerable lack of data on exposure of nanomaterials to the environment, requiring further research (EC, 2014a; OECD, 2011c; Fahlman, 2011).



ADDITIVE MANUFACTURING

Progressively adding material to make a product take shape is an unprecedented approach to manufacturing that warrants new business models and implies significant changes to existing industries. However, this technology must overcome several challenges if it is to permeate industrial processes on a large scale.

A new manufacturing paradigm is emerging...

Manufacturing today is primarily subtractive (i.e. products are built by using material and removing unnecessary excess), or formative (i.e. material is forced to take shape using a forming tool). Additive manufacturing – also commonly known as 3D printing – encompasses different techniques that build products by adding material in layers, often using computer-aided design software (OECD, 2015c; VDI Technologiezentrum GmbH, 2015).

3D printing processes use plastics, metals and ceramics and have three main applications. Rapid prototyping is used industrially in R&D for model and prototype production. The application at later stages of product development is known as rapid tooling. Rapid manufacturing refers to the production of end-use parts using layer-manufacturing techniques directly without the need for any tooling (Hague and Reeves, 2000).

...promising to expand the capacities of production processes

The global additive manufacturing market is estimated to grow at a compound annual growth rate of around 20% from 2014 to 2020 (MarketsandMarkets, 2014). As 3D printing processes continue to mature and grow, they can potentially address many important needs. In intensely competitive consumer product markets, 3D printing can meet rising expectations for quality design and personalisation. It allows much room for design flexibility and high complexity of samples and components. In general, additive manufacturing technologies become profitable where small quantities meet highly complex and increasingly customised products.

Originally, additive manufacturing was primarily used to create visualisation models of prototypes, thereby shortening product design processes. As materials, accuracy and the overall quality of the output improved, 3D printing started to widen its scope of application. Today, 3D printed prototypes for fit and assembly as well as presentation models are widespread and are expected to become even cheaper and faster to produce by 2030. Rapid prototyping is used by engineers, architects, designers and medical professionals, and in education and research (Gibson et al., 2015).

Additive manufacturing will lead to innovation in health, medicine and biotechnology. 3D printing technologies are set to bring about new products in health, medicine and biotechnology. Dental applications represent the largest share in the medical field to benefit from 3D printing technologies. Printed dental prostheses, hip implants and prosthetic hands (bioprinting or bioengineering), as well as prototypes of exoskeletons are already in use. DNA printers and printing of body parts and organs from the patient's own cells are in the process of development. Bioprinted biological systems not only resemble humans genetically, but they also respond to external stress as if they are living organs (Kuusi and Vasamo, 2014). Bioengineering experts estimate that animal testing could be replaced by 3D printed human cells by 2018 (Faulkner-Jones, 2014). In the future, people with particular dietary requirements could print their own fortified or functional food. Bio-printed meat made from living cells could also be a future field of application (VDI Technologiezentrum GmbH, 2015).

Additive manufacturing will also benefit metal processing in the mechanical engineering, automotive, defence, and space industries

Metal processing through the use of 3D printing processes such as selective laser melting and electron beam melting is common in the automotive, defence, and aerospace industries. Many components have already been produced for space applications; their number will continue to grow, as will their complexity. Further research in metal alloys can have long-term impacts on space exploration, as future generations of astronauts may be able to print equipment they need based on material that takes less mass at launch (OECD, 2014d). In energy technologies additive manufacturing is increasingly used for service and maintenance of highly complex replacement parts (VDI Technologiezentrum GmbH, 2015).

Accelerated digitisation and environmental concerns will influence the demand for additive manufacturing technologies...

The digitisation of 3D printing technologies will allow product design, manufacturing and delivery processes to become more integrated and efficient. As 3D printing will drive digital transportation, storage, creation and replication of products, it has the potential to change work patterns and to spark a production revolution. Companies will sell designs instead of physical products. Placing an order will be a matter of uploading the resulting file that will trigger automated manufacture and delivery processes, possibly involving different companies that can easily coordinate (OECD, 2015c).

3D printing could also offset the environmental impacts of traditional manufacturing processes and supply chains due to lower waste production. Direct product manufacturing using printing technologies can reduce the number of steps required for parts production, transportation, assembly and distribution, reducing the amount of material wasted in comparison with subtractive methods (OECD, 2015c). On the other hand, printers using powdered or molten polymers still leave behind certain amounts of raw materials in the print bed that are typically not reused (Olson, 2013). The most commonly used plastic for home use printing, acrylonitrile butadiene styrene (ABS), is recyclable. Other feedstocks (such as polylactic acid [PLA]) are bio-degradable. However, a recent study has shown that emission rates of ultrafine particles of printers using ABS and PLA are particularly high and could pose health risks (Stephens, 2013). Information on health and environmental effects of newer materials such as fine metal powders, used in selective laser sintering, is still scarce. Likewise, research on the embedded energy of materials, their carbon footprint, and the tendency to overprint objects caused by simplicity and ubiquity will need further attention (Olson, 2013).

...while their proliferation still faces several obstacles and risks

The range of materials used in 3D printing is still limited, and their use is subordinate to printing methods and devices. Surface quality and detail are often not sufficient and require cost-intensive post-processing. Conventional printing devices work slowly and quality monitoring (even though the first print heads with integrated sensors have been developed) is difficult during the printing process. Another obstacle to overcome is the price of the printing devices. Over the last few years, simple 3D printers have appeared on the electronic consumer market at very affordable prices (below USD 1 000), while at the same time more sophisticated 3D printers (for example for metal processing) often sell for more than USD 1 million (EC, 2014a; MGI, 2013). Costs are expected to decline rapidly in coming years as production volumes grow (MGI, 2013). It remains difficult to predict precisely how fast this technology will be deployed, but it will likely eventually permeate the production processes of different types of products in larger numbers (OECD, 2015c).

The abilities of additive manufacturing can also be abused. Debates on private printing of firearms and product piracy accompany the evolution of this technology. As 3D printing becomes more and more accessible, the risk of illegal reproduction of jewellery and works of art rises.



ADVANCED ENERGY STORAGE TECHNOLOGIES

Energy storage technology can be defined as a system that absorbs energy and stores it for a period of time before releasing it to supply energy or power services. Breakthroughs are needed in energy storage technology to optimise the performance of energy systems and facilitate the integration of renewable energy resources.

Energy storage technologies are essential to bridge temporal and geographical gaps between energy demand and supply...

With an increasing share of renewable energy contributions to electrical grids, it is indispensable to invest in storage technologies that allow the adjustment of energy supply to energy demand. Those technologies are implemented on small and large scales in either centralised or decentralised ways throughout the energy system. Large-scale systems (grid energy storage), of which 97% capacity is accounted for by pumped hydro storage (IEA, 2015b), can balance power fluctuations. Battery systems are suitable for decentralised but shorter-term balancing due to limited storage capacity, long charging time and self-discharge (VDI Technologiezentrum GmbH, 2015; MGI, 2013). In general, new energy storage technology could change where, when, and how energy is used.

...and represent considerable economic potential with far-reaching business opportunities

There has been a sharp increase in the deployment of large-scale batteries and thermal energy storage over the last decade (IEA, 2015b). Batteries in particular have experienced major technological acceleration, as reflected in patent “bursts” (OECD, 2014b; Dernis et al., 2015). However, most energy storage technologies are still in the early stages of development. The economic viability of energy storage and advanced batteries will likely be driven by the development of three primary applications: electric and hybrid vehicles, distributed energy, and utility grid storage (MGI, 2013).

Small-scale applications – in electric mobility and portable consumer electronics – will be important demand drivers...

Electro-chemical energy storage still represents the technological state-of-the-art in batteries and encompasses lead acid batteries, nickel-based systems, high-temperature redox flow and lithium-ion batteries. The majority of portable consumer electronics devices and passenger hybrid and electric vehicles (EVs) are powered by lithium-ion batteries which have seen consistent reductions in price and increases in performance in recent years. For example, there was a 40% price decline for a lithium-ion battery pack in an EV between 2009 and 2013 (MGI, 2013), which saw sales of EVs grow to 665 000 in 2014 compared with virtually none on the road in 2009 (IEA, 2015b). Some car manufacturers have started to sell vehicle-to-home systems, enabling customers to use vehicles to charge homes and vice versa. In the future, supercapacitors (high-capacity electrochemical capacitors) that store kinetic energy in pendulum movements and charge nearly without time delay, could also allow cars to charge during normal stops in traffic, e.g. at traffic lights (Kuusi and Vasamo, 2014).

Other new battery systems encompass for example the metal-air battery that is at an early level of research. Metal-air batteries typically use lithium or zinc (zinc-air batteries or fuel cells) for the anode, and oxygen, which is drawn in from the environment, as the cathode. This makes the battery lightweight with a long-lasting regenerative cathode.

Over the coming decade, energy density could increase to a level that battery-powered vehicles could become cost-competitive with vehicles powered by internal combustion engines. Two routes are being pursued to improve energy density: developing electrode materials with higher capacity and developing cells using higher voltage chemistry (Element Energy, 2012). Marketable products could be available by 2020 (VDI Technologiezentrum GmbH, 2015).

...as will large-scale applications in grid energy storage and distributed energy systems

Power outages cause billions of dollars' worth of damage every year worldwide. Over-generation also remains a major issue (IEA, 2015b). Large-scale energy storage systems have the possibility to balance power fluctuations and to decentralise them. These systems include hydroelectric energy storage such as pumped-storage hydroelectricity, compressed air energy storage, and hydrogen and battery systems. Battery systems will be suitable for short- and medium-term load balancing in particular, but their limited storage capacity and self-discharge makes them less suitable for long-term load balancing (VDI Technologiezentrum GmbH, 2015).

Advanced energy storage technologies are expected to reduce greenhouse gas emissions

Energy storage technologies are expected to contribute to meeting the 20C Scenario (2DS) targets by providing flexibility to the electricity system and reducing wasted thermal energy (IEA, 2015b). In fact, more energy could be sourced from renewable sources if energy output could be controlled through storage solutions (Elsässer, 2013). At the same time, as deployment of renewables continues to rise, the demand for energy storage technologies is also expected to grow (IEA, 2015b). Smart storage systems and smart grids may also encourage the production of renewable energy by local co-operative structures (ESPAS, 2014); cost-effective solar, wind and battery technologies are key building blocks for decentralised energy systems (Policy Horizons Canada, 2013). In developing economies, storage systems have the potential to bring reliable power to remote areas and places it has never before reached (US Department of Energy, 2014).

Further R&D is imperative to improve their cost efficiency

Technology breakthroughs are needed in high-temperature thermal storage systems and scalable battery technologies, as well as in storage systems that optimise the performance of energy systems and facilitate the integration of renewable energies (IEA, 2015b). R&D activities on storage solutions are also underway with a view to realising technology cost reductions (IEA, 2014b). The high capital costs of storage technologies remain a barrier to wide deployment (IEA, 2015b).

As the materials, technologies and deployment applications for storing energy are created, new techniques and protocols must be developed to validate their safety and ensure that the risk of failure and loss is minimised (US Department of Energy, 2014). For instance, the benefits of lithium batteries should be evaluated as they relate to global environmental and health impacts of lithium extraction and handling.



SYNTHETIC BIOLOGY

Synthetic biology is the design and construction of new biological parts and the re-design of natural biological systems for useful purposes. It is a new field of research in biotechnology that emphasises standardisation, modularisation and interoperability in genetic engineering. Following these principles, scientists are creating a catalogue of functional bio-components that are expected to have a wide range of applications in health, agriculture, industry and energy.

We have an increasingly profound understanding of the building blocks of biotechnology...

While humans have been involved in genetic manipulation by selective breeding for 10 000 years, it was only in the 1970s that direct manipulation of DNA in organisms became possible through genetic engineering. Synthetic biology is a recent field of research that has introduced an engineering approach to genetic manipulation. It is defined as the design and construction of new biological parts, devices, and systems, and the re-design of existing, natural biological systems for useful purposes (Royal Academy of Engineering, 2009).

While traditional genetic engineering generally uses trial-and-error approaches to produce new biological designs, synthetic biology attempts to reshape living systems on the basis of a rational blueprint (de Lorenzo and Danchin, 2008). To achieve this, synthetic biology utilises engineering principles such as standardisation, modularisation and interoperability. For instance, synthetic biologists create and catalogue functional components called "bio-bricks" based on DNA sequences that may or may not be found in nature. Bio-bricks perform certain functions that can be combined to produce innovations in a wide range of sectors including health, agriculture, industry and energy.

...which promise radical innovations across a wide range of business sectors...

As a technology platform, synthetic biology has the potential to offer significant socio-economic benefits, create new businesses and bring greater efficiency to existing ones (OECD, 2014e). It may be leveraged by several key market sectors such as energy (e.g. relatively low-cost transport fuels), medicine (e.g. vaccine development), agriculture (e.g. engineered plants) and chemicals. The latter has a wide range of applications through bio-based production of new materials including environmentally friendly bioplastics and cosmetics (e.g. synthetically designed natural fragrances). Within the field of marine biotechnology, several applications are envisaged for diatoms (plankton) that could have positive environmental effects, serve as gene-editing machines and produce biofuels (Daboussi et al., 2014). Synthetic biology may also help meet bio-economy objectives, i.e. reduction of greenhouse gas emissions and attaining food and energy security. As global population continues to grow and threats to water and soil quality increase, synthetic biology offers far-reaching agricultural applications that promise to increase productivity and efficiency. Examples include not only crops that are resistant to drought and diseases and increase yields, but also plants that produce their own fertilisers.

...particularly in view of two ongoing trends within the field.

Currently, two trends in synthetic biology stand out. Gene editing uses the natural immune defences of bacteria to create “molecular scissors” that cut out and replace strands of DNA with great precision (Sample, 2015). This technique is helping scientists further understand the roles of genes in health and how several diseases could be treated by modifying tissues and organs. Patients’ immune cells could be reprogrammed to make them attack cancer cells; immune cells could be made resistant to the HIV virus; and genetic disorders could be stopped from being passed on to offspring. Do-it-yourself (DIY) biology or bio-hacking refers to a growing community of individuals and small organisations that study and practise biology and life science outside of professional settings. Lower costs of equipment, instruments and computing coupled with the rise of open source development practices have fuelled this movement, democratising science and giving people access to their own biological data. Since 2003, the cost of gene sequencing has dropped by at least one million-fold (OECD, 2014e). Cost-effectiveness has also improved for gene synthesis as well (at a much slower pace), yet price declines in both synthesis and sequencing have recently stagnated (Carlson, 2014). DIY biology represents a potential engine of innovation similar to Silicon Valley, with a large number of individuals discovering and finding applications for bio-bricks. In the future, innovation in this field could be further democratised, allowing users to tinker and improve products and services from large firms, as has already occurred in manufacturing sectors (von Hippel, 2005).

The roadmap for synthetic biology has several obstacles, including biohazards...

The development of this technology poses a number of risks for biosafety and biosecurity. Biosafety covers the range of policies and practices designed to protect workers and the environment from unintentional misapplications or accidental release of hazardous laboratory agents or materials. Biosecurity is usually associated with the control of critical biological materials and information, to prevent unauthorised possession, misuse or intentional release (OECD, 2014e). Risks are difficult to assess given the unbounded amount of emergent properties of products and genetically engineered systems (SCHER, SCENIHR and SCCS, 2015).

...that may be exacerbated by the open source nature of development...

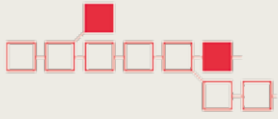
The open source practices in synthetic biology also give rise to both biosafety and biosecurity concerns. Compared to many other types of science, experimentation in this field may be exposed to additional hazards (e.g. dealing with pathogens) given the self-replicating and transmissible nature of organisms (Wolinsky, 2009). As for biosecurity, DIY biology could be directed towards illegal activities, some which could threaten public safety (e.g. biological weapons). As the technology becomes globally adopted, uses for bio-bricks will become difficult to track, regulate or mitigate (NIC, 2012). For gene editing, although much additional expertise would be needed to produce infectious agents, authorities need to ensure sufficient oversight and review.

...by ethical issues...

While gene therapy (i.e. altering the body’s ordinary tissues) is an accepted medical technique, this is not the case for modifications that would alter a person’s reproduction cells. The later type of genome editing (referred to as germline editing) could, in principle, alter the nature of the human species. Representatives from the National Academies of Science of the United States, the United Kingdom and China gathered recently to agree on a moratorium on permanent alterations to the human genome (Wade, 2015). The group called scientists around the world to abstain from germline editing research until risks are better assessed and a broad societal consensus about the appropriateness of these techniques is reached.

...and by technical and legal uncertainties.

The future of synthetic biology depends on reliable, accurate and inexpensive DNA synthesis. While the cost of DNA sequencing is now negligible, costs for writing genetic code need to tumble by similar orders of magnitude. The technical difficulties involved in reaching parity with sequencing are considerable and create high financial risks for the typically small, high-technology companies working to develop synthetic biology. Major hurdles must also be overcome in bioinformatics and software infrastructure, though the relevant software will likely be available to a mass audience long before DNA synthesis. This can be good for synthetic biology (e.g. by creating interest among school pupils) but it increases the need for biosecurity vigilance, as sequence designs could be easily sent to other countries for manufacture without appropriate controls. At the same time, the large number of regulations that need to be followed to legally produce transgenic organisms (particularly to prevent harm in humans and their escape from controlled environments) is likely to restrict applications (OECD, 2014e; Travis, 2015).



BLOCKCHAIN

Blockchain is a database that allows transferring value within computer networks. This technology is expected to disrupt several markets by ensuring trustworthy transactions without the necessity of a third party. The proliferation of this technology is, however, threatened by technical aspects that remain to be resolved.

Blockchain technology...

Internet applications such as web browsers and email programs use protocols that define how software on connected devices can communicate with each other. Whereas the purpose of most traditional protocols is information exchange, blockchain enables protocols for value exchange. This new technology empowers a shared understanding of value attached to specific data and thus allows transactions to be carried out. In itself, blockchain is a distributed database that acts as an open, shared and trusted public ledger that nobody can tamper with and that everyone can inspect. Protocols built on blockchain (e.g. bitcoin) specify how participants in a network can maintain and update the ledger using cryptography and through general consensus. The combination of transparency, strict rules and constant oversight that can potentially characterise a blockchain-based network provides sufficient conditions for its users to trust the transactions conducted within, without the necessity of a central institution. As such, the technology offers the potential for lower transaction costs by removing the necessity of trustworthy intermediaries to conduct sufficiently secure value transfers. It could disrupt markets and public institutions whose business model or *raison-d'être* lies in the provision of trust behind transactions.

...although initially developed to support a new digital currency...

Blockchain technology was originally conceived for bitcoin, a digital currency that is not regulated nor backed by any central bank. Instead, the technology aims to be trustworthy by itself (i.e. it makes a trusted third party unnecessary) by preventing double-spending and constantly keeping track of currency ownership and transactions (OECD, 2015I). The supply of bitcoins is limited and regulated by a mathematical algorithm that defines the rate at which currency will be created. The procedure for updating the ledger rewards users who devote computing resources to encrypt transactions (called miners) with new bitcoins that enter the network's monetary base. Once a set of transactions has been encrypted, the entire network (including non-miners) verifies its validity by a 51% majority consensus. As in regular currency trade, bitcoin exchange rates with traditional currencies are determined through a double-auction system. This set-up incentivises scrutiny and thus secures the network: if bitcoin is increasingly adopted and its value increases relative to other currencies, there will be additional incentive to devote computational power for rewards.

...promises to disrupt many markets, in finance and beyond

While the experience of bitcoin is already forcing a rethink of currencies, expected impacts of the underlying blockchain technology go beyond digital money. This technology could destabilise incumbents in asset management businesses, but also government authorities, and could transform the way many services are provided. Potential applications can be clustered into three categories:

Financial transactions

Financial applications of blockchain technology go beyond bitcoin and digital money. For example, the technology provides opportunities for cross-border remittance payments, which often represent high transaction costs in proportion to the remittance amount. Equity crowdfunding provides another opportunity, as it often involves large amounts of administration efforts relative to the size of individual investments (Collins and Baeck, 2015). In view of potential applications, clearing houses (e.g. the New York Stock Exchange and Nasdaq), banks (e.g. Goldman Sachs), credit card companies (e.g. Master Card) and insurance companies (e.g. New York Life Insurance Company) have already invested around USD 1 billion in start-ups using blockchain technologies (Pagliery, 2015; de Filippi, 2015).

Record and verification systems

This technology can also be used for creating and maintaining trustworthy registries. The blockchain distributed ledger provides a robust, transparent and easily accessible historical record. It can be used for storing any kind of data, including asset ownership. Possible uses include the registration and proof of ownership of land titles and pensions, and verifying authenticity of works of art, luxury goods and expensive drugs (The Economist, 2015; Thomson, 2015). A key difference of this category of applications is that blockchain relies on a central institution for updating and storing the ledger. Already Honduras has plans to build a land title registration system using blockchain (Chavez-Dreyfuss, 2015), which could radically change the way notary offices manage real estate. The shared blockchain ledger could also bring significant improvements to resource allocation in the public sector by consolidating accounting, increasing transparency and facilitating auditing to prevent corruption and boost efficiencies. A shared ledger within the different levels of government could ensure that transactions are consistent and error free. Also, given that key public and private institutions in emerging countries are less developed and trusted for financial markets to flourish and for public services to be efficient, blockchain could offer a “fast track” for the development of financial services and public registry keeping.

Smart contracts

Blockchain technology offers the opportunity to append additional data to value transactions. These data could specify that certain rules are required to be met before the transfer takes place. In this way, a transaction would work as an invoice that would be cleared automatically upon fulfilment of certain conditions. Such “smart contracts” based on blockchain are also referred to as programmable money (Bheemaiah, 2015). The conditions specified in the transfer as programming code could be used to express the provision of services such as cloud storage of data (e.g. Dropbox), marketplaces (e.g. eBay), and platforms for the sharing economy such as Uber and AirBnB (de Filippi, 2015). Microsoft is setting up a joint venture in this field to power its services renting out computer servers (Pagliery, 2015).

Several technological uncertainties remain...

A critical uncertainty for “institution-less” applications is that their security depends greatly on the number of users. This means applications have to sufficiently scale before becoming trustworthy. Moreover, the standard mathematical algorithm that ensures a tamper-resistant ledger (currently employed by bitcoin) becomes more computationally intensive as the network becomes more scrutinised. This translates into vast amounts of electricity required to process and verify transactions conducted within the network. Less computationally-intensive alternatives for reaching a secure consensus are currently being developed and tested. An additional uncertainty specific to smart contracts lies in the extent to which complex services can be sufficiently programmed into rules. In order for such networks to completely run by themselves (i.e. without a

firm backing the service), instructions embedded in transfers should provide an exhaustive definition of the service. While this is likely possible for a great amount of routine services (e.g. computing), it is questionable whether this could be achieved with more complicated applications such as marketplaces and the sharing economy of Uber and AirBnB. These often require mechanisms of dispute resolution that are difficult to codify and delimit.

...and their resolution could enable unlawful activities

The pseudo-anonymity of transactions raises several concerns around the technology's potential exploitation for illegal activities. While all transfers conducted through blockchain are permanently recorded and immutable, it contains information only relative to agents' Internet identity, which may not necessarily lead to their real identity. Some users of virtual currencies have already been involved in improper use and illegal activities, including money laundering and transfer of value for illegal goods. More effective methods of identification could lead to more effective law enforcement in digital currencies compared with the use of cash (OECD, 2015l). However, smart contract applications could also allow the creation and operation of illegal markets that would operate without a responsible firm or institution subject to regulatory compliance.

RESEARCH SYSTEM TRENDS

The future of research remains uncertain, and forthcoming developments will depend on the capacity of policy makers to enable a digital and open science and to gain efficiency in tackling societal challenges. Global and national research systems are in full flux as a result of a complex interplay of internal dynamics and external megatrends. The orientation, practices, actors and means of science are fast-changing.

More is expected and intended...

The imperative to restore a more inclusive growth; the needs of ageing societies; environmental pressures; the depletion of natural resources; threats to energy, water and food security; and various health issues all require new technological breakthroughs for which the disruptive potential of research will need to be mobilised.

Research policy has risen in importance in recent years as reflected by steady increases in research capacity worldwide, even in times of crisis (Figure 29, Panels 1 and 2). The mission of science has also evolved to respond to a wider socio-economic context. There has been a general shift in research policy agendas towards environmental and societal challenges – for instance, the “greening” of national research policies has been prominent in many OECD countries since the late 2000s (OECD, 2010, 2012d).

Research is likely to remain high on policy agendas, and the utilitarian view of science is poised to strengthen. The increasing attention paid to ethical and societal dimensions of research is already reflected in the framing of more “responsible research and innovation” policies. Following these recent policy developments, governments will likely encourage greater involvement of civil society in research policy.

Still, science will not be in a position to address all sorts of issues it is presented with. Moreover, there is a threat that citizen- and challenge-driven scientific agendas may focus on more immediate and applied outcomes to the detriment of longer-term blue-skies research. Fundamental research is by its nature unpredictable and a too-risky endeavour for market interests. To ensure future opportunities are not to be missed, fundamental research that is disconnected from current challenges will need to be preserved.

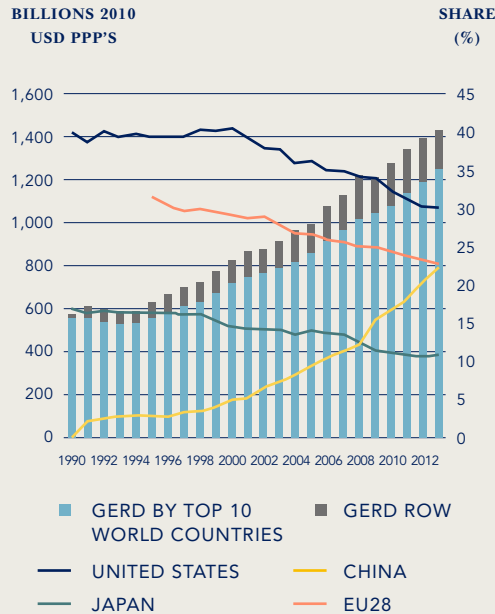
...calling for new ways of doing research

Opening access to public research results

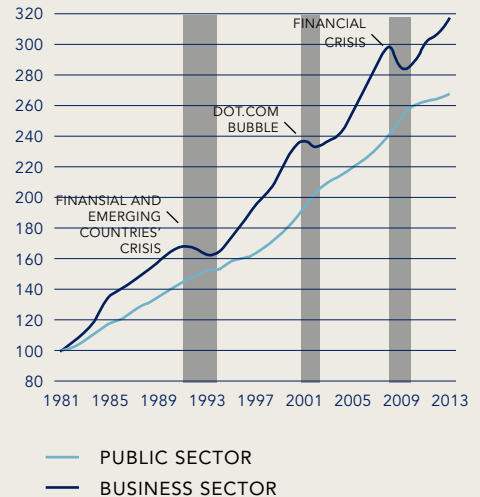
Increasing access to scientific research results has the potential to make research systems more efficient by reducing duplication and data management costs. The same data could generate more research and more opportunities for domestic and global participation in the research (OECD, 2014b). Supporting this, there is general recognition that scientific goods generated with taxpayer money are public goods and should be made public with a view to increasing social return. Open access to scientific knowledge, especially for low-income countries and especially in fields of general interest (e.g. health), may be a key driver of more inclusive growth.

FIGURE 29: Long-term dynamics in OECD research systems and beyond.
Shifts in R&D expenditure, 1981-2013 (or nearest years available)

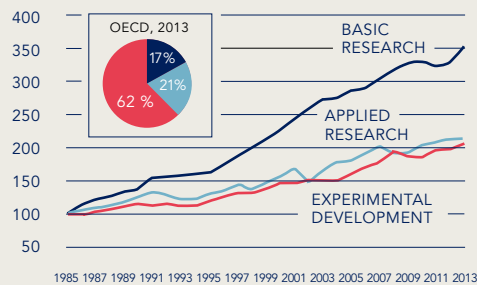
1. Growing research capacity worldwide
Gross domestic R&D expenditure (GERD), billion USD 2010 PPPs and % total.



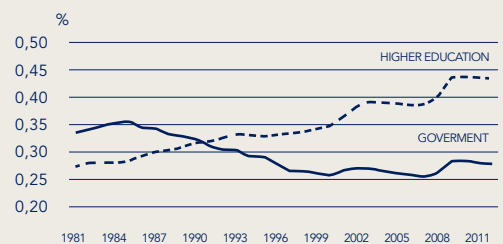
2. Research systems expansion in times of economic growth and recession.
OECD, index 1981=100



3. Stronger focus on breakthrough research.
OECD, index 1981=100



4. The rise of the "Humboldtian" university.
OECD, as a % of GDP



Source: for (1) and (2), OECD (forthcoming), based on OECD (2015m), Eurostat R&D Indicators and UNESCO Institute for Statistics, S&T Indicators; for (3), OECD (2015o), calculations based on OECD Research and Development Statistics database, www.oecd.org/rds, June; for (4) OECD (2014b), updated with OECD (2015m). Data extracted from IPP.Stat on 12 January 2016, <https://www.innovationpolicyplatform.org/content/statistics-ipp>.

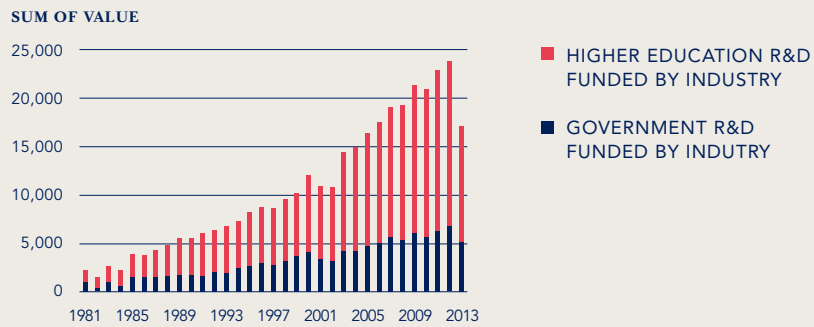
A more entrepreneurial science

Demands for cost-saving, as well as an opening up of science, have encouraged universities and public research institutes (PRIs) to forge closer links with other research and innovation system actors, notably industry. In return, firms can access complementary knowledge, solve problems and recruit new talent. Knowledge transfer has become the “third mission” of universities and PRIs. A growing number of policy initiatives aim to foster industry-science co-operation and speed the transfer of public research results to society, while a growing number of research system intermediaries aim to smooth and improve transfers (e.g. technology transfer offices, patent funds, intellectual property brokers).

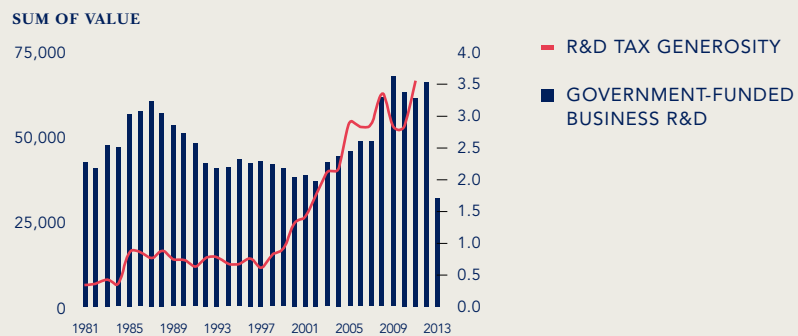
The rise of entrepreneurial science will be further strengthened by a more active participation of industry in the governance of research institutions, for instance in high-level advisory bodies or institutional executive boards. New public-private partnerships (PPPs) have emerged and reinforced a market perspective in academic research. As public budgets remain under pressure, PPPs will remain strategic policy instruments in the near future, and the traditional industry-science dichotomy will continue to blur through further cross-sectoral funding (Figure 30, Panels 1 and 2).

FIGURE 30: Cross-sectoral funding of research systems is on the rise.
 Figures 30.1 & 30.2: Shift in R&D funding, OECD, million USD PPP at constant prices – left hand axis.
 Figure 30.2: Average generosity of R&D tax incentives, OECD, 1- B index – right hand axis

30.1: Industry funding to public research:
 Universities take the lion’s share



30.2: Public funding to business research:
 Tax incentives on the top of increasing subsidies



Source: for (1) and (2), OECD (2016, forthcoming), based on OECD (2015m); and for (2), Warda J. (2013). Data extracted from IPP.Stat on 12 January 2016, <https://www.innovationpolicyplatform.org/content/statistics-ipp>.

The rise of citizen science

Participation in research systems has expanded beyond the traditional researcher, university, government lab and firm, to involve broader communities of students, local actors, networks and society as a whole. Society is increasingly engaged in research policy design through public consultation. Awareness campaigns, norms and scientific communication could encourage the uptake of innovation, greater acceptance of scientific discoveries and the embrace of scientific careers.

Society will also be increasingly involved in research activities per se, for instance in data collection, project definition or crowdsourcing. Because of higher levels of education and widespread availability of a cheap Internet and online information supports (e.g. science blogs), citizen science is emerging as an open, networked and increasingly polarised and “bottom-up” process.

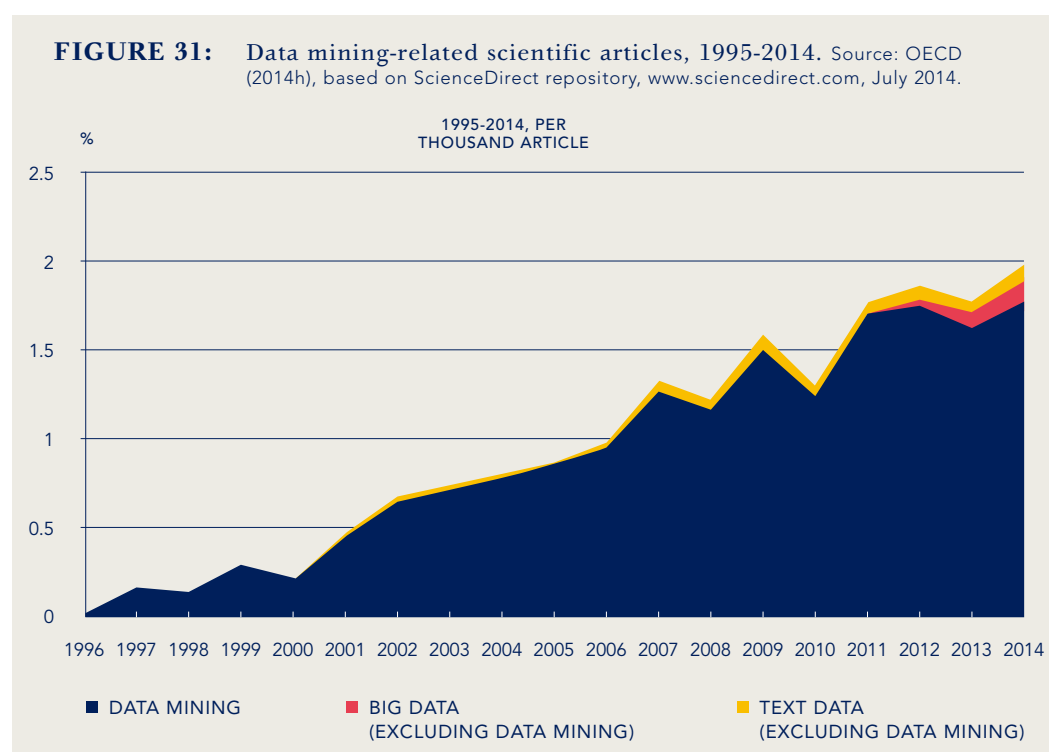
Breaking the silos of science

Multidisciplinary sciences have drawn increasing policy attention. The convergence of key emerging technologies, encompassing information and communication technologies (ICTs), nanotechnology, biotechnology and cognitive sciences, is expected to create opportunities that may be difficult to seize in discipline-based public research systems. Many countries have already started to reform public research governance, evaluation and funding to encourage greater cross-fertilisation of ideas (OECD, 2014b).

But more technology platforms and physical spaces for researchers to meet are still needed. Likewise, governments will also need to support the interoperability of scientific infrastructure, shared methodologies and tools (e.g. codes, applications), standards for digital repositories, and common access rules.

Reaping the promises of future technological developments

Technological change is deeply transforming research systems. Research is more than ever data-driven (Figure 31), meaning that not only the volume of data available to conduct research is growing exponentially, but research subjects, methods and practices, and visibility are changing irrevocably.



New research fields are emerging

The Internet of Things (IoT), i.e. greater connectivity of a growing number of apps, sensors and self-tracking tools, combined with participatory sensing and self-reported data, are generating trillions of bytes of information whose storage, curation, preservation, protection and dissemination require new knowledge and capacity. Novel research fields will develop around data mining, machine learning, privacy, database interoperability etc. with a view to enabling big data science (EC, 2014b). Big data analytics should open new research avenues and create new business models. New research fields will also emerge from the convergence of technologies (e.g. bioinformatics, biosensors).

Research methods and practices are evolving

Data will increasingly precede the research idea and guide experimental research design (EC, 2014b). Traditional approaches through hypothesis and “grand theories” development are giving way to data-driven research that starts with massive amounts of data and may combine hybrid methodologies and algorithms from different research areas.

In addition, information is codified and made available online at a scale and speed that have never been reached before. The so-called Science 2.0, supported by ICTs, allows information sharing, user-generated content and a more collaborative approach in research activities globally. Digital science tools foster, for instance, interaction between public and private sectors and public engagement in science. Paperless research labs record raw data on research projects and processes, including failed experiments that would have not been published in traditional scientific journals.

New skills are required, even beyond the research community

A digital and open science will require the deployment of new skill sets. Data-related skills development will be essential for making efficient use of new scientific datasets, tools and methods. The more open nature of science and the closer links science is building with industry will require researchers to reinforce their ‘soft’ skills, including in project management, team-working, and business and intellectual property awareness. At the same time, students and citizens will need to acquire skills for participating in the scientific endeavour, interacting with the research community and contributing actively to an open scientific culture. Some countries are currently developing data science curricula to address this issue, but more will need to be done.

Sharing results openly online and reusing results and data produced by others supposes a radical shift in academic culture. Recent surveys on the behaviour of scientists reveal that not all researchers are necessarily aware of the possibilities offered by open science (OECD, 2015n). As scientific information is increasingly discussed and disseminated through science forums, blogs or conference proceedings, patterns in publishing and recognition are changing. Research culture and career paths will have to change accordingly.

The research assessment system of science will be under pressure...

Current research assessment systems are losing relevance. The system of research evaluation based on publication counts / citations and peer review has become costly and burdensome (EC, 2014b), while the emergence of new channels of scientific dissemination means that citation databases are covering a decreasing part of the scientific literature (EC, 2014b). Despite this, bibliometrics indicators are increasingly used in evaluating research programmes, institutions and staff (e.g. assessment formulae, university league tables, tenure appointment) (OECD, 2014b; EC, 2014b), creating a

source of critical tension. Alternative metrics, or altmetrics, could be developed from a broader range of digital supports and practices and could even go beyond the scientific community. For instance, new indicators could be generated from activities on social networks, their frequency and their nature. However, these same indicators could easily be altered unless controls and validation processes are implemented and prevent distortions of evaluation results, ranking and ultimately funding allocations.

...and available resources will be prioritised

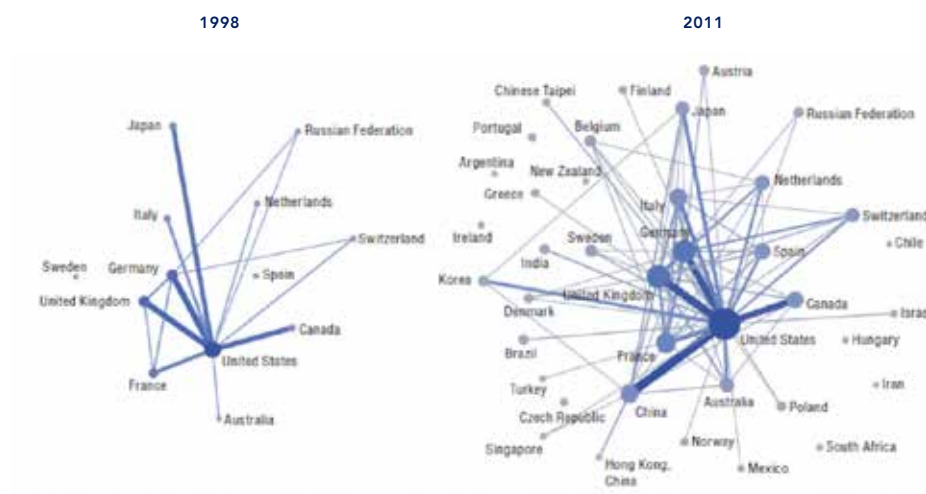
There has been a global shift in national public research systems towards academic excellence and a concentration of resources into world-class institutions (OECD, 2014b; 2014g; 2014h). The rise of the “Humboldtian” university illustrates the popularity of an institutional model that links teaching and research activities more closely by involving students upstream in research activities, and that reinforces the prioritisation of public spending, especially on fundamental research (Figure 29, Panels 3 and 4).

Lacklustre economic conditions and high levels of public debt are placing research systems under pressure. As public budgets tighten and challenges intensify, public funding of research will be increasingly allocated on performance criteria. The relevance of performance evaluation systems is therefore key to ensure efficiency and improve international competitiveness of research.

An international perspective will be imperative

National research policy frameworks are increasingly shaped by a more global context, as science, technology and innovation networks extend beyond national frontiers. Countries, firms, universities and researchers are increasingly organised into open and collaborative networks that connect local research and innovation hubs across frontiers (Figure 32). Ideas, assets and resources concentrate in these pockets of excellence. At stake is the capacity of research ecosystems to offer attractive environments to highly mobile talent and international investments, including robust (and expensive) research infrastructures, e.g. libraries and information archives that both will need to be renewed as they wear out or become outdated.

FIGURE 32: International collaboration networks in science are densifying.
Source: OECD (2013f) based on Scopus Custom Data, Elsevier, version 5.2012, June 2013.



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