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Iceland and the fourth industrial revolution

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Introduction

The discourse on the Fourth Industrial Revolution (4IR) has spread like wildfire all over the world in recent years and have been centered on understanding the nature and scope of the rapid technological changes in recent decades. What can humankind expect from the vast technological innovations that have taken place and are foreseeable in coming years and decades? Is there a risk of a permanent reduction in jobs, with machines and automation taking over and thereby undercutting people's livelihoods? How can technology be harnessed so as to enhance prosperity and wellbeing in society? What can governmental authorities do to steer these developments in a positive direction? When answering these questions it is important to remember that the impact of technology is not predetermined; it depends on how people use it.

Since 2016, the World Economic Forum (WEF) has focused on the idea that the rapid technological breakthroughs of recent decades represent a Fourth Industrial Revolution (4IR). Although the term 4IR has been widely embraced, it can be difficult to determine whether the developments underway represent an escalation of societal changes accumulating over a long time, or a watershed in technological development that can be justifiably referred to as the beginning of a new societal revolution. This present report does not take a position on that question but instead directs attention to the rapid technological changes of recent years and their potential impact.

In mid-2018, the Prime Minister of Iceland appointed a committee on the Fourth Industrial Revolution (the 4IR Committee), with the aim of "explaining the global discourse on 4IR, its implications for Icelandic society, and the opportunities it represents for Iceland".

Members of the committee were:
Dr. Huginn Freyr Þorsteinsson, chair, partner at Aton Consulting and part-time lecturer in the philosophy and history of science at the University of Iceland,
Ragnheiður H. Magnúsdóttir, departmental director at Veitur and chair of the Science and Technology Policy Council's Technology Committee,
Lilja Dögg Jónsdóttir, economist, MBA from Harvard University,
Dr. Guðmundur Jónsson, professor of history at the University of Iceland,
Dr. Kristinn R. Þórisson, professor of computer science at Reykjavík University and director of the Icelandic Institute for Intelligent Machines.

The committee has compiled a report with the aim of gathering knowledge about the enormous technological advances that have been classified as part of 4IR, and to stimulate discussion of the challenges and opportunities they entail. The committee has taken account of the current global discourse on 4IR. In addition, with the assistance of Statistics Iceland and the Organisation for Economic Co-operation and Development (OECD), the committee has analysed the potential impact of automation on the Icelandic labour market. The report contains the committee's conclusions on a number of issues that arise when 4IR is under discussion. The 4IR Committee wishes to thank the employees of Statistics Iceland and the Prime Minister's Office for their assistance. Members of the committee hope the report will facilitate further discussion of the critical issues that arise as a result of technology-driven societal change.

Conclusions of the Committee on the Fourth Industrial Revolution

The rapid technological advances of recent years that are considered part of 4IR have triggered international discussion of their potential impact on society and the economy in coming decades. On the one hand, the technological advances have increased uncertainty and even generated fear that new technology will eliminate large numbers of jobs, thereby jeopardising the livelihood of millions of people, while on the other hand, they have given rise to the hope that they will vastly increase opportunities to create new and better jobs, improving the quality of life in many segments of society.

Discussions of the impact of 4IR on Icelandic society are still relatively new. However, the Icelandic business community has long been receptive to tech innovation and has increasingly adopted the innovations that characterise 4IR. It is important that Icelanders take part in structured discourse on these innovations, and the report from the 4IR Committee appointed by the Prime Minister is a contribution to that discourse. The committee took note of international discussion of 4IR, including recent research on technological developments in the past few years and the impact they may have, as well as attempting to evaluate Iceland's position vis-à-vis these developments and what impact they may have on society.

1 The Fourth Industrial Revolution: Powerful new technology with broad-based impact. Advances in artificial intelligence (AI) and related technologies in recent years will revolutionise many parts of society. The effects can already be felt in jobs and production in a number of sectors. Unlike the automation of previous industrial revolutions, including the IT revolution, modern AI is virtually independent of data type and is based on a variety of possibilities for automation of data processing and industrial processes. Technologies already in use — such as robots, social media, and booking engines for travel and accommodation, to name just a few — have already benefited from newer technologies, but they will change even more in the coming years as automation becomes more powerful. In the decades to come, further advances in fields such as biotechnology, nanotechnology, the Internet of Things, and many more will create synergies that will have a wide-ranging impact on our daily lives and our society.

2 New types of automation cause disruption. Before 4IR, technology usually replaced repetitive tasks that were carried out by manual labour. This will continue, but with 4IR, new technologies will increasingly be able to carry out tasks that have hitherto required human intelligence. Not only will tech advances speed up the automation of previous industrial revolutions, they make entirely new automation possible. This will inevitably be disruptive, as the technology will change societal structure significantly. This brings with it many challenges, but also a host of opportunities.

3 Major changes ahead in the labour market. With increased automation, some jobs will become unnecessary, but new ones will be created. With the assistance of Statistics Iceland, the 4IR Committee calculated the potential impact of automation, using methodology adopted by the OECD. The results show that in Iceland, it is highly likely that some 28% of the labour market will undergo radical changes or elimination of jobs because of automation. As of 2017, this applied to 53,398 individuals in the labour market, and the percentage is similar to that elsewhere in the Nordic countries. It is also forecast that 58% of jobs (113,020 individuals) will change considerably due to the impact of technology, whereas only 14% (26,796) will undergo little change. Based on this forecast, it can also be seen that different groups in society will be affected to differing degrees by these changes. The impact is examined based on education, gender, age, residence, and nationality.

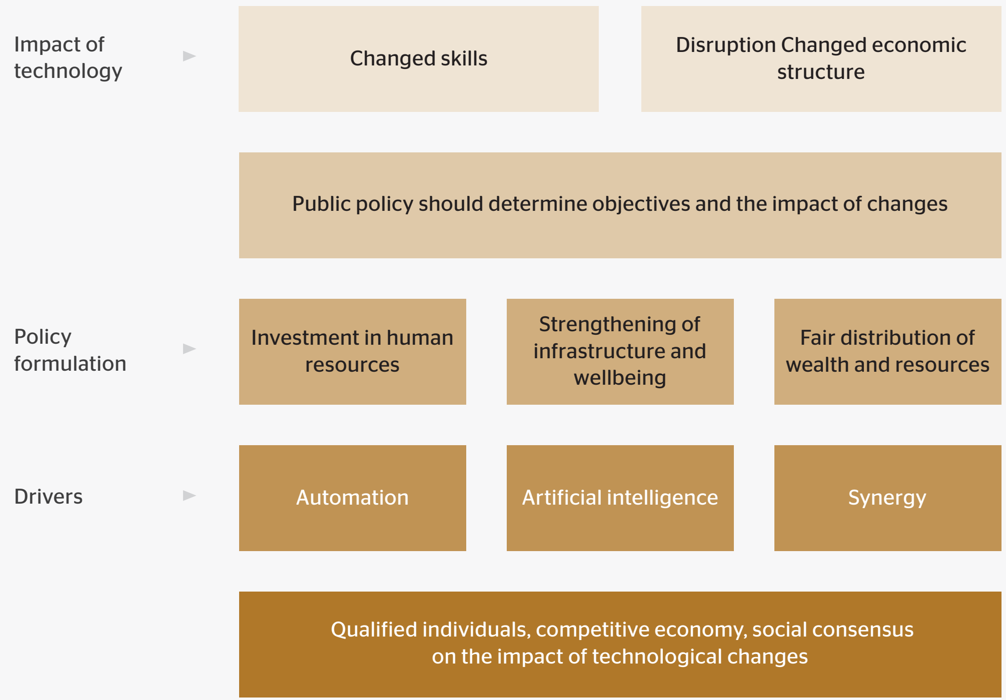
4 **Iceland is well prepared technologically to participate in the Fourth Industrial Revolution.** Icelanders are very familiar with technology-driven societal changes. Major technological advances have come to Iceland in waves since the early 20th century, bringing societal changes, as they have in other countries. A recurring theme in earlier industrial revolutions is automation, where machines replace humans and animals in performing certain tasks. In many areas, Iceland has successfully introduced 3IR technology (mobile phones, internet, computers, and information technology). Iceland is on a par with its Nordic neighbours, which are in the vanguard as regards technological infrastructure.

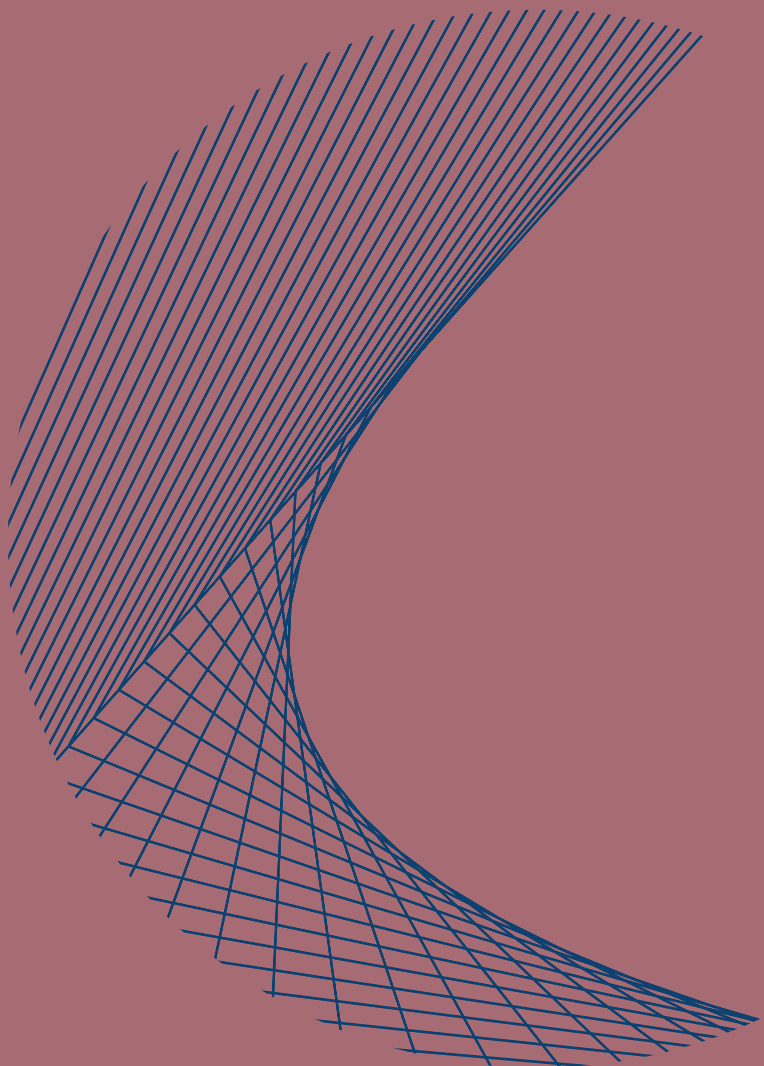
5 **Public policy strongly affects how societies adapt to and utilise technology.** Disruption caused by technological changes will put the structure of our society to the test. It is important to ensure that the productivity growth that follows from increased automation is distributed fairly throughout society. There is also a need to bolster the support systems available to those affected by automation, whether the effects are positive or negative. The welfare system plays an important role in supporting individuals through the changes caused by technology. It is also important to discuss how technological advances can deliver benefits other than improved productivity or increased material well-being. Societal changes in the wake of increased automation should bring with them improved standards of living; for instance, by enhancing labour market flexibility so that individuals are better equipped to decide how their time is best spent.

6 **New support for proficiency in basic 4IR technology is vital.** Without proficiency in fundamental 4IR skills, it is virtually a given that Iceland will fail to keep up with other countries. Many countries invite people with specific expertise to immigrate without overdue complication. The authorities must bear this in mind so as to prevent an exodus of people with specialised education from Iceland to countries that offer more, in terms of either education or employment. The first step in this direction is to conduct a systematic appraisal of the labour market's long-term needs as regards skills, education, and human resources. This should be followed by structured measures to promote the build-up, maintenance, and utilisation, within Iceland, of knowledge in fields relating to 4IR, particularly to include automation. The education system and scientific work will play a key role in enabling us to utilise foreign technology and foster strong local proficiency in the development of new technology. Numerous foreign studies have shown that it is important for people to have the capacity to solve complex problems, apply critical thinking, think creatively, and communicate effectively with others. In order for value creation to increase during 4IR, we must continue to underpin and promote innovation in a large number of fields, in addition to strengthening education and basic 4IR skills.

7 Disruption due to technological changes brought about by 4IR creates ethical issues. Rapid technological developments and disruption often give rise to a tug-of-war between ethical values and the perceived benefits of the technology concerned. For example, data compilation and usage can jeopardise individuals' freedom and autonomy. With increased automation and technological advances, ever more complex decision-making processes will be carried out by robots and computer systems. Questions regarding the ethical responsibility for the decisions taken will be complicated. Further processing and utilisation of genetic information put human rights and understanding to the test. Misuse of information and information sources can pose a threat to democratic systems when disinformation is spread systematically with the aim of misleading people. Development and application of new technology must not be in the hands of homogeneous groups but should reflect diversity and gender equality. There must be a social consensus on which objectives are to be achieved by utilising new technology.

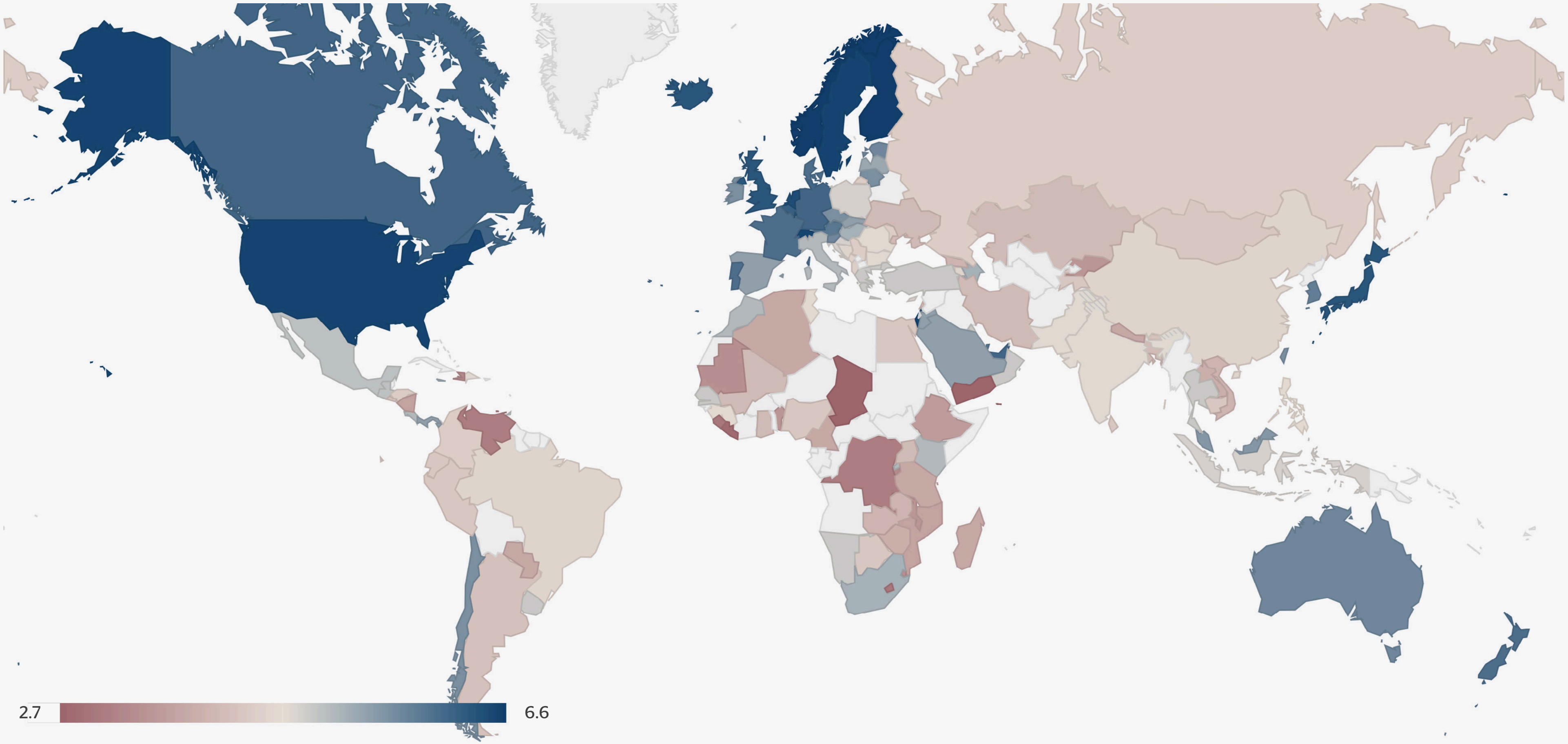
Figure 1: / The Fourth Industrial Revolution.





Discussion of the Fourth Industrial Revolution is taking place worldwide. It centres not only on the technological changes encompassed by the concept of 4IR, but also on the societal changes that may take place. What can humankind expect from the wave of changes that are forecast to occur in coming years and decades? In this regard, it is instructive to examine previous technological milestones and their societal impact. For a short while, it was customary to speak of three industrial revolutions in human history, but recently a fourth one has become established in public discourse — a revolution characterised by the rapid technological changes of the past few years, particularly in the fields of automation and AI. Dating industrial revolutions precisely can be a complicated task. The beginning of an industrial revolution is generally characterised by several technological milestones that have broad economic and social impact. Then, over time, new innovations appear, different in nature from the technology already existing, and transform society. At that point, it can be said that a new industrial revolution has begun. The beginning of the first three can be identified with reasonable accuracy, but they have no particular endpoint because the innovations

Figure 2 ╱ Access to most recent technology, by country – Source: World Bank..



remain in place and trigger further changes. It should be borne in mind that the dates mentioned here apply to advanced industrialised countries in the West and that many countries have not yet reached the technological level of the Second Industrial Revolution. According to figures from the United Nations, some 1.2 billion of the world's inhabitants were still without electricity in 2015, and universal access to electricity is not expected before 2030.

The four industrial revolutions have been characterised by technological breakthroughs – the steam engine, electricity, the internal combustion engine, the computer, AI – that have radically changed societies the world over. New discoveries made during each industrial revolution were gradually adopted by businesses to boost productivity and output, ultimately improving living standards. Structural changes in businesses – for instance, increased division of labour, changes in work arrangements, and factory operations – pulled in the same direction. Technological innovations had a labour-saving effect, with machinery replacing muscular strength and increasing productivity and output by leaps and bounds. Entire occupations were rendered obsolete by technological advances: artisans were replaced by factory workers, domestic workers were replaced by electrical appliances, and computers eliminated many office jobs.

Not only did the industrial revolutions affect output and the labour market; there were wide-ranging societal implications as well. The benefits they brought with them varied across groups, classes, and countries. They disrupted societies when the focus of production shifted from agriculture to industry, with the associated migration, urban growth, new class divisions, and disruption of wealth and income distribution. Countries' demographic patterns changed, and the role of the family was completely altered, as were people's day-to-day lives.

The common element in previous industrial revolutions was that the radical changes they brought were largely driven by automation, which either supplanted human effort or opened up new possibilities, although numerous other technological advances also took place.

The First Industrial Revolution began in England around 1760 and spread to other Western European countries and the US between 1820 and 1860. It was characterised by technological innovations in many areas: the textile industry, metalworking and mining, and above all, the harnessing of the power of steam. The steam engine was a prerequisite for the revolution in transport, as steam-powered ships and railroads replaced older means of transportation.

The Second Industrial Revolution took place in the latter half of the 19th century, with new industries – steel production, the chemical industry, the electrical industry, and the machine industry – which utilised recent technological discoveries. The leading role in industrial development shifted gradually from Britain to the US and mainland Europe, Germany in particular. Around 1900, the internal combustion engine, powered by oil or gasoline, had begun to supplant steam engines. Electricity grew steadily in importance as an energy source, particularly after 1920, when mass production with conveyor belts and assembly lines began.

The Third Industrial Revolution began with the integration of telecom and computer technologies in the 1960s and

1970s, laying the foundations for modern information technology (IT). Computers, fibre optic cables, satellites, mobile phones, and the internet are salient features of this process. IT became an important driver of globalisation that characterised societal development in many parts of the world in the late 20th century.

The Fourth Industrial Revolution is a continuation of this — powerful technology replaces its predecessors, transforming economies and societies with ever-increasing speed[1] A recurring theme in the technological developments of recent decades is automation that involves performing calculations on digital data. In fact a common feature of all industrial revolutions is that they were driven to a large degree by automation, which either supplanted human effort or opened up new possibilities for production, although numerous other technological advances also took place. It can be said that during the first two industrial revolutions, automation aimed at replacing the physical labour done by humans and animals, while the emphasis in the third was to replace mental efforts by humans. Such automation has accelerated during 4IR, reaching a new level where machines not only follow orders but can improve their own capacity to carry out tasks by "learning" to do them better.

Automation can now be found virtually everywhere: When we press the button labelled "n" on a computer keyboard, a symbol forming the letter "n" appears in the spot where the cursor is located on the screen. Although few people think of this as automation, it is based on a number of underlying processes, from electrons travelling along circuits in response to commands from millions of transistors, to commands that microprocessors load in order to produce codes that control the position of pixels on the screen, thereby stopping the backlighting of the screen where the reverse form "u" appears and creating the "n" of the next word. Electronics take the place of typesetting. What we refer to as automation at any given time depends on context; we often think of the most *recent* form of automation as the standard bearer for the term "automation" and consider everything else a given: the routing of a telephone call, dishwashers, the heat settings on an oven, automatic teller machines, and the focus in a mobile phone camera.

At present, there are various recent technologies and types of knowledge that fall into this category. At the top of the list is the technology that offers the greatest potential for continuing automation and multiplier effects: AI, artificial education, and related technology centring on the automation of complex processes.

Iceland's Industrial Revolution(s)

Examining economic developments in Iceland through the lens of the four industrial revolutions reveals clearly how concentrated the changes have been, taking place over only 120 years. The First Industrial Revolution began late in Iceland — not until around 1900 — although Iceland had for decades benefited from industrialisation in Europe, through increased demand for its manufactured goods and improvements in transport, including steamships. The Industrial Revolution took a different form in Iceland than in many Western European countries, as it was characterised by mechanised factories, primarily in the mechanisation of the fishing industry. However, the mechanisation of agriculture did not begin until the end of World War II. Industry grew stronger, and machines were used where appropriate, but what is notable is that industrial manufacturing never became a core sector of the Icelandic economy in terms of either its share in GDP or its share of the labour force. The industrial sector's share of the labour force peaked around 1980 at about one-third, as can be seen in Figure 3.

The tech revolution in the fishing industry proceeded at an astonishing pace. Motorised vessels and trawlers supplanted decked vessels and rowboats, dramatically increasing output. Fish catches grew by a factor of five over the first three decades of the 20th century, and by 1930 Iceland had joined the ranks of Europe's leading fish exporters. The Industrial Revolution entailed much more than technological changes: the emergence of a market economy, urbanisation, and a transformation in job distribution. New economic sectors developed in densely populated areas, including carpentry, iron- and metalworking, and knitting and sewing. The changes delivered improved standards of living, and economic growth was much stronger than in many European countries at that time, even though Icelanders were among Western Europe's poorer nations around 1940. In part, this can be explained by the fact that the tech innovations of the First and Second Industrial Revolutions were still limited to specific segments of the economy, but as jobs in low-technology sectors – agriculture in particular – declined in number, economic growth gained pace. The number of agriculture jobs fell rapidly, while the number of industrial and, especially, service-related jobs increased. By 1950, a majority of Icelanders worked in service-related jobs, and agriculture had lost the lead as

Figure 3 / Sectoral distribution of employment in Iceland 1870–2010. – Source: Statistics Iceland.

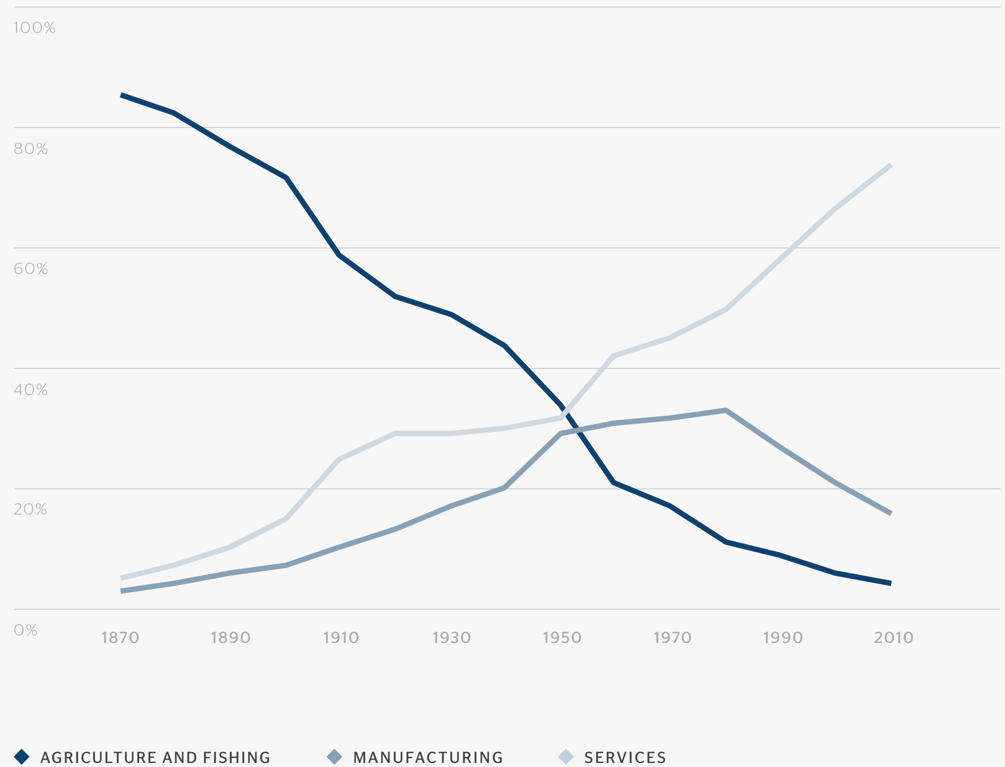
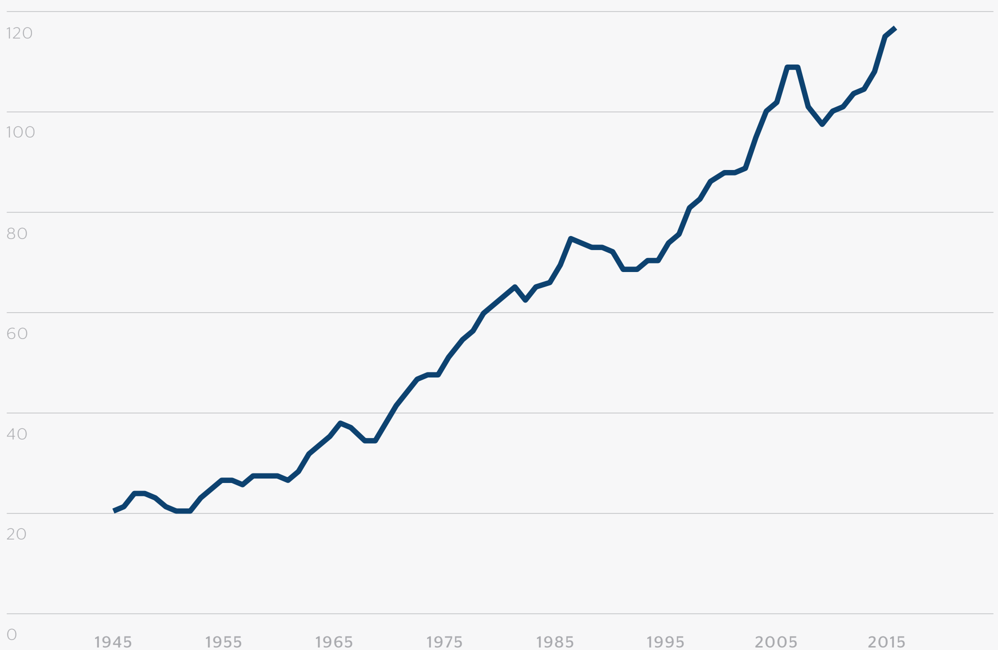


Figure 4 / GDP per capita, index 1945-2017. – Source: Statistics Iceland.



the country's main employment sector. In 2010, 76% of Icelanders worked in the services sector, 18% in industry, and only 6% in fishing and agriculture.

The Second Industrial Revolution came more or less on the heels of the First. Electric lighting was introduced soon after the turn of the century, and for quite a while it was virtually the only thing for which electricity was used. Home generators were built in many rural communities, and the first large hydropower plant was built by the Elliðaár river in 1921. There were big plans to harness hydropower and build fertiliser plants, but they stalled during the years between the two World Wars because of political opposition. The telegraph came to Iceland in 1906, and the motor vehicle age began in Iceland just before World War I. The introduction of cars represented a major improvement in transportation, not least because plans to build a railroad network never materialised due to the lack of an economic foundation for it. Technological innovations relating to the Second Industrial Revolution came to Iceland through imported goods: textiles, electrical equipment, and machinery. The textile and machine industries did not become prominent sectors of the economy[2]

World War II marked a turning point in Iceland's economic development, as it was then that Icelanders' living standards reached those in other Western countries. For the most part Iceland has retained that position until the present day, and for several important reasons, including Iceland having gained full control of the bountiful fishing waters surrounding the country. It is also of paramount importance that Iceland has drawn even with other advanced industrialised economies and achieved a technology level similar to that in neighbouring countries. Icelanders were receptive to foreign innovations, and adoption of technology therefore proceeded rather quickly. This could be seen best in the fishing industry, which became more technologically advanced than in most other countries. Moreover, Icelanders' educational level rose steeply, enabling them to respond to the demands made by industrialised and technology-driven societies. And finally, Iceland's broad-based welfare system, including healthcare and education, contributed to general wellbeing, a relatively well-educated population, and widespread participation in the labour market.

The Third Industrial Revolution came to Iceland around the same time as it arrived in neighbouring countries. The beginning of computerisation can be traced back to the 1960s, when SKÝRR and the University of Iceland's first electronic calculators were put into use. In the years following, the capacity of computers grew exponentially, and businesses and institutions began to use them. The personal computer emerged after 1980. Adoption of the internet began in 1995, revolutionising the flow of information both domestically and internationally. Information technology caused a reduction in jobs in various areas but also created new jobs, including the hundreds of software development companies that emerged. And last but not least are the social media that have affected our communication patterns and societal discourse.

With fundamental changes in Icelandic society, we have managed to boost value creation and prosperity. For example, gross domestic product (GDP) per capita has grown in real terms by a factor of 16 since 1945, placing Iceland among the countries with the highest per capita GDP. In order for living standards in Iceland to remain high, it is therefore important to realise what drives the next industrial revolution, how we can prepare for it, and what the challenges and opportunities are.

The Fourth Industrial Revolution

In order to understand more fully what the "Fourth Industrial Revolution" entails, we can consider the various technological innovations that have emerged or are considered imminent, and we can try to analyse the underlying drivers of the changes.[3] Professor Klaus Schwab, founder and executive chairman of the World Economic Forum, divides innovations and related inventions into three categories: physical, digital, and biological.[4] Some of these innovations that are covered regularly in the media still sound like science fiction, but many are already in use, even more than most people realise.

Among *physical* tech innovations are autonomous vehicles, 3D printing, advanced robotics, nanotechnology, big data, and new raw materials. Most people are familiar with self-driving cars and drones, which have been proposed as possible solutions to urban congestion. 3D printing centres on producing tangible objects by printing layer upon layer, on a three-dimensional drawing or model. The technology has been used for large items and small, from wind turbines to tiny objects implanted in human beings. The next step will be "4D printing", which is printing objects that can respond to the environment and adapt to heat and humidity, offering, for instance, the possibility of printing new organs to implant in people. Nanotechnology, which enables us to work on a smaller scale than before, is just around the corner.

Robots have been used extensively in factories around the world since the 1960s, but they are now becoming ever more sophisticated and are advancing by leaps and bounds with artificially intelligent control systems. As they develop further, they will be used more widely and be able to handle more complex tasks, including communicating with people. Public interest in robots for entertainment and education has grown substantially in recent years, and although robots have "just left the factory", so to speak, by now there is no turning back. Scientists are working constantly on developing new raw materials, a field that has been revolutionised in recent years. Material made from carbon atoms, which conducts heat and electricity effectively, is 200 times stronger than steel and a million times thinner than a human hair.[5] At present, it is still one of the most expensive materials on Earth, but further development will make it less expensive and therefore permit wider use.

The digital revolution will continue and will facilitate the use of big data. Computers, which previously were used only in universities and governmental institutions, can now be found in people's pockets. We connect with one another on the internet, virtually anywhere in the world, and we navigate by consulting the computer that is our mobile telephone. It is difficult to find manufacturing that does not rely in some way on computers, and computers affect most people's day-to-day lives. Forthcoming is the introduction of the Internet of Things (IoT), with a wide range of appliances – from smartphones to coffeemakers to refrigerators – that connect to the internet and, through it, to one another. This will bring with it an enormous amount of data that can be used for many purposes. The production of big data will grow phenomenally as a result. In fact, it has already surged with social media, cheaper data storage, and increased computing power. A similar impact is expected in the healthcare field in coming years and decades. Alongside this, utilisation of big data as well as smaller databases has grown significantly, and further growth is foreseeable.

Rapid advances have taken place in biological science, particularly in knowledge of human *genetics*. A massive campaign was launched in 1990 when work began on mapping the human genome. About 13 years later, it was announced that the task was complete and the mapping had been successful. The study was massive in scope and is estimated to have cost nearly 3 billion US dollars. Since then, the cost of processing genetic information has fallen dramatically, creating opportunities to use such information. Genetic discoveries have already affected treatment of disease, and the possible uses of the knowledge are increasing constantly as the technology evolves.

The more tech innovations are utilised in day-to-day life and in various types of manufacturing, the broader the impact will be. This is important in terms of comprehending 4IR because the technology gains increasing traction as more information and more systems connect with one another. Such escalation is a key factor in understanding the characteristics of 4IR; i.e., the underlying influences and their implications. Key concepts in this approach are *artificial intelligence*

(AI), *synergy*, and *disruption*, which are discussed in the following sections. The automation of 4IR is certainly a continuation of previous tech developments, and it moves in the same direction as the information revolution, but 4IR automation differs in nature from automation in previous industrial revolutions — the processes at which it aims, the ways in which it links to other technology, and the implications it will have.

When mass production came about with the advent of factories about 200 years ago, the energy sources involved, such as oil and electricity, were used to replace muscle power. The Third Industrial Revolution is generally called the "information revolution", as it centred first and foremost on the automation of a specific type of brain power — *computing*. With the automation of computing, the telephone system has been redesigned from the ground up — analog transmittal of information gave way to digital — and a number of other methods of providing information were introduced, including websites, blogs, podcasts, video on demand (VoD), and many others. These developments are based on multiplier effects in the production of microprocessors, as the number of transistors in circuits has nearly doubled every 18 months since the mid-20th century.[6] Signs of this growth can be seen everywhere: when we compare modern mobile phones with the first computer used by the University of Iceland Computing Services department in 1976, an IBM 360/30,[7] we see that the computing power of a mobile phone like those carried by many people today is about a million times that of the IBM 360/30.

4IR automation centres on brain power *in a broader sense* than computation, as it uses more detailed and diverse data than before so as to allow computers to handle *multiple tasks* apart from the calculations themselves. These new systems rely on knowledge that is not directly programmed; instead, the machine "learns" in a purpose-built environment. An example is a system that is trained to simulate human and animal sense of sight (computer vision), respond to a variety of stimuli, and carry out complex tasks such as automated piloting of cars, drones, and robots. As in previous industrial revolutions, machines are assigned tasks that their predecessors are incapable of carrying out, but unlike the automation of the past, 4IR is based on utilising a new type of automated operating systems that to some extent "program themselves". The result is a synergistic effect, where nearly all processes that use digital data and can utilise AI technology are converted into automated processes.

Automation using artificial intelligence

Before the age of computers, calculations were done by people, but modern computers can carry out mathematical operations that previously required human intelligence. Therefore, all computers are actually “automatic” with respect to computing and necessary connections to the outside world: network systems, computer screens, reading and writing of data to and from hard drives, mice, keyboards, and so forth.

When we compare 4IR automation with automation from previous industrial revolutions, the main difference lies in the diversity of the data that machines can utilise, the diversity of the conditions they can handle, and the diversity of the operations required by the tasks concerned. There was a time when fertiliser bags were lifted exclusively by people and beasts of burden, and people were in sole control of complex industrial processes. Now there is no doubt about whether a forklift that lifts a tonne is “really lifting”. “Intelligence” and “thinking”, however, are not yet as well defined as terms relating to muscular strength. Although the terms are reasonably useful in daily speech, they refer to complex phenomena, and attempts to define them usually omit something important.

AI is still far from equalling human intelligence — or the intelligence of most domesticated animals, for that matter. The diversity that characterises the behaviour of a person or a dog that extricates itself from an unpleasant situation far surpasses the “ingenuity” of the most powerful AI in most respects: the person or dog can respond to unforeseen circumstances, learn new tasks and concepts, take into consideration many different factors, explain and predict sequences of events, switch from one task to another, and much more — all of these are currently far beyond the capacity of AI. The fact is, however, that this revolution — i.e., *automation of human inventiveness and imagination* — is well underway, as is witnessed by the most recent tools and technology. Because all societies are based on human intelligence, radical changes can be expected in the wake of these developments, particularly in the long run. How rapid this evolution will be and how it breaks down into periods is difficult to predict. It is possible to find indications, however, by considering the forces that shape the scientific and technical progress of this technology.[8]

Automation using AI can be utilised to make existing technology more reliable, more efficient, more economical, and faster. For all processes with quantifiable variables that affect digital notation, it is potentially possible to use AI for automation. The set of such processes is now very large and is growing continuously. AI therefore works as a multiplier, whether its utilisation is limited to a small part of each process or a large one. But it has an even broader impact because it opens up the possibility of entirely new methods, approaches, goods, and services that hitherto were not possible — not with technology, nor with additional staff, nor with humans and machines combined. A good example of this is the sharing economy as represented by Airbnb for housing and Uber for urban transport, requiring pattern analysis and planning that could not be carried out before the advent of the applicable AI technology. Because AI has such a wide range of applications, it can be used for new division of tasks between humans and machines, as AI strengthens or improves processes already carried out by people. Such combinations will probably become the most common use of AI in the future. The results of all of this are synergies where both new and old technologies are elevated to a higher level, workers are utilised better and in new ways, and new possibilities open up.

Whether machines will ever become “as smart as” or even “smarter” than people is an important question that we will leave to philosophers and the scientific community to struggle with. On the other hand, it is vital to discuss the use of automation and the impact of AI on the economy and society in a structured way, and to map out a strategy that Iceland can — and should — follow so as to be on a par with other countries in this area. In order to do this, it is necessary to determine how much knowledge of AI technology exists, what factors drive it and, in particular, what factors determine how rapidly it will progress towards artificial general intelligence. In the next few years, numerous manifestations of the technology will be used in ever-increasing measure in all areas of human existence, from industry and manufacturing to recreation, education, and communication. Applied AI has become a force that will shape our society enormously in the decades to come.

Disruption in the wake of automation

As is discussed above, automation has already affected human life over the centuries — mechanisation, conveyor belts, electrification, the computer revolution — all of these processes have changed some jobs, reshaped others, and rendered still others obsolete.

Earlier industrial revolutions brought social disruption with them. The Luddites were a group of textile workers in 19th-century Britain who were dissatisfied with the risk that industrialised textile manufacture posed to their livelihoods. Until then, artisans had been able to earn a good living by selling their textiles to merchants, and they had developed an industry around their work. In Britain, textile artisans could be found all over the country. The introduction of steam power made it possible to mass-produce textiles using more powerful looms. This disrupted the process of production, as the number of skilled artisans declined and the sector grew more concentrated. Small family-owned companies that specialised in textiles could not compete with mass-produced goods.

Another example is the disruption accompanying the rise of shopping malls in the US, long a symbol of American consumer culture. American cities have devoted large planning areas to shopping malls. In recent years, however, malls have declined in number, owing to increased online shopping. Online shopping has changed consumers' shopping behaviour, and people order goods online instead of going to malls. This also brings about a change in the physical structure of retail stores: instead of large shopping centres, large warehouses are built, and the organisational structure of retail trade focuses on ensuring smooth transit of goods to buyers.

With the advent of AI, it is now possible to allow technology to solve problems that previously required human intelligence. Computers can transfer big data, and algorithms can determine what is important in the data and decide both how production shall be handled and how to respond. Because opportunities, changes, and reshaping take place based on new premises, disruption seeks a new channel. Furthermore, during 4IR, technology will disrupt conventional business plans and social structures. As a result, current industrial and technological markets will be replaced by production of something entirely new — something more efficient, more effective, and more secure, or in some other respect more desirable. This disruption therefore entails innovation and the breakdown or destruction of what previously existed.

One way to analyse 4IR is to ask how a given technology could lead to disruption. The disruption caused by technological changes can vary in scale and scope. For instance, utilisation of virtual reality (VR) can disrupt the methods firms use to develop prototypes of equipment they wish to market. Until now, the conventional approach has been to build prototypes, often at significant expense, in order to test whether a tool or service works. Tests are then conducted and malfunctions are fixed, whereupon a new prototype is built. With simulation, VR, and AI, it is possible to pre-test new products, equipment, and services in a new way. This dramatically reduces product development costs, which has a multiplier effect by increasing the number of innovation attempts and boosting new players' chances to gain a foothold in their sectors, revolutionise them, and create new ones.

Using AI for automation changes conventional jobs or eliminates them, as is discussed further in the section on automation and the labour market. As automation gains ground, it is amplified; it affects not only economic or labour market productivity, but also the structure of societies. For instance, the structure of urban communities where widespread private car ownership is assumed will change markedly if autonomous cars become widespread, which in turn will call for changes in urban planning. Using AI to make decisions on lending will not only affect bank employees but will open the opportunity for new players to enter the market. A person's business history will no longer be stored in the bank branch where they do business; instead, lenders will be able to access centralised digital data on them and use AI to take decisions on loans to the borrowers concerned.

Forecasts of automation and developments in the labour market

In the age of artificial intelligence, the gap between what people can do and what technology can do is constantly shrinking. New jobs are created, some jobs disappear, and others change. Some tasks are more easily assigned to computers than others are, and the effects – positive and negative – on some jobs are greater than the effects on others. As Erik Brynjolfsson, Director of the Initiative on the Digital Economy and the Center for Digital Business at Massachusetts Institute of Technology in the United States, says,

"... the idea that technology is coming for our jobs is a huge misconception. The bigger opportunity is to use technology to enhance performance and augment human activity." He adds, "Technology can be used to destroy and create jobs. There is no economic law that everyone is going to benefit equally. You have to put the policies in place." [9]

These words show the importance of preparing society for the changes ahead. In coming years and decades, there will be opportunities to think carefully about how technology can move society towards equal rights, equal prosperity, and a contented citizenry. Automation of the labour market is an international trend that will ultimately affect all countries, sectors, and jobs. The nature of the underlying technology gives cause to expect that the changes will be rapid and widespread, as is stated above. Of course, it is impossible to say precisely what effect all of this will have on specific jobs, as technology is changeable and jobs are also. However, there are various indications in the nature of the technological advances that have already taken place — indications that can suggest where the impact of automation will be concentrated.

Many observers have studied this and tried to forecast how many jobs will be lost and when, where new jobs will be created, and how other jobs may change. Although research findings seldom agree on exact numbers or timing, they do convey a fairly strong consensus on the nature of the changes ahead; i.e., which jobs are likeliest to disappear or change considerably, and how individual sectors and occupations are likely to evolve.

One of the best-known studies was carried out at Oxford University in 2013.[10] The authors, Frey and Osborne, engaged a group of specialists to assess the likelihood that computerisation would affect a given sample of jobs, based on technology that already exists or is expected in the next decade or two (i.e., by 2033). They applied this assessment to the technological properties of AI and their relationship to occupations existing today, together with statistics on the number of jobs in each occupation (using the US labour market), and concluded that *47% of all jobs* are "potentially automatable over [...] perhaps a decade or two." It is safe to say that these findings made quite a stir, and the methodology used by the authors has laid the foundations for a number of subsequent studies.

The flaw in Frey and Osborne's approach is that their findings are based solely on occupational titles, which underestimates most jobs' complexity and diversity. They and others have corrected for this in subsequent work. Within each job are a variety of tasks requiring a variety of skills. For example, jobs increasingly require integration of technological and general knowledge, and the same job in two different companies (not to mention in two different countries) can require utterly different sets of tasks. *In assessing the impact of technological advances on jobs, it is therefore important to consider skills and tasks rather than focusing on job titles and positions*. Consultancy firm McKinsey and the OECD are among researchers that have based subsequent work on Frey and Osborne's methodology but amplified it, both by taking into account the skills required for various jobs and by considering various countries.

A two-year study carried out by McKinsey in 2017 examined 2,000 activities falling under 800 job titles. The finding was that more than half of the activities carried out will potentially be done by computers, using technology already in existence. Even though computers can fully complete only about 5% of all jobs, McKinsey estimates that at least one-third of activities carried out in *60% of all jobs* could be computerised.[11]

One of the most recent studies on this topic was carried out by the OECD and published early in 2018. The study used the results of the Programme for the International Assessment of Adult Competencies (PIAAC) to make a more detailed assessment of likely changes in jobs in member countries.[12] In addition, the study was based on a more precise classification of jobs than had been used before. For example, it was possible to examine with greater clarity the skills required *for different jobs in different places*. In the 32 countries included in the study (Iceland has not completed the PIAAC survey and was therefore not included in the sample), the findings were that about *half of all jobs will probably be significantly affected* by automation. The effects of these changes are widely distributed, however. About 14% of jobs in the countries sampled are very likely to be automated; i.e., with a more than 70% probability of automation. About 32% are at moderate risk of change; i.e., with a 50-70% probability of automation. [13]

The impact of AI on the labour market will differ from one country to another. There are several reasons for this. Educational levels and educational system quality are important, as are the composition of economic sectors and, not least, the skills and activities currently required for jobs. Corporate investment in adoption of technological innovations and employee training is one factor that affects these skills and activities. The international battle for specially educated workers has begun. Many countries invite people with specific expertise to immigrate without overdue complication. Iceland must consider this in order not to lose a large share of its specialised population to countries offering better employment terms.

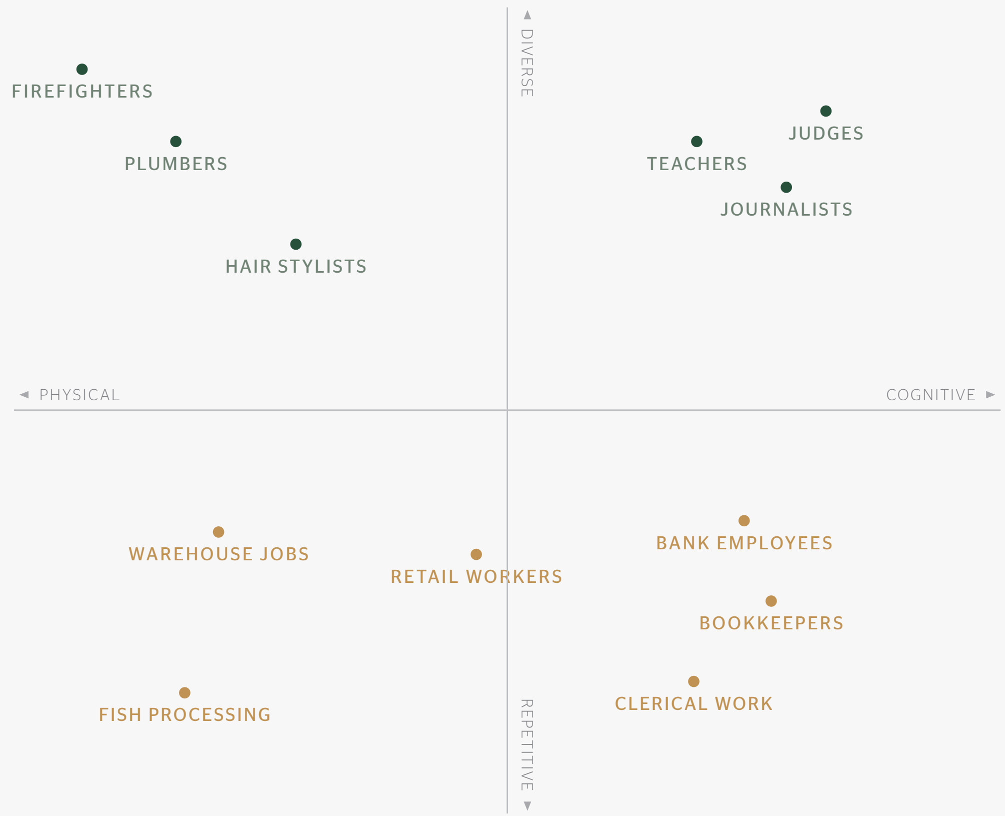
Which jobs are most likely to be affected by automation?

In general, the higher the educational level of an individual in a given job, the lower the probability of automation in the short run. The same applies to income, which often (but not always) goes hand-in-hand with educational level: the higher the income, the lower the probability of automation. This came clearly to the fore in the OECD study, which shows a comparable relationship between income and probability of automation in all 32 countries studied except Russia, where the risk of automation is more or less equally distributed across income groups.

Highly repetitive jobs that are carried out in a structured, predictable environment are the easiest to automate. Machines can replace human effort in jobs involving repetitive physical labour. This has not required AI, but with the advent of AI it will be possible to use computers and robots to carry out more diverse tasks that require thought.[14] It is therefore virtually assured that AI will eventually be used for jobs involving standardised data and information and repeated information processing. This represents a radical change because there are many such jobs in modern societies, and they are carried out by large groups of middle-income workers. But it should be borne in mind that it is far from a given that machines will replace certain types of jobs entirely; it is much more likely that the jobs will change with the introduction of AI.

Complex mental tasks requiring judgment and emotional intelligence, problem-solving skills, insight, and creativity have not yet been automated, nor have physical tasks requiring significant adaptability or interactions with other people. Experts think it likely that this will remain unchanged, at least in the short run. The same experts point out, however, that with big data, AI, and increased computing capacity, together with advances in baseline research on mechanised learning, automation of more complex and varied tasks will become ever more probable. An example is the already demonstrated ability of computers to diagnose illnesses, write legal text, and drive cars in traffic. Continued developments in the same direction could lead to automation of jobs requiring more complex skills and higher education.

Figure 5 / Impact of automation on labour market .[15]



Assessment of the impact of automation on the Icelandic labour market

If we assume that jobs in Iceland are similar in nature to those in neighbouring countries, the aforementioned OECD[16] study provides an interesting opportunity to assess the impact of 4IR on the Icelandic labour market. Linking the average probability of automation in various occupations in the OECD with Statistics Iceland's labour market study enables us to sketch a picture of the probability of automation of Icelandic jobs, based on the structure of the domestic economy.[17]

In 2017, there were just under 194,000 people aged 16-74 in the labour market. Iceland's labour participation rate is high in comparison with other countries, at around 82%, and unemployment is currently low, at 2%. In 2017, just over 50,000 people held jobs with a very high probability of automation in the next 10-15 years, according to OECD methodology. This corresponds to about 28% of the Icelandic labour market. These are the jobs that could disappear entirely or change so much that they are no longer considered comparable to what they were previously. Jobs in manufacturing and in sales and services are most likely to contract the most.

The majority (about 60%) of those working in the Icelandic labour market hold jobs with moderate risk of automation in the near future. This means that it will probably be possible in the near future to use technology to carry out a large share of the tasks or skills pertaining to these jobs. As a result, it is likely that even if a given job does not disappear entirely, it will at least change markedly. For example, 90% of jobs (25,086 jobs) carried out by people with technical or specialised education are at moderate risk of automation. Among them are carpentry, metalsmithing, baking, and other jobs requiring a certain level of specialisation or specialised training. Because of this specialisation, it can be assumed that these individuals will more often than not be in a good position to change with the jobs, but only if they have the facilities and opportunity to receive the training or continuing education needed.

Of those working in the Icelandic labour market in 2017, only 14% held jobs with a low risk of automation. They include specialised jobs and management positions and can be found mainly in education, healthcare, and administration. As Figure 7 shows, the impact can vary within a given occupation, because of how different from

Figure 6 / Probability of automation of Icelandic jobs (Number of jobs and percentage, 2017)

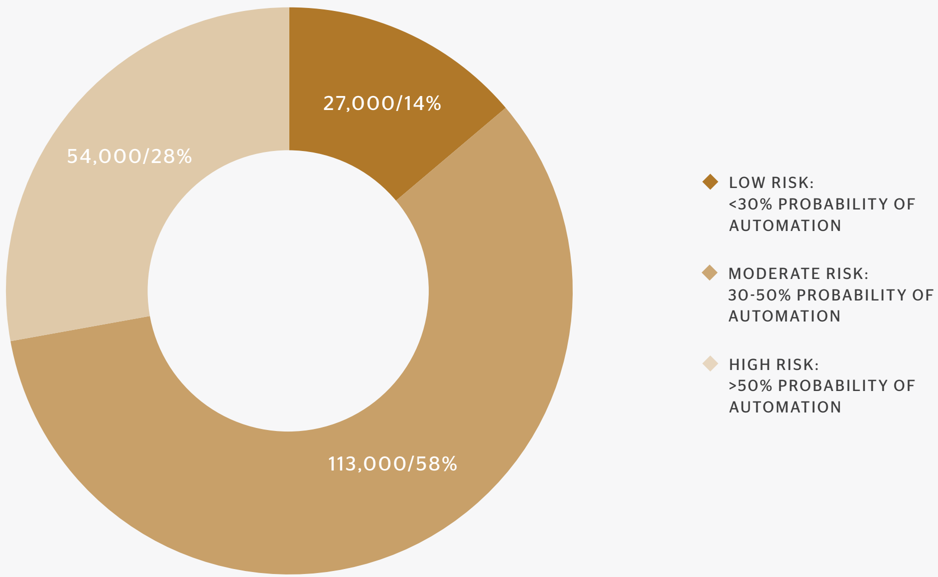


Figure 7 / Risk of impact from automation in Iceland, by occupation.

OCCUPATION								
	HIGH RISK OF AUTOMATION			MODERATE RISK OF AUTOMATION			LOW RISK OF AUTOMATION	
1	Industrial workers and specialised tradesmen	12,546	1	Experts and specialised workers	33,823	1	Experts and specialised workers	15,367
2	Service and sales workers	12,287	2	Service and sales workers	28,265	2	Managers	8,870
3	Non-specialised workers	11,475	3	Technicians and specially trained workers	25,086	3	Technicians and specially trained workers	2,559
4	Machinists and machine operators	9,042	4	Managers	11,142	4	Service and sales workers	-
5	Agriiculture and fishing sector workers	5,685	5	Industrial workers and specialised tradesmen	7,873	5	Industrial workers and specialised tradesmen	-
6	Office workers	2,628	6	Office workers	6,330	6	Office workers	-
7	Technicians and specially trained workers	273	7	Machinists and machine operators	501	7	Machinists and machine operators	-
8	Managers	-	8	Non-specialised workers	-	8	Non-specialised workers	-
9	Experts and specialised workers	-	9	Agriiculture and fishing sector workers	-	9	Agriiculture and fishing sector workers	-

one another jobs can actually be and yet still be considered to belong to the same occupation. Specialised jobs are a good example of this. It is estimated that over 30,000 specialised jobs carry a moderate risk of automation, while just over 15,000 of jobs in the same category are at low risk of automation. The difference stems from the varied nature of the jobs concerned, some of which involve tasks that are easier to automate than others. The same is true of jobs in sales and services, some 12,000 of which carry a high risk of automation, while another 28,000 are at moderate risk.

It is also possible to examine the potential impact of automation on economic sectors rather than occupations. Figure 8 shows the number of jobs in specific sectors that are at high risk of automation, together with the ratio of that number to the total number of jobs in the same sector. It shows clearly the difference between sectors such as construction, where 60% of jobs are at high risk of automation, and education, where only 8% of jobs carry a similar risk. Most of the jobs that are highly susceptible to change are in the manufacturing sector, although this category includes a wide variety of jobs from many sectors of the economys.[18]

Figure 8 / Impact of automation, by sector (number of jobs in the category "High probability of automation").

	SECTOR	Number of jobs (% of all jobs in the sector)
1	Manufacturing	10,668 (57%)
2	Construction	7,407 (60%)
3	Reatail and wholesale trade; motor vehicle repair	6,879 (27%)
4	Hotel and restaurant operations	6,724 (61%)
5	Agriculture, forestry, and fishing	5,343 (73%)
6	Transport, transit, and storage	4,536 (34%)
7	Leasing and miscellaneous specialised servicesa	2,246 (30%)
8	Healthcare and social services	2,183 (10%)
9	Education and training	1,850 (8%)
10	Cultural, athletic, and recreational activities	1,269 (20%)

Disruption in the Icelandic labour market

Statistics Iceland's labour market study makes it possible to examine the potential impact of AI adoption on various societal groups. For example, it is possible to analyse the gender and age distribution within a given occupation, as well as the educational level and nationality of individuals, and thereby determine how the impact of automation could be distributed throughout Icelandic society.

1. The relationship between educational level and risk of automation is the same in Iceland as in other countries; i.e., the risk of automation declines with rising educational levels. Disruption will probably be greatest among those with only a primary school education. About half of their jobs, or about 26,000 jobs, are at risk of being eliminated, and another 45% are likely to change radically. For those who have completed technical school or upper secondary school, about a third of jobs are at risk of elimination and just over 60% likely to change radically. Jobs done by workers with a university degree are also likely to change substantially, with 65% of jobs falling into the middle category. On the other hand, very few of these jobs (6%) are at risk of elimination, and more of them are considered secure (29%). The impact also differs somewhat by gender, as is discussed further below.

2. Jobs outside densely populated communities are more likely to be affected by automation. For example, 44% of jobs in rural communities are at risk of automation, as opposed to 22% of jobs in densely populated communities. One of the reasons for this is that jobs deemed likely to change because of automation are concentrated more in rural communities than in more populated areas. This applies, for instance, to farmers' jobs, where the risk of automation is very high. Furthermore, there are fewer management positions and specialised office jobs in sparsely populated communities.

Figure 9 / Impact of automation, by gender and educational level

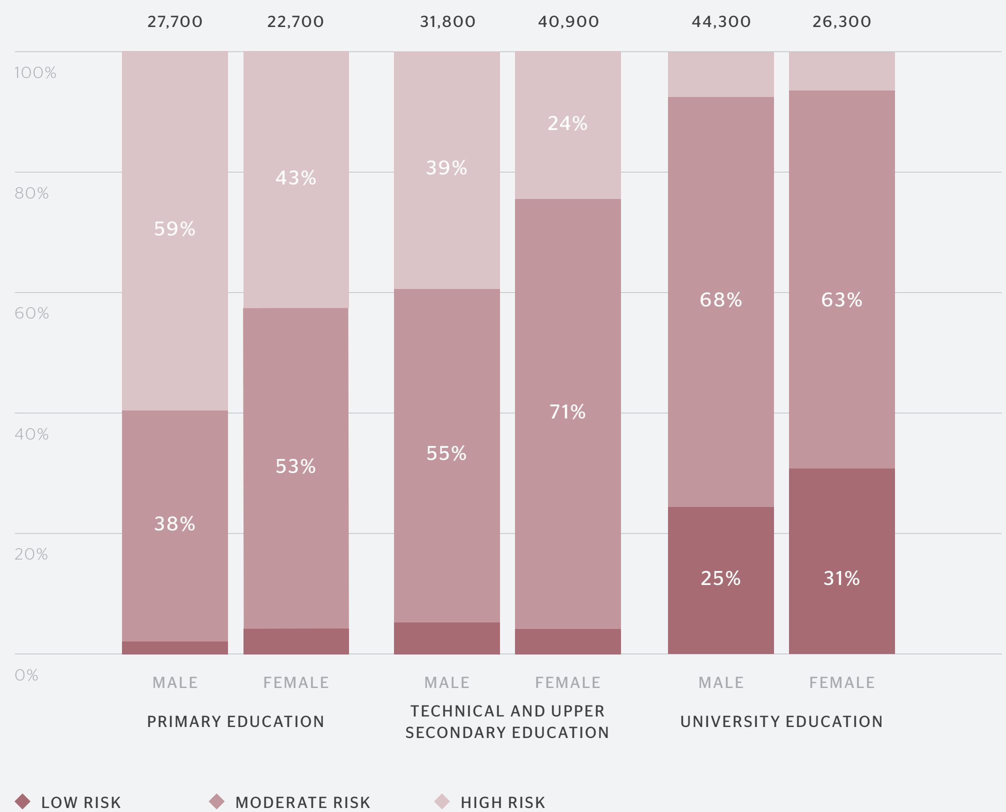
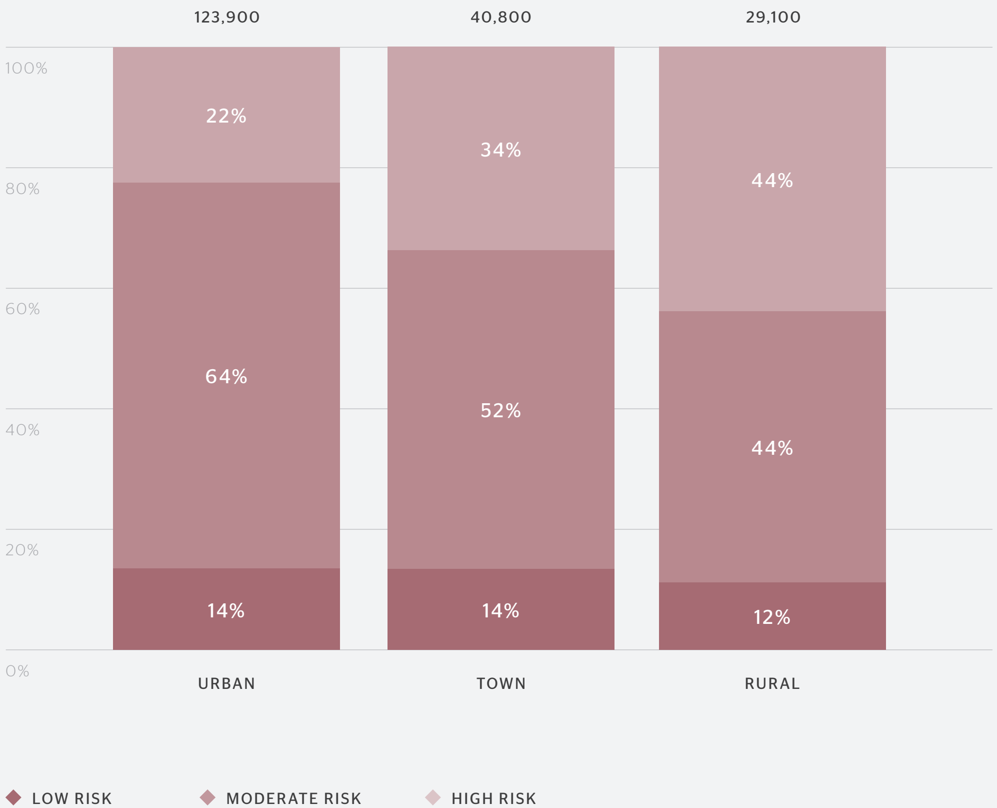


Figure 10 Impact of automation, by residence.



3. Examining the findings by gender in given occupations revealed that men are likelier than women to hold jobs potentially affected by technology. This applies irrespective of age or educational level. The share of women who work in caring and educational fields may explain this in part, as these jobs are among the least likely to be affected by automation. Furthermore, men account for a large majority of workers in the construction sector, where there is greater risk of automation. The largest share of men at risk of being affected by automation is among those with a primary school education, or 59%, as opposed to 43% for women with the same education.

4. Younger people have less education and are likely to hold jobs with a high risk of automation. For example, about half the jobs carried out by workers aged 15-24 have a high probability of being affected by automation, a much larger share than for other age groups. This is particularly important in view of the high labour participation rate among young Icelanders. As these jobs often represent young people's first foray into the labour market, they play an important role in providing training in various types of general skills, and even in introducing workers to various sectors and industries.

Figure 11 / Impact of automation, by gender and age.

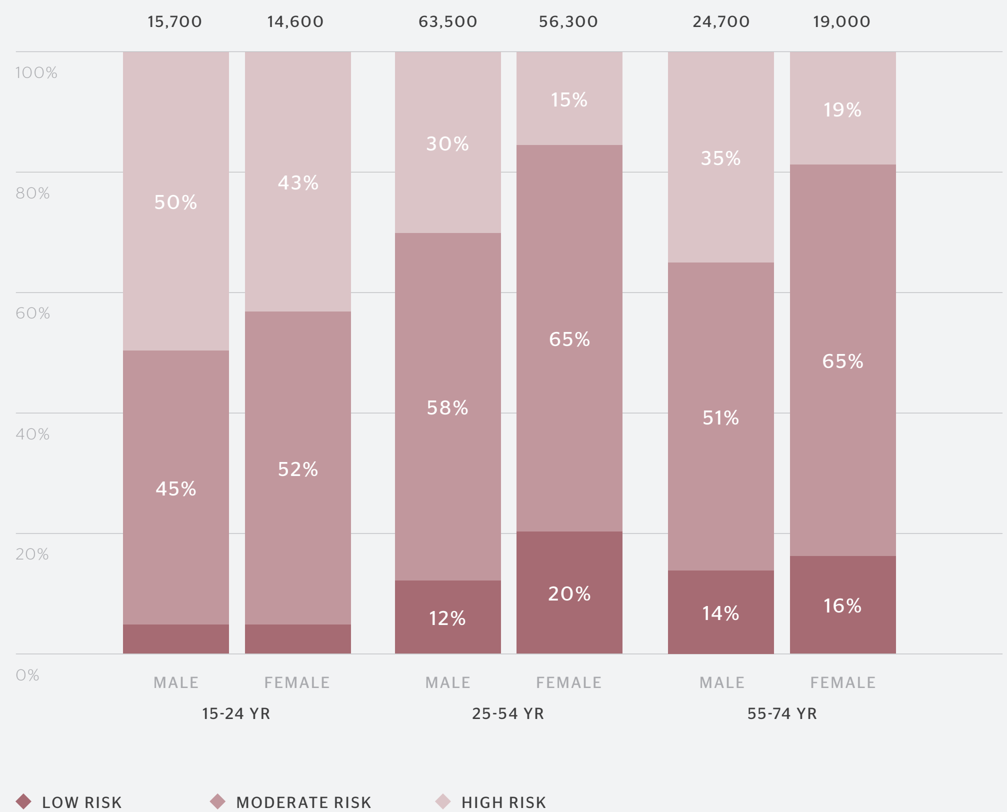
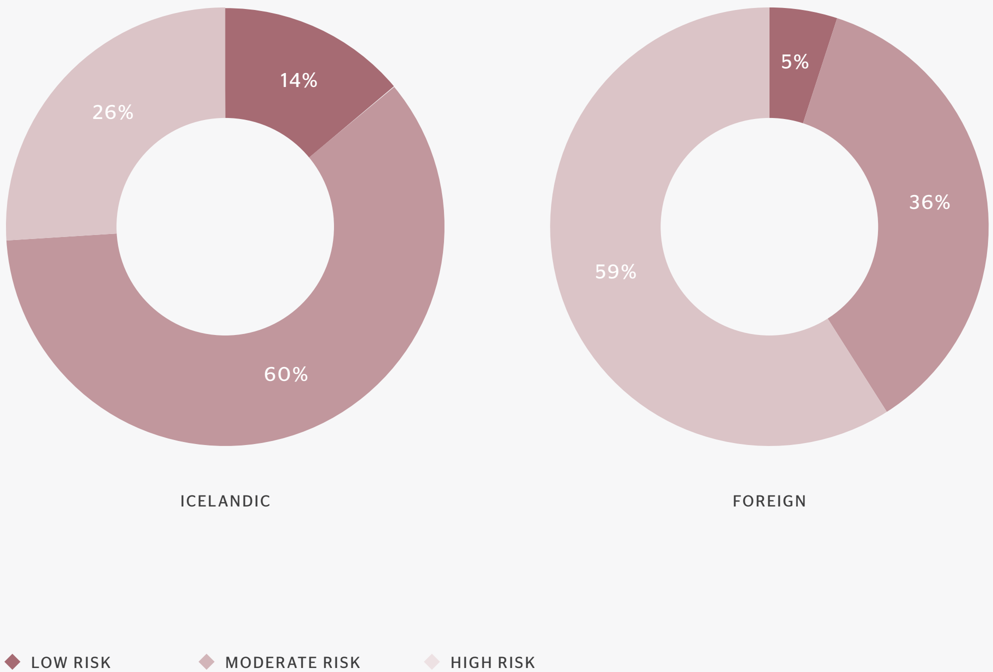


Figure 12 / Impact of automation, by nationality.



5. There is a significant difference in the potential impact of automation on the jobs of Icelandic nationals and foreign workers. About 26% of Icelandic nationals in the labour market will be affected strongly by automation, as compared with about 59% of foreign nationals. What is also interesting is that there is virtually no gender-based difference in this group. This is probably because foreign nationals are more likely to hold jobs that are highly likely to change as a result of automation, including industrial labour, service jobs, and construction work. In recent years, the number of foreign nationals in Iceland has skyrocketed, owing to the strong economic growth that has created demand for labour in these sectors.

Reservations about the forecast of automation risk

The findings herein are based on simultaneous processing of data from Statistics Iceland and the OECD. The Statistics Iceland labour market study is a random sample study intended to provide reliable information about people's jobs, working hours, job searches, education, and more. It therefore gives more detailed information than would otherwise be obtained concerning the composition of occupations and sectors in Iceland, as well as enabling an analysis of factors such as employees' age distribution and gender. The results described herein are obtained by linking these findings with OECD estimates of automation probability of jobs according to three-digit ISCO-8 classification codes. The findings are all weighted by gender and age. It should be noted that because the labour market study is a random sample study, some figures may be based on small samples; i.e., a small number of individuals.

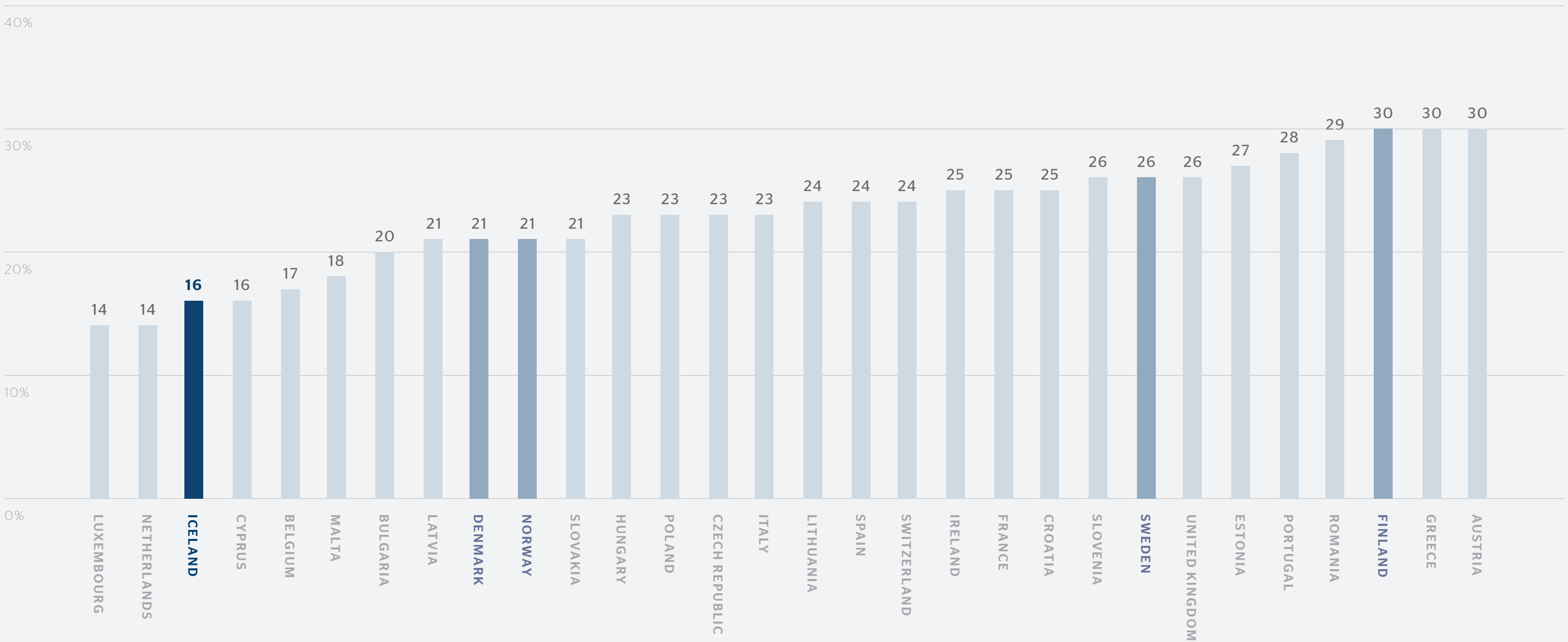
It is important to bear in mind that the OECD report is a forecast only and is intended solely to provide an informed idea of how jobs could develop in coming years. Furthermore, it is unclear how applicable that forecast is to jobs in Iceland; however, it will be possible to examine this more closely once the PIAAC survey has been conducted in Iceland. The technological level within specific sectors varies from country to country, and the scope for automation therefore varies likewise. For example, is the scope for automation in the Icelandic fishing industry the same as in the French fishing industry?

Finally, it should be noted that this is a statistical assessment covering only the jobs that could disappear or change; it does not include jobs that may be created. As is discussed above, these findings must not be interpreted to mean that the individuals in these jobs will leave the labour market, although it certainly could happen. But these workers are at risk, and they will probably need, even more than others, to acquire new skills and perhaps take an entirely different path when seeking work.

Skills and education

If forecasts of the impact of automation prove to be any indication of the direction developments will take, a response is clearly necessary. This is just as important for individuals and groups whose jobs will be eliminated as it is for those whose jobs will change to a large or small degree. For example, we can already see changes in the demands made by employers when hiring staff, as they now place stronger emphasis on characteristics that are less automatable, such as cross-disciplinary skills. In conventional technical positions, for instance, emphasis is often placed on communication skills, and designers may need basic familiarity with various types of software.[21] The nature of these changes is such that they will affect all participants in the labour market; therefore, it is wise to be prepared. The public sector could prepare the ground, for example, with a systematic assessment of the labour market's long-term skills, education, and personnel needs;[22] with targeted support to meet those needs; and with structured steps to support high-tech development, transfer of knowledge and technology, and innovation. Employers can help their employees to acquire appropriate continuing education and retraining so that they can respond to changes; furthermore,

Figure 13 / STEM-educated (Science, Technology, Engineering, Mathematics) labour force, by country..



firms can devote more time and capital to research and development, in cooperation with universities, other companies, or research institutes. The labour movement can also help union members by strengthening their continuing education and retraining environment, and by shaping it to fit new priorities. And finally, individuals must seek out opportunities and acquire new skills as applicable.

It can be said that the education system is in a sense the glue that holds all of this together. There are many things to bear in mind when looking ahead. Today, STEM-educated (Science, Technology, Engineering, Mathematics) individuals comprise only 16% of university-educated people in Iceland, a very low percentage in comparison with other European countries. It is important to increase the number of people educated in STEM fields so that Iceland will be better prepared for the technological changes forecast for the next 15-20 years.

Other education-related factors must be considered as well; for instance, how teaching is carried out, the structure of interdisciplinary study, increased weight of practical courses and the arts, as well as improving the emotional health of children and youth in schools. In this context, it is appropriate to note that in 2015, the World Economic Forum asked thousands of CEOs what skills they thought employees would need in 2020. Their answers were intriguing in many ways. Topping the list was complex problem-solving, a prime example of a skill that will be of paramount importance during 4IR. As has been mentioned previously, major changes can be expected in jobs requiring thought (brain power) but entail repetition of processes. Individuals capable of solving complex problems will therefore be in demand in the job market. Furthermore, various skills and competencies support one another. For instance, critical and creative thinking can greatly facilitate complex problem-solving. Moreover, many of these skills and competencies are important not only for participation in the labour market but also for participation in a democracy based on freedom of expression and respect for the views of others. The ability to take a critical position on issues helps in solving complex problems at work, but it also enables individuals to use their own powers of reasoning instead of being led by others in their private lives.[23]

If the skills in the table are to be used as criteria, significant changes must take place in national educational systems in order to emphasize these skills. The Finns, for instance, have made major changes in their school system in order to home in on new skills. They have placed stronger emphasis on cooperation than on competition, for example, and to underline this shift, they have stopped using standardised tests in primary schools. The Danes have decided to devote significant resources to continuing education and retraining. Various other trends have emerged as well, including individualised education; project-centred education; flipped classrooms; computer programming instruction from an early age; increased emphasis on empathy, cooperation, and emotional intelligence; education centring on creating or producing something new (i.e., maker learning and entrepreneurship); and so on. Major changes have also taken place in the Icelandic education system in recent years. Formative evaluation has been adopted in primary schools, and greater emphasis has been placed on individualised education. Furthermore, critical thinking has been introduced in the national curriculum guide for compulsory school. University-level offerings have been expanded, and upper secondary education has been shortened. The Ministry of Education, Science, and Culture is currently preparing an education strategy for the period through 2030, which will have to take into account the societal changes that will take place in coming decades. It must also explain how the changes that have already taken place in the Icelandic educational system have better prepared Iceland to take on these changes.[24]

Figure 14: The 10 most important skills for individuals to have: World Economic Forum forecast, 2016

	2020		2015
1.	Complex problem-solving	1.	Complex problem-solving
2.	Critical thinking	2.	Coordinating with others
3.	Creativity	3.	People management
4.	People management	4.	Critical thinking
5.	Coordinating with others	5.	Negotiation
6.	Emotional intelligence	6	Quality control
7.	Judgment and decision-making	7.	Service orientation
8.	Service orientation	8.	Judgment and decision-making
9.	Negotiation	9.	Active listening
10.	Cognitive flexibility	10.	Creativity

Iceland on the threshold of the Fourth Industrial Revolution: technology and innovation

There is no single answer to the question of how a nation can gain a foothold in 4IR. Public policy, sound infrastructure, equality, a strong economy, effective administration, and education are key factors: Other capabilities — such as harnessing new knowledge and technology, knowledge creation, and transfer of technology and knowledge — are also important in a digital economy characterised by great speed and rapid renewal. A key factor is to avoid approaching technological changes in a way that leaves the society watching technological advances from the sidelines, and instead to adapt technology to society's needs.

Icelandic society is relatively receptive to new technology. This can be seen, among other things, in the World Economic Forum report on general competitiveness, which attempts to assess how successfully various nations have adopted technologies. A large number of other international appraisals point in the same direction. The WEF report, which is based on data from the World Bank, confirms Iceland's success in adopting new technology, ranking it 10th in a field of 140 countries[25] The technologies discussed in the report — such as mobile network coverage and internet connectedness — are part of 3IR, which is the foundation on which the next steps into 4IR will be taken. Indicators like these suggest that Iceland is well positioned in comparison with other countries as regards several fundamental aspects of the information revolution, which makes it easier to take the next steps towards capitalising on the technology. As Figure 15 illustrates, much of Iceland's technological infrastructure is at a level comparable to that in other Nordic countries, all of which rank highly in this area. Furthermore, the Nordic countries are willing to work together towards joint implementation of new technology. In fact, the Nordic prime ministers recently issued a joint press release announcing a cooperative effort to lead the world in 5G mobile network development, which entails enormous opportunities.[26]

Innovation, the economy's ability to adopt new technology, research and development, and scientific institutions are also important in an assessment of Iceland's possibilities. Although it is always difficult to evaluate such factors in order to generate a cross-country comparison, it is also done in international appraisals. Comparing Iceland with

Figure 15 / Internet and mobile phone use in the Nordic countries — Source: World Bank.

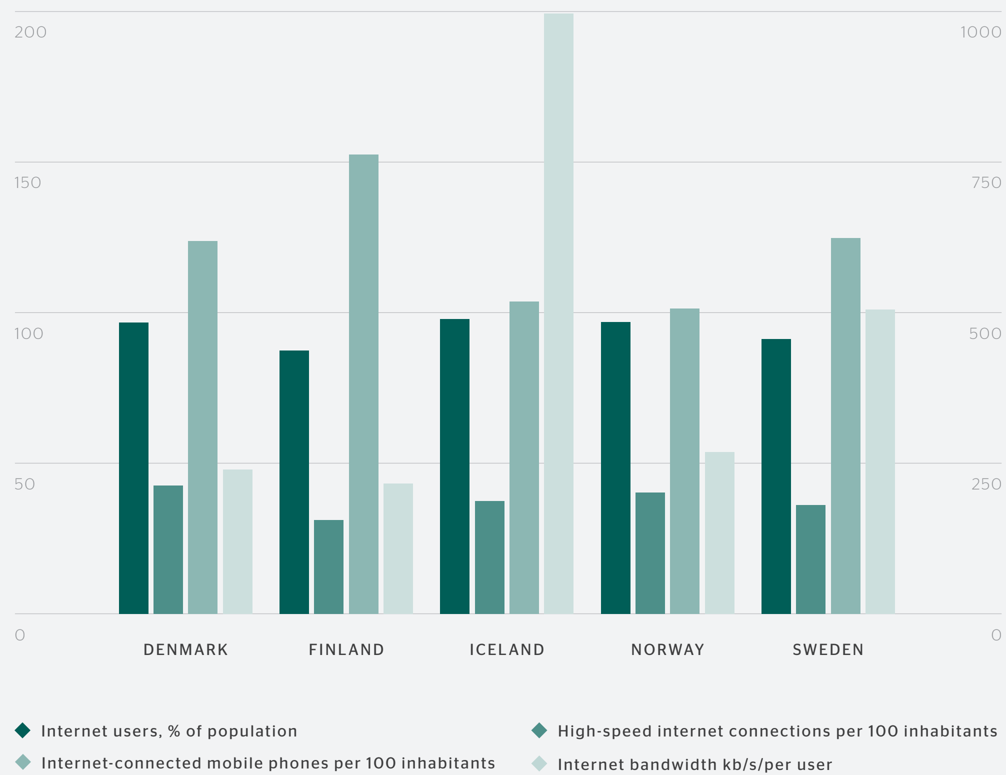
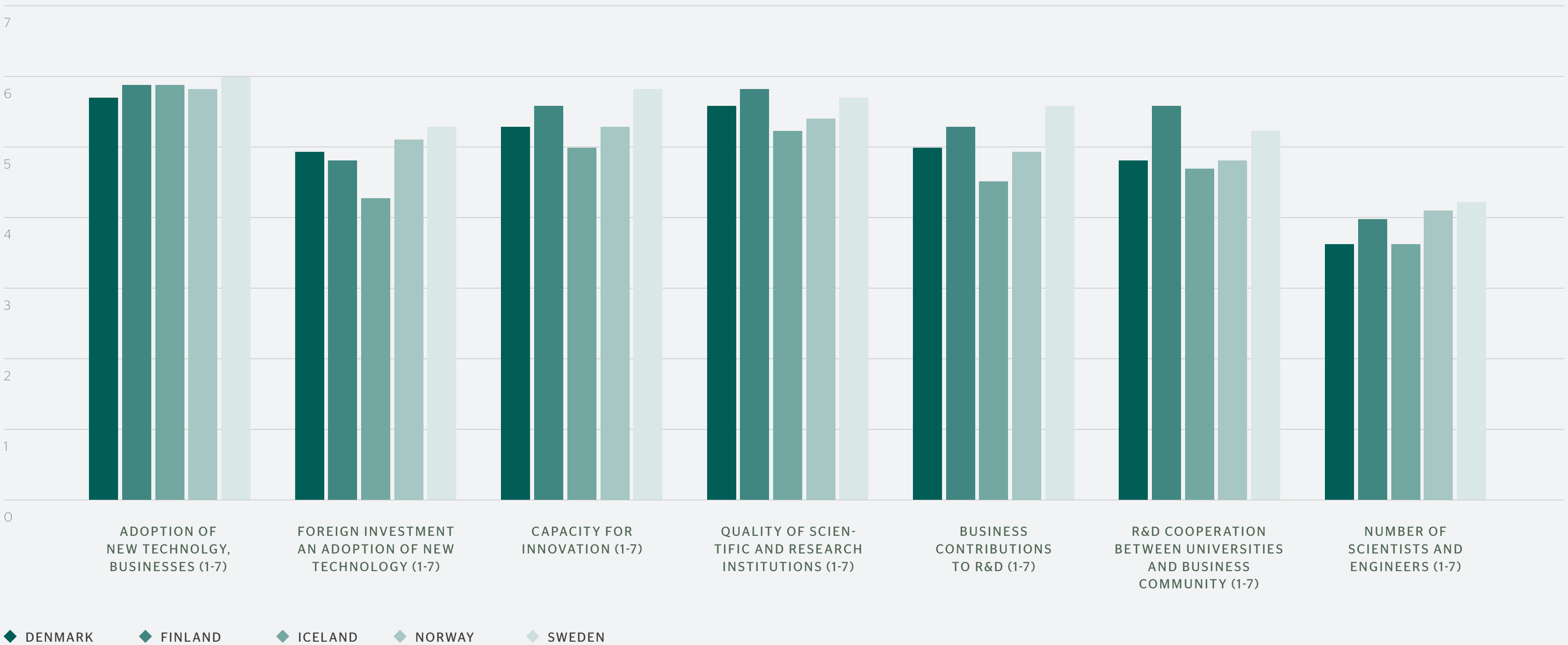


Figure 16 / The Nordic countries: innovation and technology — Source: World Bank.



its Nordic neighbours as regards these factors shows clearly that we have room for improvement, as Figure 16 indicates.

The Government has set targets for improvement in these areas. For instance, contributions to research and development have been increased in recent years. R&D contributions totalled 1.76% of GDP in 2013 but had risen to 2.13% of GDP by 2017. The EU average was 2% in 2016, and the Nordic countries are well above it. Sweden, for example, ranks first in the EU in terms of R&D support, with 3.25% of GDP, followed by Denmark (2.87%), Finland (2.75%), and Norway (2.03%).

Iceland's goal is to devote 3% of GDP to R&D by 2024, a substantial increase.[27] The Federation of Icelandic Industries has estimated that in order to meet this target, contributions must increase by about ISK 40bn per year.[28] What is interesting about the increase in contributions to R&D over the past several years is the share from the business community: over 60% of total contributions. Although the increase shows firms' growing interest in investing in knowledge creation and new technology, it is also the result of successful Government measures. The Government has supported this shift by granting concessions for R&D expense since Parliament passed legislation for the purpose (Act no. 152/2009). With this Act in place, firms can receive reimbursements of R&D-related expense, upon satisfying specified conditions (Figure 17).

In 2018, Parliament passed amending legislation (Act no. 134/2018) significantly raising the ceiling on reimbursements, so that firms' R&D spending can be expected to increase. This is a welcome move, as it enables the business community to use technological changes as a springboard for innovation. On the other hand, it is necessary to examine how contributions from the Government and education institutions increase in line with companies' contributions.[29]

In terms of more clearly delineated factors such as the number of scientists and engineers, Iceland lags behind Finland, Norway, and Sweden. Furthermore, there is a foreseeable need for tech-educated workers. There has been a dire shortage of computer scientists and engineers in Europe and the US in the past two decades. In the fields of automation and AI this trend will clearly accelerate,, although the need for tech-educated people in general is not likely to subside. To an extent, Iceland's small population works against it as regards its supply of highly specialised personnel. Such weaknesses can be compensated for, however, by luring people with certain kinds of specialised knowledge to the country.

In terms of the most abstract aspects of 4IR, Iceland stands roughly on a par with the rest of the Nordic region: There is a shortage of people with first-hand knowledge and experience of AI technology, including its most common forms. Actually, the only university in the Nordic region with an AI centre is Reykjavík University (RU), which established its Center for Analysis and Design of Intelligent Agents (CADIA) in 2005. In addition, the Icelandic Institute for Intelligent Machines (IIIM) has been in operation since 2010, in close cooperation with RU. IIIM's primary objective is to increase the speed and quality of knowledge transfer from baseline research to practical applications in automation and AI. Germany has substantial experience of this, as its AI centre, the German Research Centre for Artificial Intelligence (Deutsches Forschungszentrum für Künstliche Intelligenz – DFKI), which has the same objectives and type of operations, celebrated its 30th anniversary in 2018. Institutions as such — including Fraunhofer in Germany, SINTEF and Simula in Norway, and the Interactive Institute in Sweden, to name a few — play important roles in enhancing the flexibility of the R&D environment in their respective countries.

Figure 17 Companies receiving R&D concessions — Source: Directorate of Internal Revenue,

OPERATIONAL YEAR	NUMBER OF COMPANIES	DEDUCTION FOR R&D EXPENSE (ISK M)	PORTION REIMBURSED (ISK M)	PORTION OFFSET AGAINST INCOME TAX LIABILITY (ISK M)	NUMBER OF FIRMS; SUPPORT SUBJECT TO MAXIMUM
2010	61	635,000,000	572,000,000	63,000,000	9
2011	87	926,000,000	854,000,000	71,000,000	17
2012	101	1,085,000,000	937,000,000	148,000,000	22
2013	117	1,244,000,000	1,083,000,000	162,000,000	24
2014	117	1,285,000,000	1,109,000,000	176,000,000	28
2015	126	1,575,000,000	1,314,000,000	261,000,000	39
2016	143	2,797,000,000	2,359,000,000	438,000,000	10
2017	144	2,939,000,000	2,315,000,000	624,000,000	11

Iceland's opportunities as a resource- and knowledge-based economy

4IR brings with it enormous opportunities for Icelandic society. The country has a highly educated population, and emphasis on innovation is growing steadily. It is small, and cooperation among different types of participants is therefore easier than in many larger countries. Icelanders have the opportunity to be at the forefront in adopting technological innovations, and we have already shown our ability to lead in this area.

When it comes to practical application of tech solutions, Iceland is in many areas a recipient; i.e., development takes place abroad, and Icelanders adapt to it. For instance, it is likely that companies in retail and wholesale trade will keep abreast of global tech developments and adapt their operations accordingly. Developments in telephones, computers, and other equipment that will make major advances during 4IR will also come from abroad.

Furthermore, Iceland possesses two important natural resources — fish and energy — which to an increasing extent have been harnessed using high-tech methods. This applies to development and production within the innovation sector, but also to the economy more generally.

Resource utilisation is a pillar of the Icelandic economy. With increased emphasis on innovation and technological advances, the opportunity develops for a mixed economy based on both conventional resource utilisation and innovation, giving Iceland the advantage over many other countries.

In 2012, consulting firm McKinsey published a report entitled *Charting a Growth Path for Iceland*,[30] which contains important observations on Iceland's potential policy path for the future. The report discusses, among other things, future opportunities for the Icelandic economy, including the need to boost value creation in export sectors in order to sustain general prosperity. The authors of the report assert that Iceland needs to double its export revenues by 2030 to bring output growth up to 4%, which must be deemed a handsome growth rate. They conclude that in order to achieve this objective, new export sectors must be created, as the potential economic benefits from traditional sectors such as tourism, energy-intensive industry, and fishing industry are limited.

Value creation will not be driven by these sectors in the future because a slowdown in tourism growth is foreseeable after the recent boom and fishing and energy-intensive industry are both subject to capacity constraints because they depend on finite resources. As a result, these pillars of the Icelandic economy cannot be relied upon for increased export revenues. Sustainability concerns place certain limitations on resource-based sectors; for instance, fishing quotas cannot be increased to any marked degree without depleting fish stocks. The Government's Master Plan and concerns about sustainable resource utilisation place limitations on energy harnessing.

McKinsey's split between resource-based sectors, on the one hand, and innovation and knowledge, on the other, is well known. However, Klaus Schwab points out in his discussion of 4IR that economies that are able to mix ingenuity and resource utilisation successfully should do well. Iceland is not mentioned as an example of this, but it is obvious that opportunities lie there. By capitalising on technology and human ingenuity, we can extract more from our resource-based economy than is assumed in the McKinsey report. We need not sacrifice sustainability in energy utilisation and fishing in order to increase Iceland's export values: the concept of sustainability is a wellspring of more value creation.

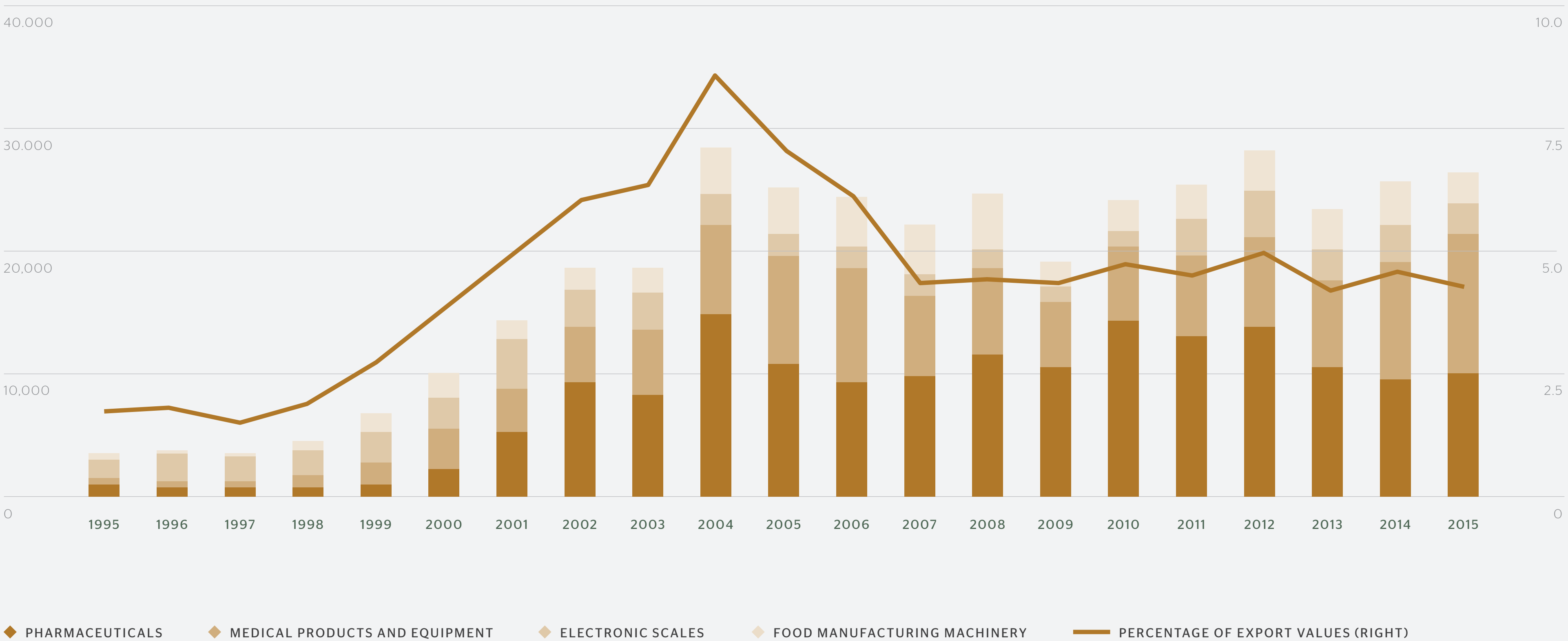
Iceland has vast opportunities to be a producer rather than a recipient of 4IR-related tech solutions in the fishing industry, provided that the knowledge and education are in place within the country. The Icelandic Ocean Cluster has pointed out that five domestic high-tech companies (Marel, 3XSkaginn, Hampiðjan, Valka, and Curio) generate ISK 40bn in turnover from solutions for the fishing industry. Another 60 firms generate ISK 30bn in turnover. This sector as a whole generates twice as much turnover now as it did at the beginning of the decade. Furthermore, Marel is by far the biggest company on Iceland's stock exchange, as it has evolved from developing high-tech solutions for fisheries to developing similar solutions for the food industry more broadly. Fishing companies have also invested heavily in recent years, thereby supporting innovation companies' operating environment. Iceland's fishing sector has a long history, and a strong institutional environment supports the Marine Research Institute, the Directorate of Fisheries, and the Icelandic Coast Guard. Moreover, extensive research has been carried out, and applied science has been the foundation for the development of knowledge in the fishing industry, through institutions such as Matís.[31]

Success in solving problems relating to marine resource utilisation based on tech solutions can also create opportunities in other sectors, such as the food industry. For example, developing high-tech solutions such as using AI to sort and process marine produce can lead to tech innovations in other types of food production. By the same token, firms and workers engaged in manufacturing high-tech equipment for companies become highly specialised in specific areas, which boosts the possibilities for innovation elsewhere. Metalworkers who develop high-tech equipment for filleting machines need to have a particular set of skills that could be of use in sectors other than fish processing.

In the energy industry, there is also the possibility of developing high-tech solutions based on Iceland's experience in energy harnessing. Iceland has emphasised sustainable energy utilisation, and this focus has given it a unique position in the global community. One of the challenges of the 21st century in the fight against climate change is to use different energy sources for transportation — by switching to electric vehicles, for instance. The Government's action plan on energy switching assumes that the share of renewable energy in transportation will be 40% by 2030, up from 6% in 2016. The Government has also adopted a policy prohibiting new registration of fossil fuel-driven cars by 2030. In order to achieve these objectives, focus has been on economic incentives and infrastructure development, which are both important, but technological development is also vital. In the 20th century, the development of Iceland's energy system entailed building large power plants and a centralised distribution network. We have strong energy companies such as Landsvirkjun, a transmission system overseen by Landsnet, a sophisticated legal framework, and institutions such as the National Energy Authority. Energy distribution and processing could be disrupted with reduced electricity production costs, new ways to generate electricity (wind power, ocean energy), increased resource capacity (e.g., with deep drilling), and increased automation of distribution systems. With AI system development, big data use, and the Internet of Things, it is possible to create small distribution utilities to meet the needs of a society that uses electricity increasingly as an energy source.

But the opportunities are not limited to previous success, although one means of gaining a competitive advantage is to use mature industries as a springboard in one way or another. Iceland has made great strides in health technology, sectors classified as high-tech are expanding, and exports of such products have grown, as Figure 18 shows. They spiked towards the end of the 20th century, and then growth eased during the high-exchange-rate episode before the financial crisis. In 2015, high-tech exports accounted for just over 4% of total exports, broadly the same as in 2007 (Figure 18). But even though high-tech exports have not grown significantly during the post-crisis period, exports of computer and software services have skyrocketed. This is just a taste of what lies ahead with 4IR, where value creation lies more and more in services (ingenuity/brain power) than in goods manufacture. The innovation environment has grown by leaps and bounds in the past two decades, but there is room for much more, particularly as regards 4IR-related knowledge and technology.

Figure 18 / Statistics Iceland (trade reports).



Icelanders are therefore no strangers to automation, and there are dozens of examples to prove that they can identify opportunities and exploit the possibilities that lie in new knowledge, methods, and technologies. These technologies come not only from abroad: there are also numerous examples of knowledge creation in Iceland, which has grown substantially as a share of the economy in the past 50 years. As the role of digital technology in the evolution of knowledge, manufacturing, and communication grows, Icelanders will have more opportunities to innovate and export their ideas. The cost of delivering digital products is often lower than for any other goods and services delivery, and growth is not subject to resource constraints as in the fishing and energy industries; it depends solely on labour and knowledge. It is here that the uniqueness of 4IR comes clearly to the fore: automation makes it possible to remove some of the growth constraints relating to labour, not only by boosting productivity, filling gaps, and enhancing the quality of work done by human beings, but also by using AI to carry out tasks that no humans are willing to do. But without proficiency in 4IR fundamentals, it is all but a given that Iceland will lag behind other countries. As a result, this revolution probably makes more demands of Icelanders than its predecessors did.

It is also important to consider factors other than value creation and productivity growth when discussing technological advances. Technology can be used to make life easier and enhance well-being. For instance, there has been widespread discussion of employee burnout, a term referring to a situation were prolonged strain has a severely negative impact on people's mental health. Demands are being made for increased flexibility in the work environment. As a result, it is worth considering whether people can boost their quality of life by reducing their working hours so as to spend more time with friends and family or to pursue personal interests, or whether it is possible to help people switch jobs during their working career by enabling them to take a break before beginning the new job. Technology can also improve people's facilities at work and enhance their wellbeing in the workplace. It is vital to consider such goals when discussing labour market disruption as a result of technological change.

Ethics and technological development

Technological advances bring with them a wide range of ethical issues that must be addressed. Increased technology tests ethical norms that are considered important in protecting people's freedom and autonomy. A clear example of this is the massive collection of personal data on social media and the internet. Data collection is not a new phenomenon, but with recent tech developments it has grown exponentially in scope. For example, experts from IBM estimate that 90% of the digital data in existence today are no more than five years old.[32] Every day, more is added to this vast ocean of data. It is obvious, of course, that the scale and scope of this information is such that not even an army could oversee it all. On the other hand, it is possible to use AI to process the information so that it can be used to monitor people's behaviour and activities. And because computer use and information sharing on the internet and social media are so widespread in our societies, we must take step to protect individuals' personal freedom. The advent of new personal data protection regulations in the EU and the passage of data protection legislation by Iceland's Parliament (Act no. 90/2018) were important steps towards addressing this issue. Act no. 90/2018 includes provisions on consent to the use of personal data, individuals' right to know what data about them are available, and the right to be forgotten. Article 22 contains a provision explicitly dealing with the use of AI in data processing. The provision is intended to guarantee individuals' rights, so that decisions pertaining to important interests are not taken solely on the basis of automated data processing. But even though Act no. 90/2018 provides for a significant improvement in human rights, the collection of information and the use of that information to influence individuals remains a significant cause for concern. It is not a given that individuals fully realise what is entailed when they authorise companies to use information about them. An example of this is when an individual installs an app in their mobile phone and consents to detailed terms of use that include authorising access to the device's microphone, thereby enabling surveillance of their telephone conversations. Collecting personal data not only poses risks to individuals' freedom and autonomy, but it also gives rise to questions about data security and the status of democracy. During the 2016 US presidential election campaign, for instance, the company Cambridge Analytica used data from social media to influence voters. It is estimated that information on more than 80 million social media users was used for this purpose. In the years to come, societies must grapple with misuse of personal data and the risks accompanying inadequate data security. And even though the new personal data protection legislation is an important improvement, much more explicit restrictions must be placed on information gathering.

There are also major ethical issues centring on artificially intelligent devices. One way in which 4IR is unlike its predecessors is that even though automation was a facet of previous industrial revolutions, the fourth entails automation controlled by intelligent machines. With decisions being made by machines instead of human beings, questions of responsibility and accountability arise. One question is whether robots are ethically or morally responsible for their actions. For example, if a robot makes a wrong decision, is the robot responsible for it, and how is that responsibility identified? The problem with this is that even though robots may possess artificial intelligence, they are not ethical beings in the sense that they do not possess common sense. In the field of ethics, human common sense and moral rules are closely related, and our ideas about human rights, human dignity, autonomy, freedom, commitments, and responsibility are based on that relationship. If a computer makes a decision on a matter involving significant interests of people, and the decision cannot stand up to ethical scrutiny, who is then responsible for it? Closely linked to this problem is the question of how to program computers to make decisions on issues involving conflicting ethical rules, or when conditions are such that all possible options could have severe repercussions. Let us say, for example, that a self-driving car is driving straight at five individuals but could avoid colliding with them by swerving and hitting only one individual. Is it right to program the car to swerve?

Technological changes also require more precise definitions of concepts. A well-known example of this is how medical advances resulted in the passage of special legislation in Iceland on the determination of death (Act no. 15/1991). Until that time, it had been customary to define death as occurring when breathing and heartbeat ceased, but medical advances made this accepted definition of death obsolete, as it had become possible to keep people alive with respirators and lengthen their lives with organ transplants. Under the definition in the new Act, an individual was considered dead if medical testing showed that brain activity had ceased, even if the heart and lungs continued to function with the assistance of machinery. The health sciences will continue to take great strides forward in coming decades as a result of technological changes. In a 2016 survey conducted by British weekly magazine The *Economist*, 45% of respondents expected the benefits of 4IR to be greatest within the healthcare system. And it is true that the changes there could be enormous: AI has been used to diagnose various illnesses, and significant advances have taken place in diagnostic imaging using AI. As developments continue, more information will become available, which will make the machines better able to analyse and use the information. A vast amount of information has become available with advances in genetics, and the cost of mapping the human genome has plummeted. This has made it possible to develop new drugs and diagnose illnesses with greater accuracy. So-called CRISPR gene editing has enormous implications for the practical application of genetic technology. But it will test our human understanding and the norms we have set for ourselves in the health sciences. For example, advances in genetics will probably bring greater success in treating difficult hereditary diseases. However, increased exploitation of genetic technology could open the door to more controversial changes, such as in eye or hair colour, muscular strength, intelligence, or personal appearance. Perhaps this technology will be available only to the wealthy, thereby creating a gap between those with the financial strength to buy genetic enhancements and those who cannot afford them.

Equality and technological changes

Disruption caused by technological advances can surface in rising social inequality, partly because changes in jobs can cause certain groups to lose income. Increased productivity as a result of technological advances can also generate substantially greater benefits for some sectors than for others, perhaps even delivering higher income to individuals with certain skills.

These issues must be examined in light of the changes that have already taken place. Since 1980, many jobs have moved from industrialised countries to developing countries, as companies have found it more profitable to move the jobs than to adopt technology or keep jobs in their home country, simply because of the low cost of labour in developing countries. On the other hand, jobs requiring specialised skills have increased in number, and the wages paid for those jobs have risen. There is also stiff competition for workers with such skills. At the same time, many middle-income jobs have been eliminated because of technological developments and the implications of 3IR. This “disappearance of the middle class” has drawn considerable attention and has been studied closely in both Europe and the US. It is frequently linked with the geopolitical turmoil of recent years and the rise of nationalism on both sides of the Atlantic. A large international survey carried out by McKinsey showed that in 25 industrialised countries, incomes had stagnated or declined for 65-70% of households during the period 2005-2014.33 Developments in Iceland have been somewhat different. Over a longer period (2000-2017), disposable income has risen in all income deciles. Furthermore, disposable income (i.e., after tax and benefits payments) net of financial income has risen proportionally the most in the lowest decile.[34]

Inequality will occur not only because of wage distribution but also because of the distribution of capital and returns to wage-earners and owners of capital. Wages have not kept pace with productivity since about 1970 in industrialised countries and about 1990 in developing countries.[35] Many fear that instead of being divided more or less equally, with everyone receiving a small slice of the pie, wealth will be increasingly concentrated in fewer and fewer hands.[36] This already strongly affects household income distribution, not least because wages generally account for a larger share of income among those lower on the income distribution scale, where the impact is proportionally greater. There is also the risk that this trend will continue to accelerate because of the nature of competition in the new technological sectors, where there seems to be room for only a few winners – in the current market environment, at any rate. This can be seen, for example, in social media and online shopping, where the value to users of a company's goods grows in line with user numbers, so that the competitive position of the company concerned improves as the company grows. International trade has the same characteristics. Furthermore, tech innovations often enjoy temporary patent protection, and it is also worth noting that the development of AI is based in large part on "training" the computer. The greater the volume of available data for use in training computers, the better. Clearly, this can amplify the competitive advantage of those that entered the market earlier and are further advanced, and can therefore rely on more data and a longer operational history. All of this could result the emergence of in a few, extremely strong companies in the marketplace. If this trend continues, it could widen the gap between the wealthiest and the poorest, either at the global level or within individual countries.

This applies not only to companies but also to entire countries. The US and China are now competing for world leadership in AI, with investments that will give them the edge (and have already done so) in the development of technology that could be a major determinant of the future balance of power. To be sure, these giants are competing in an entirely different arena than small countries like Iceland, but their determination to take the lead is nevertheless a strong indication of the potential importance of such investment. This is mainly because of the multiplier effect that access to technology can have, as has been explained in this report.

Although the Government and other social partners can affect how rapidly tech innovations are implemented, we know that nothing is going to stop such changes, particularly in a small and open economy like Iceland.

We also know that these changes will cause temporary unemployment among certain groups in society, as well as causing shifts between sectors and occupations. The section on the labour market discusses which groups will probably be most strongly affected by automation of human brain power. The distribution of wealth and resources will change. As a result, the Government has many roles to play in supporting those most profoundly affected by technological changes, and in ensuring that the benefits brought by those changes are distributed fairly.

Artificial intelligence and diversity

The labour market is still highly segregated by gender, and there are many sectors that could be considered almost the sole province of either women or men. That being the case, it is obvious that if the adoption of AI affects one sector more than others, it could affect one gender more than the other. In many countries, it is likely that technological advances in factories will affect women more than men: in Asia, for instance, where the preponderance of clothing industry workers are women. The situation in Iceland is different than in many other countries, in that the labour participation rate among women is high. Furthermore, the composition of the labour market in Iceland is such that women are less likely to be affected by automation. All of these things matter, particularly in any consideration of policy measures to assist groups disproportionately affected by automation.

In examining tech advances, it is also important to consider who shapes the technology, not merely what impact automation has on jobs. This is particularly the case with 4IR, which centres on AI utilisation. Who programs the algorithms that shape AI? There is particularly noticeable gender disparity in sectors such as computers and IT, which have the strongest impact on developments in AI. In the US, women account for only 24% of the labour force in technology sectors. In Iceland, they are even more underrepresented, at between 10% and 20% of the tech labour force.[37] This is highly important in discussions of adopting new technology. Technology sectors have a lasting impact on our entire environment, whether in society (e.g., through social media) or in the labour market (through software, media, and services).

The problem is that if the group of people who shape a technology such as AI is a homogeneous one, that homogeneity could skew AI "thought processes". For instance, the demarcation within the technology of what is considered normal and what is branded a deviation could become entrenched, thereby reflecting a given power structure in society and solidifying it further. AI should not lead to the exclusion of societal groups, but this could happen even if those who develop the technology do not intend it. Furthermore, homogeneity among groups involved in AI development could reinforce certain views and values, thereby promoting their acceptance.

Hidden prejudices within a society can mean that when an artificially intelligent device gathers substantial information about marginalised groups, the device may adopt the same bigoted attitudes. A simple hypothetical example is a computer that is tasked with reading millions of news articles. The computer is taught to recognise words that imply negative and positive judgments of people. The computer also analyses other factors such as gender, nationality, age, and so forth. Let us assume that in this society there is prejudice against young people of a particular nationality. As a result, news articles appear regularly about violations of the law by these people, although it is not mentioned when people from other societal groups commit the same types of violations. If news reports are distorted in this way and the development of AI is based on those reports, the AI will be distorted in the same way.

Technological developments are not ethically neutral; instead, ethical norms must be borne in mind during the development process and when considering what limits to place on the technology. Because development of AI centres in part on simulating, standardising, and improving human thought processes, it is particularly important to consider the ethical dimension of this technological revolution. It should therefore be the goal of government authorities the world over to ensure that a broader range of societal groups are involved in the development of artificial intelligence.

References

1. Technologies and methods designed to expedite processes – such as the production of goods, energy, and food – can lead to a cycle of constantly increasing speed if they lead to improvements in the technologies and methods themselves, as when computers are used to design and manufacture better computers. AI systems are software, and their production is therefore dependent on software development methods: if it were possible to apply AI to software development, it would be possible to envision a cycle where intelligent software manufactures even more intelligent software – a seemingly endless process. The "multiplier effect" generally refers to use of the technology in many areas, so that it functions as a multiplier on the factors being measured..

2. The railroad networks that revolutionised transportation in many countries never saw the light of day in Iceland, in spite of lofty ideas about the possibilities they entailed. This story is interesting in terms of the paths technological development takes, and there are important lessons to be learned from it. It can be risky to generalise about future technological developments. Technologies that appear to gain a foothold in many other countries may not become established here, and it can be difficult to forecast about technological developments during the middle of a tech revolution. There can be many reasons why capitalising on technology is not easy.

3. The term *Fourth Industrial Revolution* gained traction at the WEF's 2016 annual meeting in Davos, when it was introduced as an umbrella term for a large number of recent tech innovations that were the main item on the agenda of the meeting. There were discussions of various aspects of 4IR, the impact – good and bad – it would have, and how to master it.

4. Schwab, Klaus, *The Fourth Industrial Revolution*. Penguin, UK, 2016. 14–25.

5. This technology is discussed in the following report from the University of Manchester: https://www.graphene.manchester.ac.uk/learn/applications/

6. G.E. Moore (1965), "Cramming more components onto integrated circuits", Electronics, 38(8). Moore originally forecast that transistors would double each year, but in 1975 he revised his "principle" to a doubling every 18 months.

7. Anna Ólafsdóttir Björnsson (2018) Tölvuvæðing í hálfa öld: Upplýsingatækni á Íslandi 1964–2018, Skýrslutæknifélag Íslands. [A Half-Century of Computerisation: Information Technology in Iceland 1964–2018, The Icelandic Society for Information Processing (now Clouds)]. pp. 60–61.

8. See the report from the Icelandic Institute for Intelligent Machines, *Vísindatæknilegur grunnur 4. iðnbyltingarinnar [The Scientific/Technological Foundations of the Fourth Industrial Revolution],* Þórisson and Þorsteinsson (forthcoming).

9. See the report from the WEF's 2016 Annual Meeting: Mastering the Fourth Industrial Revolution. http://www3.weforum.org/docs/WEF_AM16_Report.pdf

10. Frey & Osborne. (2013). "The Future of Employment: How Susceptible are Jobs to Computerisation?" https://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf

11. *McKinsey Global Institute (2017).* A Future That Works: Automation, Employment, and Productivity. McKinsey&Company. McKinsey's analysis is based on data from the US statistical bureau. The findings have been adapted to reflect local conditions in 45 countries.

12. The Programme for the International Assessment of Adult Competencies (PIAAC) is a survey carried out by the OECD. It measures adults' skills in literacy, numeracy (mathematics), and problem-solving with IT assistance. At present, 32 countries participate in the survey.

13. Nedelkoska, L. and G. Quintini (2018), "Automation, skills use and training", OECD Social, Employment and Migration Working Papers, No. 202, OECD Publishing, Paris.

14. Use of terms like "thought" in this context represents a significant simplification, as modern artificial intelligence bears little resemblance to thought as we know it, just as automation of "physical strength" with motors bears little resemblance to muscles.

15. For a detailed discussion, see Acemoglu, D., & Autor, D. (2011). "Skills, tasks and technologies: Implications for employment and earnings. Handbook of labor economics", (Vol. 4, pp. 1043–1171). Elsevier.

16. The methodology used in the OECD study is described more fully in Nedelkoska, L. and G. Quintini (2018), pp. 40–62.

17. The probability was examined across all member countries and using a smaller sample of countries most closely resembling Iceland: the Nordic countries, the Netherlands, and the UK. There was no decisive difference in the results from the two samples, and the results published here are based on the average for all member countries.

18. For further information, see Statistics Iceland's sectoral classifications and definitions. According to them, manufacturing entails "physical or chemical transformation of material, chemicals, or units so as to generate new products, although this definition is not a universal criterion for manufacturing (see the comment below on waste processing). The manufactured good is produced using products from agriculture, forestry, fishing, mining, or other processing of raw materials from the Earth, as well as products of other manufacturing activity. If a major change, renewal, or reconstruction of goods takes place, it is usually considered manufacturing." For further information, see: https://hagstofa.is/utgafur/nanar-um-utgafu?id=54698

19. See Icelandic Federation of Labour (2018). [in Icelandic] The Icelandic Labour Market. https://www.asi.is/media/314075/ny-vinnumarkadsskyrsla-2018.pdf

20. The International Standard Classification of Occupations (ISCO-08) is, as the name implies, an international standard used to classify jobs.

21. Burning Glass Technologies (2019). *The Hybrid Job Economy: How New Skills Are Rewriting the DNA of the Job Market.*

22. In mid-2018, a group of experts submitted recommendations to the Minister of Social Affairs and Equal Rights on how such a forecast might be carried out. At the same time, the University of Iceland Institute of Economic Studies introduced a new analysis of the Icelandic labour market, the first of its kind. It has been pointed out that a shortage of data is the only reason Icelanders have lagged behind neighbouring countries in formulating a comprehensive strategy in this area. If the Minister's response to these reports is any indication, there is reason to hope this will be remedied sooner rather than later. (Source [in Icelandic]: *Mannafla- og færnispár á íslenskum vinnumarkaði [Personnel and skills forecast for the Icelandic labour market].* News release published on the Government Offices of Iceland website, 26 June 2018).

23. The WEF's observations can be found at https://www.weforum.org/agenda/2016/01/the-10-skills-you-need-to-thrive-in-the-fourth-industrial-revolution/

24. *Formulation of Iceland's educational strategy through 2030 [in Icelandic].* Press release on the Government Offices website 9 August 2018 https://www.stjornarradid.is/efst-a-baugi/frettir/stok-frett/2018/08/09/Motun-menntastefnu-Islands-til-arsins-2030-fundarod-i-haust/

25. *The Global Competitiveness Report 2017–2018 p. 147* http://www3.weforum.org/docs/GCR2017-2018/05FullReport/TheGlobalCompetitivenessReport2017–2018.pdf

26. The Nordic prime ministers' press release can be found here: https://www.norden.org/en/news/nordic-prime-minsters-call-best-5g-world

27. *Stefna og aðgerðaáætlun Vísinda- og tækniráðs 2017–2019 [in Icelandic: Science and Technology Council: Strategy and Action Plan],* p. 7. https://www.stjornarradid.is/lisalib/getfile.aspx?itemid=7997a35e-54d8-11e7-9410-005056bc4d74

28. Ísland í fremstu röð (2018) [in Icelandic: Iceland in the front ranks]. Federation of Icelandic Industries, p. 55.

29. The Government is formulating an innovation strategy for Iceland, which is to be submitted on 1 May 2019. (Source: Press release on the Government Offices website, dated 21 September 2018 https://www.stjornarradid.is/efst-a-baugi/frettir/stok-frett/2018/09/21/Styrihopur-um-motun-nyskopunarstefnu-fyrir-Island/)

30. *Charting a Growth Path for Iceland* (2012). McKinsey Scandivia https://www.stjornarradid.is/media/forsaetisraduneyti-media/media/Skyrslur/charting-a-growth-path-for-iceland-2012.pdf

31. *Tæknifyrirtækin vaxa hraðast í sjávarklasanum [in Icelandic: Tech companies grow fastest in the Ocean Cluster]*, March 2018: http://www.sjavarklasinn.is/wp-content/uploads/2018/03/Tæknifyrirtækin-vaxa-hraðast-%C3%AD-sjávarklasanum.pdf

32. See the report from the Royal Society: *Machine learning: the power and promise of computers that learn by example*: https://royalsociety.org/~/media/policy/projects/machine-learning/publications/machine-learning-introduction.pdf

33. McKinsey Global (2016). Poorer Than Their Parents? Flat or Falling Incomes in Advanced Economies. https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Employment%20and%20Growth/Poorer%20than%20their%20parents%20A%20new%20perspective%20on%20income%20inequality/MGI-Income%20-Inequality-Executive-summary-July-2016.ashx

34. Axel Hall et al. (2019). Endurskoðun tekjuskatts og bótakerfa hjá einstaklingum og fjölskyldum [in Icelandic: Review of income tax and benefits systems for individuals and families]. Ministry of Finance and Economic Affairs, pp. 23-24.

35. Karabarbounis, Loukas, and Brent Neiman, 2014, “The global decline of the labor share”, *The Quarterly Journal of Economics*, Vol. 129, No. 1, pp. 61–103.

36. Berg, Andrew, Edward F. Buffie, and Luis-Felipe Zanna. “Should we fear the robot revolution? (The correct answer is yes)”. *Journal of Monetary Economics 97* (2018): 117–148.

37. Lilja Dögg Jónsdóttir (2018). *Vísbending* magazine.