Ten more technologies which could change our lives

IN-DEPTH ANALYSIS

EPRS | European Parliamentary Research Service
Author: Christian Kurrer with James Tarlton
Scientific Foresight Unit (STOA)
PE 598.626

EN

Ten more technologies which could change our lives

In-depth Analysis

July 2017

PE 598.626

AUTHORS

Edited by Christian Kurrer with James Tarlton (Scientific Foresight Unit (STOA), Directorate-General for Parliamentary Research Services (DG EPRS), European Parliament)

Main contributors:

Andrés Garcia, *University Castilla La Mancha, Spain* (Chapter 7)
Mihalis Kritikos, Scientific Foresight Unit (STOA) (Chapters 9 and 10)
Christian Kurrer, Scientific Foresight Unit (STOA) (Chapters 1, 2, 4 and 8)
Laura Panades, *Truman Bodden Law School, Cayman Islands, affiliated to the University of Liverpool, UK* (Chapter 3)
James Tarlton, Scientific Foresight Unit (STOA) (Chapters 1, 5 and 6)
Lieve Van Woensel, Scientific Foresight Unit (STOA) (Chapters 5 and 6)

Acknowledgements

The authors would like to thank Gianluca Quaglio (Scientific Foresight Unit (STOA)), Gregor Erbach (Economic Policies Unit, DG EPRS), Lieve Herman and Marc De Loose (Flanders Research Institute for Agriculture, Fisheries and Food - ILVO, Melle, Belgium) for additional input.

LINGUISTIC VERSION

Original: EN
Translations: DE, ES, FR, IT, PL, PT

ABOUT THE PUBLISHER

To contact STOA or to subscribe to its newsletter please write to: STOA@ep.europa.eu
This document is available on the Internet at: http://www.europarl.europa.eu/stoa

Manuscript completed in July 2017 Brussels,

PE 598.626
ISBN: 978-92-846-0700-6
doi:10.2861/36645
QA-01-17-154-EN-N

Table of contents

Introduction

Technological developments and innovations punctuate the history of human civilisation, profoundly impacting the development of modern life. Inventions such as archery revolutionised hunting, with the wheel doing the same for transportation. The arch radically changed construction techniques, the loom revolutionised clothing, and printing transformed the storage and sharing of ideas. The steam engine led to industrial production, followed by the electric motor's democratisation of power. Vaccines and antibiotics profoundly altered health and medicine. The invention of the railway, automobiles, and airplanes revolutionised transport again; and the telephone, mobile communication, and the internet have made it as easy to talk to one another as if we all lived in one global village.

While all of these technologies greatly benefited humankind, they also sometimes brought about unintended negative consequences, which civilisations had to handle. They often disrupted life and social order, causing disarray and harm. Human society needed to learn how to make best use of innovation.

Technological development continues today, at an ever-accelerating pace. It is increasingly important for society and policy-makers to anticipate possible game-changing innovations, to start analysing potential benefits, as well as harmful effects, early on, and to develop a concerted response in order to maximise the good and minimise any damage.

Such anticipatory responses can take several forms: legislation regulating technologies (possibly prohibiting certain uses); public action supporting the development of technologies or facilitating their introduction through norms and regulations; education and outreach efforts to allow society to reap greater benefits; and compensatory measures for those sections of society that stand to lose from new technologies.

The European Union (EU) institutions, along with national institutions in the Member States and a growing array of international and global policy institutions, are a key source of policy-making in the 21st century. EU policies affect not only the lives of over 500 million Europeans, but increasingly also global trends and developments in issues such as climate change, resource efficiency and sustainability, trade, health care, regional conflict resolution, and reduction of poverty.

To work more effectively, the European Parliament often needs to look beyond the short-term political agenda, and search for longer-term developments, proactively launching discussions and developing early public policy approaches.

This proactive role is part of the daily life of the Parliament at many levels, in hearings organised by individual Members and in discussions within political groups or committees. The Science and Technology Options Assessment (STOA) Panel plays a pivotal role in this reflection process. STOA supports the work of parliamentary committees on long-term policy, at their request, with forward-looking studies, and proactively initiates work to identify technological developments that could have a profound societal impact that justifies inclusion on the political agenda.

The European Parliament's Directorate-General for Parliamentary Research Services (DG EPRS) published a study: 'Ten technologies which could change our lives – potential impacts and policy implications', in 2015, with each chapter highlighting a particular technology, its promises and potential negative consequences, and the role that the European Parliament could and should play in shaping these developments. This paper continues this line of reflection, presenting ten additional technologies that increasingly demand policy-makers' attention.

No pretence has been made to rank technological developments in any particular order of importance, impact, or urgency. Instead, the topics have been chosen to reflect the wide range of subjects on which STOA has decided to focus during the Parliament's eighth term.

The aim of this publication is not only to draw attention to these ten particular technologies, but also to promote reflection about other technological developments that might still be at an early stage, but that could, in a similar way, massively impact our lives in the short- or longer-term future.

Approach

For each topic, we briefly present the technological challenges and the solutions that are being developed, the current state of advancement and the likely further path of development. We then look at their possible intended or unintended impact on wider society. In the final section, we then try to identify the particular role that the European Parliament can play, as a supranational policy-making institution, to positively shape these technological shifts.

1. Electric cars

Are we on the verge of switching over to electric cars, and what would be the consequences of this transition for the climate, our health, and the way we live our lives in the future?

© Nerthuz / Shutterstock.com

Over the last century, cars have become an integral part of our society. They offer greater flexibility and speed than alternative modes of transportation, and are affordable for a large proportion of people. Since mass-production of cars began, they have been almost exclusively powered by internal combustion engines (ICEs), which burn fossil fuels such as petrol and diesel to provide the energy required to turn the cars' wheels and perform auxiliary tasks. However, cars are also a major source of CO_2 emissions into the atmosphere, affecting global climate, as well as of nitrogen-oxide (NO_x) and particulate matter (PM) emissions that pollute the air we breathe, especially in urbanised areas. These issues are the main drivers of the renewed interest in using electric power to run our cars.

Potential impacts and developments

Electric cars have several advantages over ICE cars. Besides reducing air pollution and lowering CO_2 emissions (at least if the electricity is not produced from fossil-fuel-fired power plants), electric cars offer a range of additional advantages. They have lower maintenance costs, are quieter and easier to ride, reduce our dependence on imported energy, can positively impact on our international balance of payments, and can even possibly contribute to calming international conflicts regarding natural resources.

Unfortunately, the manufacture of electric cars remains more expensive (and more carbon-intensive) than for ICE cars. At the same time, electric cars offer only a limited range of operation, currently typically in the range of 300 km between charges, and recharging batteries takes more time than refilling the tank with gasoline.

In the face of these challenges, several Member States have introduced subsidies to help establish the market for electric vehicles, helping to ramp up production and sales volumes that will eventually drive down costs. At the same time, intensive efforts are underway to further develop battery technology, in view of producing cheaper, more powerful and more lightweight batteries that would lower the cost of vehicles while extending their range.

While it might be a realistic option that one day we will be able to produce electric cars that match the relatively low cost and long range of current ICE cars, our changing lifestyles and mobility needs might mean that such a scenario would be neither necessary nor desirable. The kind of car we want to drive in the future might be very different from the cars we currently produce.

Today, many people still own a personal car – but typically only one – and therefore they aim to possess a car that will fit all possible driving situations: it should both accelerate quickly when starting from a low speed and be aerodynamic at high speed; it should provide enough seats for the whole family for a weekend trip, and enough space to pick up furniture at large discount stores, and it should come with air conditioning for summer, heated seats for winter, stereo equipment and a big fuel tank for longer trips, as well as start-stop systems for urban stop-and-go traffic. The result is that today's 'multi-purpose' cars are exceedingly heavy and therefore fuel-inefficient. This problem is further accentuated for electric cars, where the batteries often add another 33 % to the weight of the vehicle. Ironically, this means that a large part of the energy stored in the batteries is required simply to accelerate the increasingly heavy battery pack.

However, the younger generation is increasingly moving away from the traditional system of ownership of a single, 'personal', car, towards models of car sharing. Also, as car sharing companies offer their clients a choice of different vehicles, the individual vehicles will not need to be as multipurpose as privately-owned cars. They could instead be more diverse, much lighter and also mostly offer shorter driving ranges, requiring lighter batteries, therefore significantly increasing efficiency.

As urbanites increasingly shift towards car-sharing options, private ownership of cars might gradually fall to only suburbanite families living in private houses that increasingly produce their own electricity with photovoltaic (PV) roof systems. Such PV systems are complemented by battery systems that store the energy produced during the day and make it available in the evening. For such families, having larger battery systems both in their houses and in their cars might become redundant. Instead, maximum efficiency may mean keeping only a minimum number of batteries permanently installed in the car (to cover the needs of daily commutes) and leaving the rest of the batteries at home attached to the PV system, only plugging them into their cars for the occasional longer weekend or holiday trip.

The price of electricity has a major impact on the attractiveness of electric cars. In a worst-case scenario, thousands of electric cars all being recharged at the same time could further strain the electricity grid and render it more unstable, requiring additional investments into our electricity networks. On the other hand, in the context of smart grids, electric cars making use of excess electricity supply by charging at certain times could benefit from particularly low electricity costs and help to stabilise the grid.

Anticipatory policy-making

There is wide consensus that a successful switch to e-mobility will depend on public action, incentives and support programmes. Attention is currently focused on incentivising current car owners to switch to electric vehicles, and building charging infrastructures that allow consumers to use their electric cars almost in the same way as their current ICE cars.

Anticipatory policy-making may better focus instead on promoting the development of cars that we will want to drive in the future, for the new generation that may increasingly rely on car-sharing alternatives. Promoting the development of light-weight electric vehicles for car-sharing services might make more sense than subsidising the development of heavy electric vehicles for private users who want to emulate the performance of their current vehicles.

We should also focus on how e-mobility would best integrate with the way we live in 20 years, when even more private homes will be equipped with PV systems and battery storage systems. Our changes in mobility will furthermore not only be driven by the aim to reduce CO_2 and other pollutant emissions, but also by the increasing congestion caused by private cars in urban areas. If we want to keep our cities liveable in the future, a re-invigoration of public transport solutions may be inevitable. When developing electric vehicles for the future, it may therefore be appropriate to anticipate this development and focus on vehicles that complement rather than compete with public transport offers.

In conclusion, public action to promote e-mobility may be most effective if it is tightly coordinated with parallel efforts to develop new modes of mobility, and new ways to produce and distribute our electricity.

2. Intelligent urban transport systems

How can information technology contribute to alleviating traffic gridlock in our increasingly congested urban areas?

© Fuyu liu / Shutterstock.com

Over 70 % of all Europeans live in cities and as the percentage of Europeans living in cities continues to increase, cities are becoming even more congested. Inhabitants suffer from increasingly poor air quality and more noise, as cities become generally less liveable.

The recent car emissions controversy has drawn considerable attention to the problem of air pollution generated by private car traffic. The row revealed that efforts to reduce air pollution in Europe through stricter emissions regulations are largely ineffective. There is some, justified, expectation that a switch from gasoline to electric vehicles will have a significant impact on pollution levels, but the introduction of electric cars will still take years, and switching to electric vehicles alone will do little to solve the worsening congestion problems.

In recent years, we have therefore seen a renewed interest in the possibilities of intelligent transport system (ITS) solutions.

Potential impacts and developments

Numerous initiatives are under way to investigate how ITS can contribute to making traffic flow smoother and therefore more efficient. Many possibilities arise from the fact that cars are becoming ever more intelligent and increasingly communicate with their immediate environment. Already today, cars can adapt their speeds to the car driving in front, and future interaction with intelligent traffic signals will cut delays and fuel consumption. Cars will be able to book a parking spot at their destination in advance. Currently, satellite navigation systems can optimise routes accounting for the actual traffic situation, but future systems could communicate with each other through a central computer to optimise the overall set of routes that all vehicles should take, avoiding situations where too many drivers want to switch at the same time to the same seemingly faster route around a bottleneck.

All of these technological options would certainly allow more efficient management of current traffic levels. The question is, however, whether this will actually translate into less congestion in urban areas, or whether increases in fluidity will mostly be balanced out by encouraging even more users to commute to work using their personal car.

Allowing more private passenger traffic to reach city centres smoothly would, at the same time, raise the problem of where all these cars should be parked. We would not gain much if traffic became smoother, but parking spaces increasingly difficult to find.

Anticipatory policy-making

Solving traffic gridlock in urban areas might require more than just increasing the traffic flow at individual intersections. It might require a more fundamental re-assessment of how we want to meet our mobility needs in the future, make use of public spaces, and organise our urban lives.

One option could be to aim at an intelligent traffic system giving absolute priority to surface-bound public transport such as buses or trams. Traffic signals along roads employed by public transport could be programmed in such a way that buses would never have to stop for a red light, nor for cars blocking the road. A major drawback of public bus services today is that their effective travelling speed in urban areas rarely exceeds 15 km/h, and that their frequent stops at bus stops mean that they move even slower than private cars.

With ITS, we could drastically change this situation, potentially even doubling the effective travelling speeds of buses, which also means that the same number of buses and drivers could transport twice as many passengers.

In other words, the most effective way to faster, more fuel efficient passenger car traffic might actually be an investment in the attractiveness of public transport. In addition to speed, the price of public transport is also a key aspect influencing individuals' transport choices. Many people find the price of a single ride ticket too expensive for occasional use, or find tariff structures too confusing to understand. Public transport authorities perhaps focus too much effort today in selling and controlling tickets, with ever more high-tech access control systems, rather than actually transporting their passengers. A bus driver who stops at a bus stop for a minute to sell a single-ride ticket for €2, while 60 passengers wait in the back, is a macro-economic nonsense.

If efficient public transport is considered to be a public necessity, we may need to think more fundamentally about who should pay for it, and how. Perhaps one might simply consider switching over to providing public transport for free as a rule, the same way in which we switched over to free public education decades ago. At the same time, we could re-assess whether cities should continue to provide free on-street parking spaces for residents. Charging residents for on-street parking could raise the necessary funds to make public transport free for all. Disincentivising parking of private cars on public roads could also make more public space available for even smoother public transport services. Also, instead of using increasingly sophisticated machines to sell and control tickets for people who travel to town by bus, we could use all of this technical ingenuity to install systems that control and charge motorists who drive to cities in personal cars, providing additional funds to improve public transport.

Furthermore, besides focusing on the technical infrastructure, other options at the user level could make our transport system more intelligent. Daily commuters fill the streets at present, often travelling more or less similar routes in separate cars. ITS systems that would make spontaneous identification of options for ride sharing easier could reduce the need to use individual cars most of the time.

A lot of options exist therefore to make our traffic system more intelligent. Modern information technology offers tremendous opportunities in this field, but we will still need human ingenuity and imagination to harness its full potential.

3. Maglev transportation

Magnetic levitation-based transport might soon enter our lives, providing faster, safer and more energy-efficient journeys. As longer distances can be covered faster and more cleanly, could they change the way in which we choose where to live?

© Bogna / Shutterstock.com

Technology is paving the way for new means of transportation. Some of them are the smart versions of traditional vehicles (e.g. autonomous vehicles). Some were imagined first in the pages of science fiction (e.g. hoverboards). Others are born from innovation (e.g. superconductor trains).

Hoverboards are levitating boards upon which a standing person flies at a close distance from the ground. Today, their first users are getting to grips with hovering across indoor and outdoor spaces. Superconductor trains are able to achieve speeds greater than 500 km/h by eliminating the friction of the train wagons with the railway track. Superconductor trains have begun commercial operations in China and South Korea, and are under construction in Japan. In the EU, plans to implement them have previously been considered in Germany, Italy and the United Kingdom, but only the project in Italy has recently seen renewed interest.

Potential impacts and developments

Magnetic levitation or 'maglev' is the technology behind levitating hoverboards and superconductor trains. It is based on the creation of opposite magnetic fields that repel each other to counteract gravity, thus elevating the magnetised objects off the ground. Maglev is applied in transport modes of all sizes, from individual hoverboards to high-capacity bullet trains.

The hoverboards of today still require special copper floors. Improvements to allow levitation on concrete or water are still underway. The first prototype was presented in 2015, but no further announcements have been made since then.

The first commercial superconductor train runs from Shanghai Pudong International Airport to the outskirts of the city of Shanghai connecting to the Shanghai Underground network. The service launched in 2003, delivering speeds greater than 500 km/h. Superconductor trains are expected to be deployed in Japan, serving the route between Tokyo and Nagoya (286 km) by 2027, and Osaka (410 km) by 2045, reaching speeds of 500 km/h. In the future, this technology is expected to further evolve into the Hyperloop – a travelling pod moving at a high speed inside a magnetised tube. A proposed route for the Hyperloop could in the future link Los Angeles with the San Francisco Bay Area.

In the long run, maglev trains offer the prospect of travelling faster than conventional trains without the environmental impact of aviation (noise and pollution), linking large metropolitan areas over distances of several hundreds of kilometres.

In addition to providing a convenient means of transportation, the introduction of maglev train technology could alter our perception of distances. As it allows us to cover longer distances in shorter times, it could result in a wider spread of the population within and without city limits. Superconductor trains could connect capital cities with secondary cities, thus leading to a resurgence of secondary cities with maglev stations.

Maglev trains require dedicated infrastructure, which could trigger a rethinking of EU transport policy. The Trans-European Networks for Transport (TEN-T) is an EU programme that seeks, among other things, to fund railway infrastructure, aiming at building a comprehensive network across the Union. It targets bottlenecks, as well as cross-border and multi-modal infrastructures (connectivity of railway with ports and highways). As the network is based on traditional railways, maglev would create an opportunity for a major overhaul across the network.

In contrast, hoverboards are still a relatively new technology, but could eventually revolutionise the way in which people and goods move over shorter distances, providing a fast alternative to walking, driving, or public transport, or a more efficient way to move goods around a factory floor.

Maglev hoverboards would at first be expected to share spaces with pedestrians. As the technology improves, hoverboards could manage greater levitation distances and faster speeds, bringing about the possibility of installing hoverboard-dedicated lanes to ease the coexistence of pedestrians and hoverboard riders in public spaces.

Maglev technology could, however, also develop in completely different fields of application in the near future. The EU-funded GABRIEL project (FP7 funding programme for 2007-2013), investigates the feasibility of introducing maglev for aeroplane landing and take-off, leading to a reduction in energy consumption, cost and noise.

Anticipatory policy-making

One of the major stumbling blocks facing the introduction of maglev transportation is the fact that it requires a dedicated space and infrastructure, separate from current rail or road networks.

Commercial maglev trains currently only run in China and South Korea, but might begin operating in Japan in about a decade. The EU will need to evaluate whether it wants to remain involved in this emerging technology, by supporting the development of early commercial applications in selected locations, e.g. through the TEN-T funding programme. In the longer term, maglev trains will likely see their biggest potential in connecting metropolitan areas across national boundaries in Europe, and the EU could play a decisive role in creating the right conditions for such transnational links to become reality.

4. Wood

Can new technologies contribute to a revival of wood as a source for biomass and construction material, and play a leading role in the fight against climate change?

© Kropotov / Shutterstock

Wood has been used in human civilisation for many thousands of years, playing a key role as fuel or construction material, as well as in the manufacture of furniture, machinery, transportation and everyday objects.

The pressure to convert more land to agricultural use, as well as centuries of using wood for shipbuilding, or as a fuel, have drastically reduced the earth's forest cover, even before climate change became an issue. At the same time, over the last few hundred years and in most parts of the world, wood has largely been replaced as a building material with concrete and steel, and as a fuel by fossil hydrocarbon sources.

The recent debate on climate change, triggered by rising levels of CO_2 and other greenhouse gases in the atmosphere, however, have rekindled interest in wood as a basic material for the production of bio-mass for renewable energy production, or as a construction material, as this would have a positive effect on the CO_2 balance of the atmosphere.

Potential impacts and developments

While the transportation sector is gradually moving from combustion engines to electrical power, especially for short-distance transport, we can expect that transport sector areas where hydrocarbon-based propulsion systems remain the most advantageous option, e.g. maritime transport or aviation, will always continue to exist.

In the current effort to promote a transition towards renewable energy sources, wood can play an important role, not only as a substitute for coal in power plants, but also as a basic material for the production of liquid or gaseous fuels for transportation.

In the construction sector, the replacement of steel and concrete with wood could have a significant impact on the carbon balance. While the production of steel and concrete currently results in large quantities of CO_2 being emitted into the atmosphere, shifting to a wood-based construction industry would result in a large-scale capture of atmospheric carbon by trees and a subsequent storage of this carbon in our building structures. Wood is increasingly being rediscovered as a building material even for tall residential buildings or industrial construction. Studies indicate that more widespread use of wood could have a net carbon-capturing effect that would offset half of the current transport-based CO_2 emissions. Wood as a building material also has many advantages, such as heat and sound insulation and moisture regulation, which would have a positive impact on occupants of the buildings.

In the last couple of years, the promotion of renewable energies for electricity production triggered the construction of many large-scale wood-burning power plants. However, their carbon-footprint heavily depends on the sources of wood used. In addition, to be efficient, these plants have to be big, which could pose problems finding enough wood in the immediate vicinity to keep the plants operating. If wood has to be transported over long distances to these power plants, the environmental impact of such wood-burning facilities is much less positive.

At the same time, the rising cost of fossil fuels has led to a renewed interest in using wood for domestic heating purposes. However, using insufficiently dried wood in insufficiently adapted open fireplaces can be a massive source of indoor and outdoor air pollution. If we want to exploit wood to make a positive contribution to the environmental impact of electricity and heat production, we need to optimise the way in which we collect and use the wood in decentralised power-plants and/or distribute the heat through district heating schemes, rather than a multitude of domestic fireplaces.

A renewed interest in wood as a primary material and renewable energy source will likely produce pressure to transform less productive agricultural land back into forests. This would then have to be compensated by increasing productivity on the remaining land, or reducing waste in food consumption.

While northern Europe already has relatively dense forest cover, a renewed interest in wood and an accompanying reforestation drive could have the biggest impact in southern Europe and northern Africa, where forests have been dwindling since the beginning of human civilisation.

Numerous reforestation projects in recent decades have demonstrated that the expansion of the Sahara desert region could be successfully reversed. These initiatives have so far, however, been limited regionally. A new, massive, coordinated campaign throughout southern Europe and northern Africa to reforest all available land could have a significant impact on the levels of CO_2 in the atmosphere. At the same time, it could potentially lead to the regional climate tipping from the current dry and hot conditions to a more humid and moderate environment, found in those latitudes in other parts of the world. For a relatively moderate cost, in the range of tens of billions of euro, reforestation could create millions of jobs and provide the catalyst for the development of a new wood-based sustainable economy in the wider Mediterranean region.

Anticipatory policy-making

In contrast to agricultural crops, growing trees and forests requires a much longer-term vision and approach. Furthermore, reforestation campaigns will only be successful in the long run if a new wood-based economic sector is created in parallel. Policy-making could play a crucial role at several levels. A reforestation campaign would initially require public money to be made available, and information and communication campaigns to ensure the participation of local populations in the wider effort. Popular support could be further fostered by organising a systematic transfer of technology that would allow better use of the growing forests.

A wider use of wood as building material in the construction industry requires that building codes be swiftly updated as wood technology evolves.

A wider use of wood as biomass for renewable energy production could benefit from a more efficient system of locally collecting available wood resources, while discouraging individual households from burning wood for heating or cooking purposes.

In the context of the growing world population, it would be problematic to expand the areas set aside for growing forests at the expense of agricultural land used for food production. Instead, the focus should be on areas that are unsuitable for agricultural production, e.g. more arid localities. Public research programmes could optimise tree species for cultivation in these less favourable environments, and satellite technology could help monitor the reforestation programmes and optimise their impact on the regional and global climate.

5. Precision agriculture

Could introducing more precision agriculture in Europe allow us to boost food resilience, while ensuring sustainability and jobs, while taking the wide diversity of agriculture throughout the EU into account?

© Kletr / Fotolia

Precision agriculture (PA), or precision farming, is the use of technology to improve the ratio between agricultural output (usually food) and agricultural input (land, energy, water, fertilisers, pesticides etc.). It consists of using sensors to identify precisely (in space or time) the needs of crops or livestock, and then intervening in a targeted way to maximise the productivity of each plant and animal, whilst minimising any waste of resources.

These technologies will play a key role in agricultural development in the coming decades. PA could contribute to feeding the growing global population, even with low-yield gains and a shrinking area of agricultural land. PA already offers technologies for producing more agricultural output with less input. For instance, sensor-based monitoring systems improve yield forecasts and provide farmers with better information and early warning on the status of crops. Another promise of PA is reducing the agricultural sector's negative impact on the environment. According to Eurostat, agriculture is responsible for about 10 % of the EU's greenhouse gas emissions. In addition to this, there are major concerns about the overuse of fertilisers and pesticides, as well as soil erosion. PA could help a great deal in addressing these problems.

Potential impacts and developments

The key promise of PA is that it will allow for the production of more food using less inputs such as fertilisers and pesticides, making agriculture simultaneously more productive and more sustainable. As stressed in a recent STOA study, it can also actively contribute to food security and safety. It may consist mostly of the following approaches:

- Automated steering systems, which can optimise the use of agricultural machines in fields, in combination with advanced geo-mapping techniques, which collect and provide data on soil properties and levels of nutrients for particular fields.
- Remote sensing, by which data can be collected from a distance to evaluate soil and crop health, measuring parameters such as moisture, nutrients, compaction and crop diseases. Thermal, optical, mechanical and chemical measurements by sensors are applied to quantify crop biomass, plant stress, pests, diseases, soil properties, climatic conditions, and animal behaviour.
- Specialised agricultural robots of the future will be able to minimise soil compaction due to heavy machinery. The use of swarm robots could even be envisaged – groups of simple though multi-functional robots that can be coordinated in a distributed and decentralised way, based upon the tasks required. Such machines would be lighter and able to intervene only where they are needed, remaining permanently in the fields.

PA could trigger societal changes. It might change the current perception of agriculture as a low-skill economic sector, and boost its attractiveness for the young generation. It would require a massive investment into wireless technologies in rural areas, closing the gap in comparison to urban areas. PA could thereby halt the exodus of people from rural to urban areas, as some of the main reasons for moving to cities – the availability of assistance, products and services – could vanish.

The general assumption under which globalisation has transformed our economies into knowledge economies is also valid for agriculture. New skills would need to be learned for widespread uptake of PA. Various types of skills are required for farming using PA, such as technological, environmental and managerial skills. Young farmers need to be equipped with the right mix of both job-specific and cross-cutting core skills to be able to access PA, and thereby the farming profession might become more attractive to young people. In addition, PA technologies could really boost the education level in rural areas.

PA could also contribute to changing the way our countryside looks today. The use of smarter technology would reduce the need for large, monotonous, fields dominating the landscape, allowing a transformation to a more varied landscape of fields, trees, bushes, and natural areas. It could also have a significant environmental impact, as it would allow for more selective removal of the most sensitive ecological areas from the agricultural production process.

However, when considering PA in the EU, we also have to consider that farming across the EU-28 is heterogeneous in many respects. This diversity includes aspects such as business models, production sectors, farming practices, employment as an absolute number and as a ratio of the working population, farmers' education and skills levels, and farming output. The societal impact of PA would be greatest in those countries with the largest percentage of workforce employed in agriculture.

Anticipatory policy-making

The wide diversity of agriculture throughout the EU, particularly regarding farm size, types of farming, farming practices, output and employment, presents a challenge for European policy-makers. European policy measures should differentiate between the Member States, considering that the opportunities and concerns differ greatly from one country to another.

Irrespective of what the economic context might be in the next decades, PA will be needed by EU farmers to improve their yields with less available arable land.

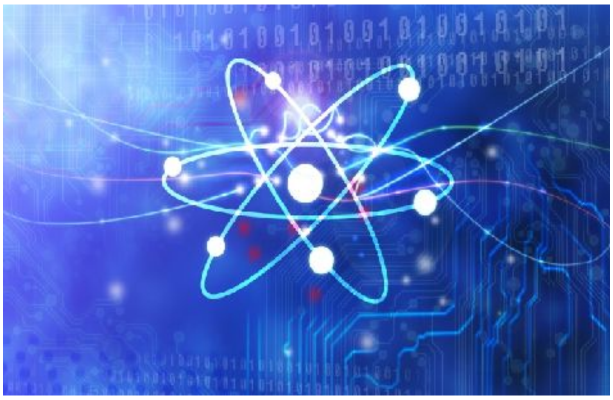
Research and development will be a key driving force in bringing about the agricultural jobs of tomorrow. Accordingly, substantial shifts from the Common Agricultural Policy (CAP) (2021-2027) to enhanced R&D in agriculture could be envisaged. More money could, for instance, be invested in cutting-edge technologies such as biosensors, robotics, spectrograph and imagery.

The EU could enhance its rural development policy, financing agricultural and forestry innovation through measures which could support the creation of operational groups, innovation services, investments or other approaches. Such programmes promoting PA practices could also serve other societal goals, such as a balanced territorial development, or life-long learning.

Another possible policy option is to create a third pillar within the CAP 2021-2027, dedicated to environmentally sustainable technologies.

6. Quantum technologies

Could the well-established, but for non-scientists counterintuitive, theory of quantum mechanics one day revolutionise commonplace technical devices such as sensors, communication devices and computers?


© Winiu / Shutterstock.com

Quantum mechanics is a scientific theory that has revolutionised our understanding of the universe, especially at the microscopic level. In the world of classical physics, a system is always in one particular state (e.g. a body at rest or in motion with a well-defined velocity), while in the quantum world, a system can be in a superposition of two or more states. Performing a measurement on such a superposition causes it to 'collapse' into a single state. Thus, in contrast to the classical world, where a system can be measured without changing it, in the quantum world a measurement can have a big impact on the state of the system.

Potential impacts and developments

As counterintuitive as quantum theory might sound to the layperson, it is already the basis for many common technologies, such as the transistor and the laser. However, scientists are now able to control the microscopic states of individual quantum systems with high precision. This ability could result in the development of new technologies, which can be divided into three areas: sensing, cryptography, and computing.

Quantum sensors encompass a wide range of devices which use quantum effects to make high-precision measurements of quantities such as time, gravity and magnetic field. Many of these devices could be commercialised within the next few years, with quantum clocks in particular already substantially surpassing their classical counterparts.

Cryptography is usually performed by the recipient of a message distributing a public 'key' for someone to encrypt a message, where the message can only be decrypted with the private key held by the recipient. This method depends upon the computationally difficultly to determine the private key from the public key, as it is possible that a hacker could find out the public key by intercepting communications between the two parties. The alternative of quantum cryptography is (at least in theory) impossible to defeat, as it relies on the fundamental law that measuring a quantum system changes that system – by using such a system to transmit information, two communicating parties can find out whether someone is listening to their messages.

Quantum computing is the technology with perhaps the greatest potential, whilst also being the furthest from being developed. Ordinary computers use 'bits' to store and process information. These are electronic components that have two possible states, one representing '0' and the other representing '1'. A quantum computer would also allow a 'quantum superposition' of these two states, which can be thought of as being both '0' and '1' simultaneously. These superpositions would vastly speed up the computation of certain problems, some of which would take billions of years on an ordinary computer, but only a matter of hours on a quantum computer.

There are several known applications for a quantum computer. One of these is calculating how other quantum systems behave, which would transform the development of new chemicals, medicine and materials, where it is currently necessary to create and test a new substance to find out how useful or harmful it would be. Another possible application is in artificial intelligence, although what improvements a quantum computer would offer in this area remains unclear.

While quantum technologies can help solve a range of problems, they can also potentially create new ones. One possible scenario is that in the future, quantum computing could allow others to break our existing cryptography protocols. This threat in turn provides considerable motivation for the development of quantum cryptography, which would provide protection from such an attack. The continued safety of our encryption systems may thus depend on advances in quantum cryptography staying abreast of advances in quantum computing.

However, a future quantum computer could be used not only to decrypt future transmissions, but also data that was intercepted and recorded in previous decades. Therefore, unless quantum computing is demonstrated to be completely infeasible, organisations who want to keep their current information secure in future decades will likely maintain an interest in quantum cryptographic systems.

Anticipatory policy-making

There is already considerable public and private interest in developing quantum technologies. The Netherlands and the United Kingdom have programmes in this area that have attracted hundreds of millions of euro in funding, both from public bodies and from industry. The European Commission recently announced a plan to invest €1 billion in a quantum technologies flagship initiative.

As with many new technologies, it is important to consider how to bridge what is known as the 'valley of death', between scientific research and commercial application. The science behind quantum technologies is widely believed to be well-understood, and research is now moving beyond demonstration experiments towards building useful devices. However, as commercial application of many of these technologies is still some way off, investment from private companies remains a fraction of that in their conventional counterparts. Public investment programmes will be important for bringing quantum technologies closer to commercial viability, and the effectiveness of current programmes should be monitored in this regard.

One particular aspect that may need large public investment is the infrastructure required for quantum cryptography. This technology is likely to require special optical fibres to transmit single photons (particles of light) in such a way that their quantum state is maintained. There are already initiatives to develop this infrastructure in China, Japan and the USA, as well as some Member States. To allow quantum communication across the EU, as well as around the world, an uninterrupted network is required. Another option would be the development of new 'post-quantum' encryption protocols with no known quantum algorithm that could be used to break them.

For quantum computers, the question of what they would be able to do is still an active area of research. The ability to break existing cryptography protocols is one application that could have negative consequences, and it is possible that more harmful applications will be developed in the future. Possibilities include the ability to hack other security protocols that are currently considered to be secure against a quantum attack. Therefore, it may be prudent to regulate access to such devices. However, a likely business model for this emerging industry would be to allow users to submit problems online, therefore such regulation may not be feasible. In addition, regulation may stifle the potential for a huge acceleration in technological progress, reducing the corresponding benefits for society.

Quantum technologies offer fascinating possibilities, which have yet to be fully explored, and progress in this area could be accelerated by increasing public investment. However, policy-makers need to devote a considerable amount of attention to the field as progress unfolds, in order to minimise the possible negative consequences resulting from these technologies.

7. Radio frequency identification tags

What will be the impact of radio frequency identification tags, and other short-range communication devices, on how the Internet of Things transforms our way of life?

© Andreynikolaev / Shutterstock.com

Radio frequency identification (RFID) is a technology that is being introduced on a massive scale, to replace barcodes as a way of tagging consumer goods. In the light of recent food scandals, this could, among other things, facilitate the traceability of food and beverages in a more efficient and exhaustive way than what is feasible with barcodes.

RFID is also the technology behind tags that are now common on some clothes, books or other products and that can be easily distinguished thanks to a kind of coil, or piece of foil, that acts as an antenna. With this technology, products can be detected when passing through a gate containing the required reader. This is similar to some older anti-theft systems, but now the specific product can also be uniquely identified for other purposes, such as billing or to consult its characteristics. This is possible because the tag contains an ID number that is longer than the ones used in barcodes, and it is structured in such a way that it can be used to automatically access databases with additional information on the internet.

This capability of the reader to not only identify the product, but also to access a plethora of related information, has given rise to ideas such as smart objects or the Internet of Things (IoT). A smart object is an object that enhances its interaction not only with people but also with other smart objects. The Internet of Things is the integration of physical devices, vehicles, buildings and other items with electronics, software, sensors, actuators and network connectivity that enables these objects to collect and exchange data.

New applications of these ideas are constantly appearing, and research in this area is thriving. RFID tags could be useful throughout the product life-cycle, from the gathering of the required parts or raw materials, all along the manufacturing and supply chains, including at the point of sale, and up to the processes of recycling and waste management. This could shorten queues at supermarkets, as all products in the trolley can be read instantaneously. Users could also benefit by taking advantage of the capability of the objects to provide access to related information, such as usage instructions, that can be automatically accessed by appliances. For example, a bag of food could update the freezer on the required temperature for adequate preservation or warn it about upcoming expiration dates, or inform the microwave oven about the required cooking temperature and time.

However, the concept of tracking objects has raised some concerns. Whereas a smartphone is likely to always be a relatively conspicuous device, that the somewhat hidden tag in an object that can mysteriously give access to so much information can be seen as a threat.

Potential impacts and developments

It is important to note that, for reasons of efficiency and price, basic RFID tags used for tracking consumer goods work in the ultra-high frequency (UHF) range and are passive (i.e. do not have batteries). This is noteworthy because it defines the properties and capabilities of the tag. Using UHF means that the reading ranges may be relatively long under certain conditions but, on the other hand, not having batteries means that they are required to use the power coming from the carrier signal provided by the antennas connected to the reader. Also, UHF is prone to malfunction in the presence of liquids (that absorb the energy) or metals (that reflect the signal creating interference). All of this results in readers being necessarily quite costly and conspicuous (e.g. as a reading arch in a shop) even if tags are not.

Another implication of the requirement for such simple tags (to use very little energy), is that the communication protocols implemented in them are rather basic. This means that they are not secure, as they do not include encryption or any other measures of protection. Further research is currently underway in these areas, but for the moment the information can be tampered with in several ways (counterfeiting, eavesdropping, cloning, spoofing, jamming etc.).

As well as basic UHF RFID tags, there are other tags that are also very common and even simpler, as is the case for those using near field communication (NFC) technology. NFC uses lower frequencies and tags can only be read at very short distances (usually by a hand-held device) and one at a time. The advantage is that they require only a cheap and simple reader. On the other hand, many other types of tags with improved capabilities also exist, as by adding a battery (to make 'active tags'), they may become sufficiently complex for many different applications. Active tags can include sensors, actuators and a large memory, and make extended communication ranges possible. All of these capabilities again contribute to public concern regarding the applications of this technology.

Anticipatory policy-making

It is important to note that the small tags that may be hidden in everyday objects are currently always simple, passive devices, with quite limited capabilities (the more powerful ones are usually bigger and far more conspicuous). Therefore, it is always difficult to read a tag, and even more so in the EU, where the power of readers has been limited to two watts by law (while four watts are allowed in the USA). This means that reading ranges are usually limited to about two metres. Furthermore, as readers work in a very similar way to radar, they are easily detected and controlled by the authorities. However, it is important to keep in mind that these tags have been designed for simple consumer goods. Therefore, even if the possibilities associated with their use are rather broad, it is unlikely that the tags will be used by any hypothetical 'Big Brother'.

On the other hand, there is a real concern on the part of the developers about the safety of this technology for certain applications. To begin with, it would be important to ascertain a realistic limit to the power used by the readers, as this creates a serious limitation. While two watts seem to have very little effect on the human body, it is important to take into account that UHF uses the same wavelengths as microwave ovens. Therefore, there is a concern regarding the possibility of 'hot spots' appearing in certain locations that may affect biological products. For example, UHF RFID tags are being used in hospitals to track bags of blood, but there does not seem to be any specific research on the effects that the readers may have on the preservation of these products.

There are still many possible improvements around RFID, but the technology is already available, and the possible applications are many. It is true that the technology is not completely guaranteed to be fault-free and tamper-proof, but the simple tags designed to identify consumer goods cannot be compared with the devices that could be used to track a person, such as smartphones. Nevertheless, the use of this interesting technology can certainly help solve the many problems that appear along supply chains, affecting consumers. It may be preferable to accept the remote possibility of the authorities knowing what you are eating, than to risk food poisoning.

8. Big data and health care

Big data can open up enormous new opportunities in health care, but how can we ensure that they bring benefits to everyone?

Advances in health care have led to dramatic increases in life expectancy and quality of life over the last hundred years. At the same time, the provision of health care requires an ever increasing share of GDP in most countries of the world.

In this context, the new tools of big data offer enticing perspectives, promising to provide better diagnoses, increase the effectiveness of current treatment methods, and allow for new cures to be found with less effort than traditional research methods require.

© Panchenko / Shutterstock.com

Potential impacts and developments

There are three different levels where huge benefits could be unlocked:

(i) Traditional medical research involving large trials or surveys could be made cheaper and faster

When conducting large clinical trials or surveys for testing a new drug, for assessing the effectiveness of new treatments, or for understanding the causes of certain health conditions better, large quantities of data are collected from a substantial group of patients in order to answer very specific questions. Once the studies are concluded, these large datasets are often archived without further consideration, despite the possibility that they could help other researchers to address related research questions. Efforts are therefore underway to make these datasets more accessible to the wider research community, allowing new additional insights to be gained at minimal additional cost.

Before this data can be made available to the wider research community, however, it needs to be anonymised, which in some cases can represent a substantial workload. The use of pre-existing datasets to address new research questions could, however, allow researchers to avoid duplication of efforts and thereby reduce the time and cost necessary for conducting new studies.

(ii) New sensors greatly facilitate the collection of datasets

We are increasingly surrounded by smart devices and sensors in our daily lives, which track our geographical location, count the steps we walk, monitor our driving style and level of alertness when driving, and measure many more quantities. Data recorded by sensors rather than by people filling in questionnaires is often more objective, and with the ever-decreasing costs of sensor technologies, a larger number of parameters could be surveyed for ever larger groups of test candidates, revolutionising the way in which we conduct research and monitor the effectiveness of treatments.

(iii) Individualised health care services

Besides facilitating studies about large groups of test candidates, the growing numbers of sensors around us daily – in the mobile devices we carry, the clothes we wear, the cars we drive, and many more items, will also increasingly allow for the provision of personalised health care services. In much the same way that sensors in cars already monitor eye-blinking rates to warn the driver of sleepiness, sensors we wear in our clothes could, in the future, warn us if the risk of a heart attack is particularly high, or if our immune system is particularly weak and we are in danger of contracting influenza.

While these new technologies promise great healthcare advances, they also pose a number of challenges to society, notably in terms of data protection.

Data protection is already a key issue to take into account in any clinical study. If researchers share these datasets even more extensively in future, it is even more important that data privacy standards provide effective protection for study participants. Due adherence to informed consent procedures will also be paramount, when the data provided by human subjects (patients or controls) is used in research other than that for which it was initially obtained.

The increasing number of sensors that accompany us in our daily life, and already today gather an increasing number of parameters about our health and well-being, will pose additional challenges. Mobile phone manufacturers, telecom operators and internet search engines already collect considerable amounts of health-relevant data about their clients today, without yet being perceived as actors in the health sectors. This will become even more critical when simple devices like mobile phones become able to derive a complete assessment of their users' health from the increasing number of parameters they collect.

Anticipatory policy-making

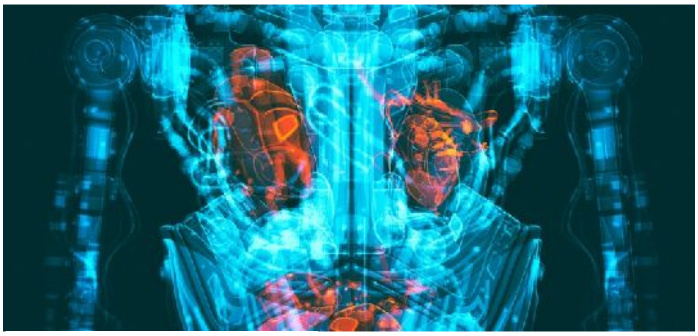
Besides the need to continuously update data protection and privacy rules as technology develops, wider issues must be considered regarding who should benefit from all of these technological advances. As an example, will sensors we wear on our body enable us to detect cancer at an earlier stage, increasing the chances for healing and lowering the cost of treatment; or will those technologies mainly help companies to increase insurance rates for those diagnosed with cancer?

Although data protection rules are continuously being updated, in an increasingly interconnected world it might become more and more difficult to hide the fact that one is affected by a particular disease such as cancer. We will need to find the right balance between an individual's interest in confidentiality concerning their health, and the benefit society could reap from easier access to anonymised medical data that could hold the key to medical innovations and breakthroughs.

Since even the best laws might not be able to guarantee privacy under all circumstances, and we therefore have to consider that a condition such as cancer might be made public, law-makers could provide an extra layer of protection by enacting legislation that minimises the potential for discrimination. For example, a system that provides for sharing of cancer patients' treatment costs between all health insurance companies will reduce the likeliness that an individual patient is discriminated against by an insurance company on the grounds of a history or propensity of developing cancer.

9. Organoids

Organoids are artificially grown organs that mimic the properties of real organs. What new possibilities for treating diseases, drug development, and personalised and regenerative medicine do organoids provide?



© Ociacia / Shutterstock.com

Organoids are small clusters of human cells that are grown in a laboratory environment to form three-dimensional structures that mimic the functionalities of real organs such as the liver, heart, and lungs. Organoids are either generated from resident progenitors in adult organs; or derived from one or a few cells from a tissue, embryonic stem cells or induced pluripotent stem cells, which can self-organise in three-dimensional culture owing to their self-renewal and differentiation capacities. These cell clusters are often grown in specially fabricated micro-containers that help the cells to arrange themselves, much like they would in an organ inside the human body. They closely resemble *in vivo* human tissue and possess the genetic characteristics of the people from whom they are taken, and so respond to drugs as the corresponding organ of the person in question would. These organ-like structures, which can be stored in biobanks, are not just a powerful tool to promote better understanding of the fundamental processes governing organ development in the human body, but also promise direct benefits for patient treatment and drug development.

Potential impacts and developments

As one of the most accessible and physiologically relevant models for studying the dynamics of stem cells in a controlled environment, organoids are expected to advance our understanding of tissue renewal, stem cell/niche functions and tissue responses to drugs, mutation or damage, as well as unlocking the mysteries of several brain diseases and neurological disorders. The blossoming of a technology that allows scientists to grow matter resembling brains, as well as livers, kidneys, intestines, and many other body parts, is seen as an important avenue to reconstituting organ functions *ex vivo*. Other possibilities include providing a sound model for preclinical screenings, targeted and personalised therapies, regenerative medicine applications, drug discovery and environmental toxicology testing.

The progress in generating organoids has extended organoid applications from a basic research tool to a translational platform with a wide range of downstream functions and uses that animal testing cannot offer, and could even revolutionise the drug discovery process. For instance, mini-guts can serve as a personalised drug-testing tool for cystic fibrosis (CF), whilst researchers are beginning to use brain organoids as accurate models for the study of a wide range of diseases such as autism, schizophrenia, and epilepsy.

Furthermore, liver-based cell organoids could form a complement to current organ transplantation to restore liver function of patients with metabolic liver disease and to serve as a model for metastasis growth, and for testing tumour cell response to current and newly discovered drugs. Pancreas organoids derived from adult pancreas stem cells are one of the most promising technologies for cellular and regenerative therapy. These 'intestinoids' already permit novel drug testing for cystic fibrosis and bowel cancer. Recently, scientists set up the world's first 'living biobank' to store patients' tumours, and used the tissue to identify the most promising drugs for each person's disease, while other scientists are making progress in creating larger assemblies of nerve cells, moving towards creating brain-sized organoids. In the near future, organoids will begin to enter routine medical use, as a way to shed light on diseases caused during embryonic development, or may even be transplanted into people to replace diseased or failing natural organs. Organoids have also been used to study what goes wrong, such as in neurons derived directly from patients with Alzheimer's disease.

Alongside the benefits organoids could provide in terms of helping researchers to understand how real organs develop, and what can go wrong with that process, the scaling-up of organoids into reproducible and user-friendly systems and commercial manufacturing entails safety and ethical risks, given that culture methods are still in their infancy. Personalised organoids may facilitate the deployment of personalised medical trials, which may in turn pose new risks, and affordability concerns.

Similar conflicts may arise when considering the type of tissue being generated. The closer scientists come to making a human brain, the greater the ethical issues. The concepts of human integrity in this context could be placed under significant threat.

Anticipatory law-making

Although many of these technologies are still relatively new and require further validation and characterisation, the fact that organoids derived today from living tissues cultivated from participants' stem cells may be stored for a very long/virtually infinite period of time underlines the urgency to deal with these issues now. Privacy requirements; terms and conditions of inclusion of participants in research/clinical trial settings; storage and use of organoids; and dissemination of results including incidental findings, all require attention. Informed consent is a major issue regarding inclusion of participants and the collection of their stem cells from residual tissue. Organoid biobanking also requires the development of tailor-made informed consent procedures that address the challenges associated with the fact that organoids are actually living mini-organs that could be used for a wide range of purposes, as well as the lack of an EU-wide legal framework on biobanks.

The use of organoids may complement or even reduce animal testing and the involvement of humans in an experimental setting, which may in turn trigger the modification of the existing medicinal testing, clinical trial and chemicals' authorisation framework.

Another central issue is the question about ownership and commodification of bodily material, as well as how true to life an *in vitro* model of human development needs to be in order to be both scientifically valuable and ethically acceptable. As interest in organoid technology grows, the commercial development of more standardised, validated organoid culture media will also be valuable in ensuring that the organoid system becomes accessible to a wide range of academic and clinical scientists, thereby helping to maximise its potential.

10. Genome editing

A new technique to simplify gene editing might herald a new era of genetic modification. What are the benefits and potential dangers of this technique, and how should policy-makers respond?

© Perception7 / Shutterstock.com

The capacity to engineer genomes in a specific, systematic and cost-effective way is a long-standing objective in the field of genomic studies. Several 'gene editing' technologies have recently been developed to improve gene targeting methods, including CRISPR-Cas systems, transcription activator-like effector nucleases (TALENs) and zinc-finger nucleases (ZFNs). The CRISPR-Cas9 system currently stands out as the fastest, cheapest and most reliable system for 'editing' genes. It is seen as the biggest game changer in the gene editing field, due to its high degree of reliability and effectiveness, as well as its low cost. This technological trajectory is expected to enhance our capacity to target and study particular DNA sequences in the vast expanse of a genome. CRISPR-Cas9 has the potential to cut the DNA of any genome at any desired location in many types of organisms, replace or add parts to the DNA sequence by introducing the cas9 protein, and appropriately guide DNA into a cell. This extremely powerful tool could help molecular biologists to explore how the genome works.

Potential impacts and developments

CRISPR-Cas9 has great potential as a tool for directly modifying or correcting fundamental disease-associated variations in the genome and for developing tissue-based treatments for cancer and other diseases by disrupting endogenous disease-causing genes, correcting disease-causing mutations or inserting new genes with protective functions. Researchers hope to use CRISPR-Cas9 to adjust human genes to eliminate diseases, fight constantly evolving microbes that could harm crops or wipe out pathogens, and even edit the genes of human embryos.

CRISPR-Cas9 can be used to alter the genes of a wide range of organisms with relative precision and ease, and also create animal models for fundamental research. Editing the genes of animals could improve disease resistance, control mosquito populations so as to mitigate or tackle malaria transmission, or even lead to the creation of 'farmaceuticals' — drugs created using domesticated animals — or better food production. The system could also facilitate the transplanting of animal organs into people by eliminating copies of retrovirus present in animal genomes that may harm human recipients.

Altering DNA in human embryos is also possible using CRISPR-Cas9 technology, which could eventually lead to transformative changes in human well-being, with consequences for people's life span, identity and economic output. The technology can also be used to create a 'gene drive', which means that a particular selected gene will be preferentially handed down to the next generation, thereby rapidly spreading through entire populations.

While CRISPR offers many fascinating prospects, the use of CRISPR has also triggered socio-ethical concerns over questions such as whether and how gene editing should be used to make inheritable changes to the human genome, lead to designer babies, generate potentially risky genome edits or disrupt entire ecosystems. The use of CRISPR-Cas9 raises social and ethical issues not only for humans, but also for other organisms and the environment, leading scientists to recommend a moratorium on making inheritable changes to the human genome. For instance, the application of CRISPR as a pest control technique may produce unintended effects and mutations, which may lead to the dispersion of gene drive, the disappearance of a whole animal population, accidental releases and/or the irreversible disturbance of entire ecosystems. In fact, research activities intended to modify the genetic heritage of human beings which could make such changes inheritable are not financed under Horizon 2020, the EU framework programme for research and innovation.

Taking the non-maleficence principle into account in risk assessment, and distinguishing the clinical and therapeutic aims of gene editing from its enhancement applications/uses, have also become major sources of concern. Another important problem is the efficient and safe delivery of CRISPR-Cas9 into cell types or tissues that are hard to transfect and/or infect. Further concerns include the prospect of irreversible harm to the health of future generations, and concerns about opening the door to new forms of social inequality, discrimination and conflict, as well as to a new era of eugenics.

Anticipatory law-making

The rapid pace of scientific developments in the field of gene editing makes regulatory oversight particularly challenging. Moreover, there is a debate over whether CRISPR-Cas9 should be regulated as a gene editing technique, or whether its products should rather be controlled ad hoc with a result-based approach. International discussion on the regulatory status of genome editing techniques has focused on whether current definitions of genetic engineering or genetically engineered organisms could also apply to these recently discovered genetic editing tools.

The European Commission is currently working on a legal interpretation of the regulatory status of products generated by new plant-breeding techniques, to minimise legal uncertainties in this area. Such an interpretation may pave the way for a decision on whether gene editing technologies should fall under the scope of the EU legislative framework on the contained and deliberate release of genetically engineered organisms.

Patenting CRISPR-Cas9 for therapeutic use in humans is also legally controversial. In February 2017, the US Patent and Trademark Office (USPTO) issued a decision on who should hold the patent on using CRISPR-Cas9 to edit genes, defining the terms and conditions for profit generation from this technology in the years to come.

The risks of hereditary, unpredictable genetic mutations raise questions regarding the safety of the technique and the attribution of liability in case of damages. In a recent report, the US National Academies of Sciences, Engineering and Medicine urged caution when releasing gene drives into the open environment and suggested 'phased testing', including special safeguards, given the high scientific uncertainties and potential ecological risks. Safety measures are necessary to avoid dissemination of organisms that may cause ecological damage or affect human health.

In fact, many scientists caution that there is much to do before CRISPR could be deployed safely and efficiently. In particular, CRISPR might create additional challenges from a risk assessment standpoint, in that organisms produced by these methods may contain more pervasive changes to the genomes of living organisms than traditional genetic modification techniques.

In 2015, the European Parliament's Directorate-General for Parliamentary Research Services (DG EPRS) broke new ground with its publication 'Ten technologies which could change our lives – potential impacts and policy implications', with each chapter highlighting a particular technology, its promises and potential negative consequences, and the role that the European Parliament could and should play in shaping these developments. This new study continues this work, presenting ten additional technologies that will increasingly require the attention of policy-makers. The topics for the current study have been chosen to reflect the wide range of topics that the Parliament's Science and Technology Options Assessment (STOA) Panel has decided to focus upon for the eighth parliamentary term (2014-2019). The aim of the publication is not only to draw attention to these ten particular technologies, but also to promote further reflection about other technological developments that may still be at an early stage but that could, in a similar way, massively impact our lives in the short- or longer-term future.

This is a publication of the
Directorate for Impact Assessment and European Added Value
Directorate-General for Parliamentary Research Services, European Parliament

PE 598.626
ISBN 978-92-846-0700-6
doi:10.2861/36645
QA-01-17-154-EN-N