DIGITISING AGRIFOOD

PATHWAYS AND CHALLENGES

CEPS

Fondazione Barilla
il tuo cibo, la tua terra

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Pathways and Challenges

As climate change increasingly poses an existential risk for the Earth, scientists and policymakers turn to agriculture and food as areas for urgent and bold action, which need to return within acceptable Planet Boundaries. The links between agriculture, biodiversity and climate change have become so evident that scientists propose a Great Food Transformation towards a healthy diet by 2050 as a major way to save the planet. Achieving these milestones, however, is not easy, both based on current indicators and on the gloomy state of global dialogue in this domain. This is why digital technologies such as wireless connectivity, the Internet of Things, Artificial Intelligence and blockchain can and should come to the rescue.

This report looks at the many ways in which digital solutions can be implemented on the ground to help the agrifood chain transform itself to achieve more sustainability. Together with the solution, we identify obstacles, challenges, gaps and possible policy recommendations. Action items are addressed at the European Union both as an actor of change at home, and in global governance, and are spread across ten areas, from boosting connectivity and data governance to actions aimed at empowering small farmers and end users.

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Centre for European Policy Studies
Place du Congrès 1, B-1000 Brussels
+32 (0)2 229.39.11
info@ceps.eu
www.ceps.eu

Fondazione Barilla

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The Barilla Center for Food & Nutrition Foundation (BCFN) is a multidisciplinary centre for the analysis of the major global issues related to food, nutrition, agriculture and environment.

Created in 2009, the BCFN bridges science and society, bringing experience and expertise to the debate in an effort to end the paradoxes of our planet, where obesity and food waste happen despite widespread hunger and malnutrition.

Awareness raising and continuous dialogue within economic, social, environmental and scientific spheres represent critical first steps towards achieving long-term change. The BCFN delivers concrete recommendations and proposes solutions to respond to these urgent challenges and improve food system along the food supply chain - from farm to people. BCFN is convinced that these issues must become priorities in the agendas of decision makers and opinion leaders around the world. BCFN is eager to play an important role and to propose sustainable solutions for the future of our planet.

Barilla Center for Food & Nutrition Foundation
Via Madre Teresa di Calcutta 3/a, 43121 Parma – Italy
info@barillacfn.com
www.barillacfn.com

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LIST OF ACRONYMS

5G	Fifth generation cellular network technology
AgTech	Agrifood Technology
AI	Artificial Intelligence
API	Application Programming Interface
AWS	Amazon Web Services
B2C	Business-to-Consumer
CAGR	Compound Annual Growth Rate
CAP	Common Agricultural Policy
CPS	Cyber-Physical Systems
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CTA	Technical Centre for Agricultural and Rural Cooperation
CWSI	Crop Water Stress Index

DFID	U.K. Department for International Development
DLT	Distributed Ledger Technologies
EBRD	European Bank for Reconstruction and Development
EIB	European Investment Bank
EPI-AGRI	Agricultural European Innovation Partnership
eMBB	enhanced Mobile Broadband
EO	Earth Observation
ESL	Electronic Shelf Labels
FAO	Food and Agriculture Organization of the United Nations
FDA	U.S. Food and Drug Administration
FPO	Farmer and Producer Organisation
GEO	Group on Earth Observations
GDC	Global Development Community
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPS	Global Positioning System
ICT	Information and Communications Technology
IFAD	International Fund of Agricultural Development
IoT	Internet of Things
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IP	Intellectual Property
IPCC	Inter-Governmental Panel on Climate Change
ITU	International Telecommunication Union
JRC	Joint Research Council
KPI	Key Performance Indicator
LAN	Local Area Network
LEADER	Liaison Entre Actions de Développement de l'Économique Rurale
LoRaWAN	Long Range Wide-Area Network
mMTC	massive Machine Type Communications

NFC	Near-Field Communication
NFV	Network Function Virtualisation
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
p2p	Peer-to-peer
PC4SD	Policy Coherence for Sustainable Development
RFID	Radio-Frequency Identification
R&D	Research and Development
SaaS	Software as a Service
SDGs	Sustainable Development Goals
SDSN	Sustainable Development Solutions Network
UAV	Unmanned Aerial Vehicles
UUID	Universal Unique Identifier
Q&A	Question and Answer
QR code	Quick Response Code
WEF	World Economic Forum
WSN	Wireless Sensor Networks

DIGITISING AGRIFOOD
Pathways and Challenges

Executive Summary

Executive Summary

We live in a crucial transition for the future of our planet. Scientists, practitioners and policymakers agree that a coordinated, ambitious wave of reforms is needed to bring our economy and society onto a sustainable path. Rising to the challenge that we have created is an urgent endeavour as much as a difficult one: complexity, inter-dependency, problems of collective action and unfavourable political trends have led some commentators to lose hope on the prospects for a shift of gear towards a more sustainable future. At the same time, younger generations are creating a new political push for climate action, while research and technological breakthroughs promise to shift the frontier of what is possible, thereby expanding the menu of options for saving the Earth, and mankind with it.

One of the most substantial contributions to future sustainability must come from a radical transformation of the agriculture and food (agrifood) value chain, which accounts for a significant part of greenhouse gas emissions and global warming, notably through excess methane and nitrous oxide. **Agrifood today uses too much land (up to three times the maximum sustainable area) and too much freshwater (70% of total withdrawals); it sprays excessive toxic pesticides; relies too much on monoculture; loses or wastes too much food (one third of the total); and ultimately leads to unhealthy and unsustainable diets.** As a result, while more than 820 million people are currently undernourished, more people are at risk of premature death due to an unhealthy diet. These imbalances are a risk for global warming, for biodiversity, and also for economic and social sustainability. **Agrifood-led climate change risks causing the extinction of a large number of species, and also new instances of poverty especially in developing countries, triggering migration flows.**

This report argues that digital technologies are an important tool for surmounting this monumental challenge. **The diffusion of digital technologies in the agrifood chain promises to increase yields, reduce waste, and trigger changes in consumption patterns, thereby substantially contributing to the Sustainable Development Goals** (SDGs). Digital technologies are already showing great potential for saving time and money and increasing efficiency and productivity in sectors from manufacturing to energy. **The great challenge of our time will be to tap this potential not only for business purposes, but also to achieve sustainability.** While the use of digital technologies in the agrifood sector is still in an early phase, it is the ambition of this report to map promising use cases, opportunities and challenges. This exercise is a first necessary step before larger investments are made and policy actions can be undertaken.

Digital technologies are essential but not sufficient to fix agrifood. Fixing agrifood is essential but not sufficient to save the planet

A new 'stack' is emerging, featuring a powerful set of new, complementary digital technologies that can revolutionise many parts of the agrifood chain. This entails the deployment of connected things equipped with sensors, which generate, send and receive data through various forms of connectivity and network architectures, triggering specific actions (e.g. irrigation) via actuators. Artificial Intelligence, also in combination with the Internet of Things, brings new prospects in food consumption, through personalised nutritional advice and various forms of 'hyper-nudging', which may help consumers consider the broader implications of their choices, both for themselves and for society and the environment. The possibility to use equipment (drones, trucks) and computing capacity 'as a service' potentially empowers smaller farmers and provides them with access to next-generation technologies. Finally, the end-to-end nature of internet architecture potentially enables new forms of cooperation between farmers, as well as new opportunities to quickly match excess food supply with existing demand, thereby further reducing waste.

Several examples already exist. Our report focuses on a variety of case studies.

- In agriculture, start-ups like **Ignitia** or **GAIA** show the potential of satellite imagery and data analytics to help farmers increase productivity and reduce yield loss. **WeFarm** provides a Q&A platform for less financially endowed farmers in sub-Saharan Africa to help them tap the knowledge of their peers without an internet connection.
- In order to reduce food waste and loss, **Winnow** demonstrates how computer vision in kitchen bins and machine learning can improve knowledge of what is being wasted and help save 40% of overproduction waste; food retailer **Albert Heijn/ Ahold Delhaize** experiments with electronic shelf labels (ESL) and dynamic pricing to incentivise people to buy products before they expire; and start-up **Too Good to Go** provides an app connecting businesses and consumers to sell food at a discount before it goes to waste.

- In order to improve health and nutrition, **Nutrino** is building a database on food and people to provide personalised dietary recommendations to fight diabetes. **FarmVR** employs virtual and augmented reality technologies to improve outcomes in agriculture education.

Not all that glitters is gold. Technology also brings new challenges for sustainability

While digital technologies have great potential, they also bring new challenges. These technologies require skills, connectivity and financial resources, three main elements that are largely missing in many parts of the world: **they consume energy, lead to electronic waste and often trigger market concentration and job automation**, a problem that has already plagued the agrifood sector over the past decades, in which smaller farmers have gradually faced mounting market power both upstream and downstream.

More specifically, **the digital transformation has the potential to empower small-scale farmers, but in the absence of dedicated public policy, may exclude them from the supply chain, or leave them in a new situation of economic dependency, in which they own their land, but rent their data**

and digital equipment from larger agrifood companies, or even tech giants.

Public policies needed to avoid thus undesirable outcome all revolve around the need for more distributed, decentralised governance in which community-based services incorporate the management of data, the allocation and coordination of asset use, and the negotiation of contracts with other actors in the supply chain. Community-based services should be incorporated in development aid.

A holistic 'policy mix': a new decalogue for future food system policies

Based on our analysis, we have identified ten key action areas – a decalogue – to consider for policymakers.

Ensuring adequate connectivity

In agriculture, it is important to ensure a wide coverage and low costs of deployment or maintenance, since most of the applications feature relatively low needs in terms of bandwidth and low latency. This makes technologies such as the legacy 2G network and low-power network technologies particularly suited for most current deployment. However, more sophisticated use cases will require either the ability to function with intermittent connectivity or waiting for the deployment of new generations of networks such as 5G.

Deploying the full technology stack

Once connectivity is in place, the whole stack has to be deployed. Recent studies have shown the potential of these technologies, but implementing them requires skills, connectivity and funding, which could come from public resources, given the extent of the positive externalities that this transition would generate. One possibility is to leverage the resources available in global funds such as the Least Developed Countries Fund, on which agreement was reached in September 2019, which will devote $160 million to help poorest countries prepare for climate change. Recent research found that investing $1.8 trillion globally in five areas from 2020 to 2030 could generate $7.1 trillion in total net benefits. The Global Commission on Adaptation recently observed that a more resilient food future must rely on sharp increases in agricultural R&D, which has demonstrated benefit-cost ratios between 2:1 and 17:1.

Promoting entrepreneurship, building capacity and facilitating technology transfer

The modern age of data-driven farming requires updated thinking around agricultural extension systems and practices. While many facets of these programmes – technology and best practices transfer, partnerships and knowledge sharing, training, market development – are still important, digital technology applied to agriculture and all its activities from farm to fork adds a new layer of complexity. In particular, besides skills and data, supportive policies and programmes (e-government) for digital strategies are needed, along with data governance policies and standards, in order to keep data open and accessible to all stakeholders, especially farmers.

Generating and sharing data for distributed, sustainable governance

According to OnFarm (a connected farm IoT platform provider), the average farm will generate 4.1 million data points by 2050. Using collected data to directly improve production practices could enable a 20% increase in income while reducing herbicide and fuel consumption by 10-20%. However, the key problem with data is that small-scale farmers are not yet well-equipped to make the best use of them, absent dedicated advisory services and third-party support. As already observed, the diffusion of data-driven agriculture may end up exacerbating the dependency of small-scale farmers on large corporations, who increasingly specialise in IoT, AI and data-driven agriculture by exploiting their outstanding resources. Accordingly, new solutions and dedicated services will be needed, possibly leading towards community-led data management, coupled with the provision of basic skills and the gradual hand-over of responsibility to the local community.

Rebalancing the bargaining power of farmers, distributors and data managers

Once connectivity, data and technology have been deployed, small-scale farmers must be connected to global value chains. There, they will normally find much larger players, and often end up in a situation of economic dependency, or weaker bargaining power. Here, governments may intervene to avoid that the superior bargaining power of both large distributors and data managers translates into unfair commercial practices and lack of profitability on the side of the smaller farmers. This requires the adoption of specific policy instruments, such as legislation on unfair trading practices in the retail sector, or rules on abuse of economic dependence. Digital technologies can help through the use of smart contracts.

Attributing responsibility for negative externalities throughout the value chain

While the agrifood chain produces massive negative externalities in terms of waste, emissions, health impacts and loss of biodiversity, the digitised agrifood chain may represent a cure that is worse than the disease, leading to greater energy consumption, e-waste and animal distress. Traditional ways to internalise externalities include the use of incentive schemes such as subsidies, taxation, or even the exclusion of certain technologies or production practices from public procurement. These policy approaches should be extended to reflect specific challenges of the digital age: for example, AI developers could be asked to declare the energy consumption costs related to the use of AI techniques such as deep learning, and the total environmental cost of using such techniques could then be included in the information available to end users.

Providing incentives to shorten the supply chain

Shorter supply chains can be more sustainable, as well as more geared towards adequate empowerment of both small-scale farmers and end users. Digital technologies can shorten the supply chain in many ways, and they have already started doing it. Obvious examples are the platformisation of food supply, which connects producers and end users more easily by reducing search and delivery costs; but also blockchain deployment to improve food traceability, which in turn reduces the need for intermediaries.

Public policies to enable reallocation of excesses

Policies can be divided in three large categories: prevention (reducing surplus at the source); recovery (reusing for human consumption); and recycling (feeding animals, creating energy or compost). Digital technologies such as blockchain and AI will lead to more predictive, accurate supply and distribution of food. Most importantly, the platform and "app" economy is already facilitating price discrimination for food close to expiry, segmenting the market, allowing for more participation of poorer consumers and thereby potentially tackling hunger and poverty.

An ethical and policy framework for AI and data management in B2C

Three aspects are most important in this domain. First, it is essential to require that personal data are not re-used for other purposes than that of providing advice or sold to third parties for commercial reasons such as advertising. Second, while personalised nutrition systems must discriminate to be useful to the end user, they should not discriminate in a way that is commercially motivated, and clear rules have to be established to avoid that a specific online platform or application discriminates across equivalent products on the market, by recommending specific brands or nudging users towards specific retailers. Finally, in the case of recommendation engines, it would be extremely important to include information on the sustainability of specific types of products, possibly even enticing users to engage in sustainable consumption practices through various forms of nudging (e.g. gamification, point-based systems, etc.).

Raising the skills and awareness of farmers and consumers

Numerous studies have confirmed a positive relationship between education and productivity in the agricultural sector. But in the case of digitised agrifood, the skills needed are quickly evolving. Technological skills should aim at training farmers to work with robots, work with processed data, choose appropriate solutions according to the farming project, gain an understanding of computer science, advanced machinery and complex apps. Environment skills include understanding legislation, gaining expertise in circular agriculture and gaining knowledge of local ecosystems. In all of these domains, technology can come to the rescue again through online courses and distance learning.

The EU can play a leading role, but it must first do its homework

The policy mix described above can be usefully applied to the case of the European Union, where the debate is very lively, in particular due to the ongoing reform of the Common Agricultural Policy, and also due to the recently announced "green new deal", which the new European Commission is expected to launch in the first half of 2020. **The EU is the only large bloc that has sufficient ability, resources and credibility to lead the great transformation in the agrifood sector that is needed to achieve sustainable development.** The European Commission has shown, at least in theory, strong commitment towards the SDGs, and promised to mainstream them in policies such as the European Semester, the EU Budget, the better regulation agenda, and the external action strategy. The von der Leyen Commission seems likely to lead to a **renewed commitment towards sustainability, in particular from an environmental perspective, thanks to the launch of a "European Green Deal"**, as defined by the new President-elect in her political guidelines. Importantly, the new European Commission will work on a **coordinated strategy for a healthier planet** by combining the actions of several commissioners. The commitments expressed so far are far-reaching, but still fall short of referring to the essential role of digital technologies. Meanwhile, in April 2019, a joint declaration between the European Commission and 25 member states was signed for the "digitalisation of European agriculture and rural areas", which may bring encouraging new developments for digitising agrifood.

Reforming the CAP to embrace sustainability

A key role in the reform of Europe's approach to the agrifood sector will inevitably be played by the ongoing reform of the Common Agricultural Policy (CAP). The European Commission, in selecting the nine objectives of the CAP, made extensive reference to digital technologies. The proposed reform however seems to be still relatively vague in proposing new tools to boost technological adoption. Possible options to promote new technologies in the CAP include **granting a "sustainability bonus" to farmers,** conditional on investment in precision agriculture technologies; and creating a dedicated third pillar dedicated to environment and sustainable technologies. Most importantly, the distribution of funding in the CAP should not leave the bulk of funding in the hands of larger players, as is currently the case. **Small-scale farmers are the ones that deserve more support** in order to lead the agrifood chain towards a more sustainable path.

Adopt a decentralised governance model in all EU agrifood-related policies and investment

The need for more balance along the value chain reverberates on the desirability of more distributed, decentralised approaches to governance. The current EU approach to the CAP and to rural development support does not go far enough in supporting the **creation of local organisations and the empowerment of these organisations with new skills and competences,** including in particular data management and sharing, but also entrepreneurship and the managerial and legal competences needed to make the most out of the new digital technologies in an ever-changing market context.

Furthermore, **the integration of new digital technologies in the current approach still seems limited**, and the Commission should adopt guidance, ad hoc funding as well as non-financial support for the development of community-based solutions. Furthermore, a **stronger integration of those solutions with the Sustainable Development Goals** should be achieved in the coming year, as the Commission finalises its Agenda 2030 as well as the Green New Deal and the From Farm to Fork strategies.

Europe as a global actor: directions for trade and sustainability policy

Three years ago, in 2016, the European Commission adopted a new global strategy, deeply rooted in the SDGs both at home and globally. One year later, **the European Consensus on Development emphasised the role of "policy coherence for sustainable development" (PCSD)** as the approach to be adopted by the Commission in development and cooperation. Today, this new orientation needs further promotion and political commitment.

A new governance: towards a conglomerate, multi-level system for sustainable development aid and cooperation

The European Commission should increasingly work together with member states to ensure that EU and national funds all move in a coherent direction to promote sustainable development in all countries in which funds and resources are deployed. Together with the EU, strong national delegations from member states are active on the ground, with a very wide reach, and often the overlap creates a duplication of resources and inconsistencies in the strategies pursued. Despite the adoption of a recent first "Joint Synthesis report", alignment between these efforts and the SDGs, as well as a systematic assessment of the effectiveness of development aid, can still be significantly improved.

Second, the EU should ensure that its instruments for development aid are coherent and oriented towards the SDGs. For example, Aid for Trade (which represents a third of EU Official Development Assistance) should seek to reduce inequality and "leave no one behind", including by empowering small-scale farmers; and the **External Investment Plan** should consistently aim to support in a systemic way those parts of the population that most need it, with a view to reducing inequality, nurturing human capital, tackling the gender gap, strengthening institutions and the rule of law, and ultimately creating the preconditions for sustainable development.

The creation of a new EU 'Bank for Sustainable Development' should be accompanied by an overhaul of the governance of development aid. This is urgent, not only for the achievement of SDGs at the global level, but also to re-establish EU's role as a trailblazer of sustainable development in a global context in which no other superpower can take on such a role. However, a considerable dose of political courage and commitment are needed given the inevitable obstacles of merging or restructuring consolidated, giant bodies such as the EIB and the EBRD, and imposing more coordination between large institutions at the national level, with different competences and traditions.

Launch new orchestration schemes to speed up digitising agriculture for sustainable development in key areas

The EU, especially if endowed with a bank for Sustainable Development, would be **in a privileged position as an orchestrator of mission-oriented initiatives in combination with public institutions (e.g. FAO) as well as private organisations and foundations** in the EU and non-EU countries, and NGO-led initiatives. These orchestration schemes could help achieve the systemic, holistic approach we advocated in this report.

Embedding digital technology and agro-ecology in the future development and cooperation policy of the European Union

Digital technology is essential, although not sufficient, to achieve sustainability in the agrifood chain: and absent a substantial commitment on the side of international donors, the digital transformation can only exacerbate inequality between and within countries. Aid in this context should thus set goals and targets in all the following areas:

- Helping developing countries leapfrog in connectivity;
- Offering an integrated bundle of technological solutions for the whole value chain;
- Using conditionalities and tech-enabled reporting to establish trust in the value chain and in international aid;
- Prioritise the reduction of inequality and of the gender gap, and the increase of human capital.

Championing digital technology 'for good'

The EU will be called to blaze the trail on the use of new technologies for good. One clear example is in Artificial Intelligence, where the EU has stated its ambition to lead the way towards "Trustworthy AI". This is a domain in which Europe could really attempt to fill a gap, and try to lead the rest of the world. Failure to recognise and publicly promote the role of AI and its related technologies for a more sustainable future society would represent an enormous missed opportunity for Europe and the world.

SUMMARY
OF OUR MAIN FINDINGS

Fixing agrifood is essential, but not sufficient, to save the planet

Digital technologies are essential, but not sufficient, to fix agrifood

A holistic 'policy mix' is needed for future food system policies

1. Ensuring adequate connectivity
2. Deploying the full technology stack
3. Promoting entrepreneurship, building capacity and facilitating technology transfer
4. Generating and sharing data for distributed, sustainable governance
5. Rebalancing the bargaining power of farmers, distributors and data managers
6. Attributing responsibility for negative externalities throughout the value chain
7. Providing incentives to shorten the supply chain
8. Public policies to enable reallocation of excesses and reduction of food loss and waste
9. An ethical and policy framework for AI and data management in B2C
10. Raising the skills and awareness of farmers and consumers

The EU can play a leading role, but it must first do its homework

The Common Agricultural Policy should be reformed to embrace sustainability through technology.

The distribution of funding should not leave the bulk of resources in the hands of larger players.

The EU must adopt a decentralised governance model in all EU agrifood-related policies and investment.

The current approach does not go far enough in supporting the creation of local organisations and their empowerment with new skills and competences, including in particular data management and sharing, but also entrepreneurship and the managerial and legal competences needed to make the most out of the new digital technologies in an ever-changing market context.

The integration of new digital technologies in the current approach still seems limited, and the Commission should adopt guidance, ad hoc funding as well as non-financial support for the development of community-based solutions.

Europe as a global actor: trade and sustainability policy priorities

The European Commission should work with member states to ensure that development aid moves in a coherent direction to promote sustainable development in developing countries.

The EU should ensure that its instruments for development aid are coherent and oriented towards the SDGs.

The future EU 'Bank for Sustainable Development' should lead to an overhaul of the governance of development aid, transforming the EU into an orchestrator of mission-oriented initiatives that implement the systemic, holistic approach we advocate in this report.

EU development aid should be based on actions such as (i) helping developing countries leapfrog in connectivity; (ii) offering an integrated bundle of technological solutions for the whole value chain; (iii) using conditionalities and tech-enabled reporting to establish trust in the value chain and in international aid; and (iv) prioritising the reduction of inequality and the gender gap, and the increase of human capital.

The EU should be a trailblazer in the use of digital technologies 'for good', for example in the case of Artificial Intelligence.

INTRODUCTION

Out of time error?

Introduction: Out of time error?

We live in a crucial transition for the future of our planet. Scientists, practitioners and policymakers largely agree that a coordinated, ambitious wave of reforms is needed to bring our economy, society and environment onto a sustainable path. Rising to the challenge that we have created is an urgent endeavour as much as a difficult one: complexity, inter-dependency, problems of collective action and unfavourable political trends have led some commentators to lose hope on the prospects for a shift of gear towards a more sustainable future. At the same time, research and technological breakthroughs promise to shift the frontier of what is possible, thereby expanding the menu of options for saving the Earth, and mankind with it. And the younger generation is increasingly alert and determined to put pressure on world leaders to change path and take action before it is too late.

The Anthropocene has led to the progressive deterioration of climate conditions on the planet.[1] A number of recent reports published by the Intergovernmental Panel on Climate Change (IPCC) and a report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have denounced the extreme urgency of the situation, at the same time showing the **tight inter-dependency between climate change and biodiversity.** The IPBES (2019) report, compiled by 145 expert authors from 50 countries over the past three years, warned that "the health of ecosystems on which we and all other species depend is deteriorating more rapidly than ever", and argued even more vibrantly that "we are eroding the very foundations of our economies, livelihoods, food security, health and quality of life worldwide". The same report found that around one million animal and plant species are now threatened with extinction, more than ever before in human history; at the same time, greenhouse gas (GHG) emissions have doubled since 1980, raising average global temperatures by at least 0.7 degrees Celsius. Using the World Meteorological Organisation's definition of global average surface temperature, and the late 19th century to represent its pre-industrial level, we just passed 1°C and are warming at more than 0.2°C per decade, which would take us to 1.5°C around 2040. One IPCC report published in late 2018 further warned that **the world has no more than 12 years to invert these trends without sliding into chaos:** but this is only an estimate, and major negative effects on climate are already visible in many regions, and will trigger chain reactions that are difficult to predict at this stage.

Deteriorating environmental and biodiversity conditions are not only intertwined, but also heavily interrelated with social and economic impacts. Climate change is disproportionately hitting poorer regions, thereby causing hunger, social unrest and migration (BCFN and Macrogeo, 2017). Not surprisingly, urban areas have more than doubled since 1992; recent data suggest that ice melting in the Arctic region, on top of coastal damage, is causing drastic decreases of West African monsoon precipitation, determining losses in agricultural areas and potentially triggering the migration of millions of people in the coming decades. These recent reports also converged on the fact that "current negative trends in biodiversity and ecosystems will undermine progress towards 35 out of the 44 assessed targets of the Sustainable Development Goals, related to poverty, hunger, health, water, cities, climate, oceans and land (SDGs 1, 2, 3, 6, 11, 13, 14 and 15). **Loss of biodiversity is therefore shown to be not only an environmental issue, but also a developmental, economic, security, social and moral issue as well"** (IPBES 2019).

Not surprisingly, social and economic disruptions are accompanied by a period of short-termism, when not outright denial, in world politics. Looking at current trends, the agreement reached in September 2015 by 193 countries on the SDGs seems to belong to a very distant era in human history. Indeed, much has changed since then, with the United States reaching a record low in its commitment to SDGs, Brazil entering a new era of populist government and China struggling to show leadership on environmental, let alone social, achievements. The failure of recent environment-related conferences such as COP24 in Katowice and the alarming evidence of a wave of de-regulation that is leading to the repeal of several pieces of health, safety and environment regulation i.a. in the US and Brazil, add to these mounting concerns.[2]

Figure 1 – Planetary boundaries

Source: J. Lokrantz/Azote based on Steffen et al. 2015.

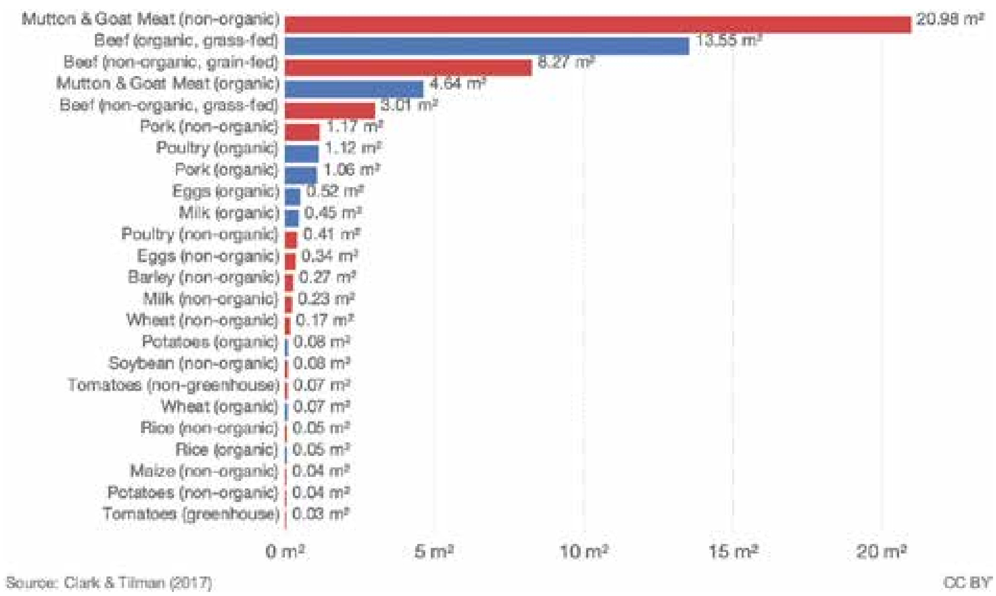
Recently, thanks to the spontaneous initiative of the younger generation in the occasion of the UN General Assembly, this period of impasse seems likely to be replaced by a time of greater awareness and concern. However, absent a major effort to transform current business models and consumption patterns, the current momentum in public opinion will not translate into meaningful policy actions.

Most of the responsibility for leading the world towards sustainability falls on the shoulders of the European Union, where a Green New Deal was recently announced by the new President-designate of the European Commission, Ursula von der Leyen, who asked one of its Executive Vice-Presidents, Frans Timmermans, to take the lead on this initiative. This initiative will have to focus i.a. on the sustainability of the agrifood chain, as a major cause of emissions and both social and environmental damage.

Outside the planetary boundaries: the weight of agrifood

Agriculture and food systems (hereinafter, 'agrifood') are both drivers and victims of these disruptions. Agriculture is responsible for a significant portion of GHG emissions, including a majority of non-CO2 emissions. The global agri-food chain, as whole, is estimated to contribute **between 21% and 37% of total net anthropogenic GHGs**[3] **and uses the overwhelming majority of water resources on Earth.**[4] **The agrifood chainis thus one of the key battlefields in mankind's struggle for a more sustainable future.** Excessive and unsustainable use of land resources, in particular, determines growing imbalances: land degradation has reduced the productivity of 23% of the global land surface, and in 2015 33% of marine fish stocks were being harvested at unsustainable levels. Up to 400 million tonnes of heavy metals,

Figure 2 – Land use per 100 Kcal by food and production type



solvents, toxic sludge and other wastes from industrial facilities are dumped annually into the world's waters, and fertilisers entering coastal ecosystems have produced more than 400 ocean 'dead zones', totalling more than 245,000 km2 (591-595), a combined area greater than that of the United Kingdom. As observed by Rolnick et al. (2019), much of modern-day agriculture is dominated by monoculture, the practice of producing a single crop on a large swath of land. Farmers to manage their fields with tractors and other basic automated tools, which strips the soil of nutrients and reduces productivity. As a result, many farmers rely heavily on nitrogen-based fertilisers, which can convert into nitrous oxide, a greenhouse gas 300 times more potent than carbon dioxide. It is estimated that agriculture contributes a staggering 58% of nitrous oxide to global GHGs.

Rockström et al. (2009) introduced the concepts of '**planetary boundaries**' and a 'safe operating space for humanity', which have more recently been revised by Steffen et al. (2015). The planetary boundaries are intended to represent Earth system processes, which, if crossed, could generate unacceptable environmental change potentially endangering human existence. The nine planetary boundaries currently recognised are land system change; freshwater use; biogeochemical cycles (nitrogen and phosphorous); biosphere integrity; climate change; ocean acidification; stratospheric ozone depletion; atmospheric aerosol loading; and introduction of novel entities. Although the approach has been criticised in various ways, it provides a useful way of looking at the limits of the Anthropocene, and the thresholds that should not be breached if humans want to preserve the sustainability of the planet.

Campbell et al. (2017) observe that **two planetary boundaries are at high risk (biosphere integrity and biogeochemical flows) and agriculture has been the major driver of this trend.** Two are in a zone of uncertainty i.e. at increasing risk, with agriculture a major driver of one of them (land system change) and a major contributor to the other (climate change). Agriculture is also a significant or major contributor to change for many of those planetary boundaries still in the safe zone. To reduce the role of agriculture in transgressing planetary boundaries, many actions will be needed, including those related to agrifood systems.

Our understanding of planetary boundaries is however still very limited. For example, Rockström et al. (2009) suggested that no more than 15% of the Earth's ice-free surface should be converted to cropland. Since then, several other studies have reached similar estimates (12.6-15.2% of terrestrial area). Today, "more than a third of the world's land surface and nearly 75% of freshwater resources are now devoted to crop or livestock production". However, more recent research has shown that the estimated sustainability thresholds should be revised to account for the impact on biodiversity. Usubiaga-Liaño et al. (2019) find that a maximum of 4.6-11.2% of the global ice-free land can be allocated to cropland (and 7.9-15.7% to pasture) to meet biodiversity constraints.

The quest for improving agricultural productivity is a cause of instability and land disruption. Intensive agriculture and the massive use of pesticides are key causes of plummeting biodiversity, and this in turn makes the land more vulnerable to contamination, thereby creating more likelihood of diseases. For example, a recent paper published by the journal Biological Conservation reviews 73 existing studies from around the world published over the past 13 years, finding that declines in almost all regions may lead to the extinction of 40% of insects over the next few decades. This may heavily affect the food chain, and may alter living conditions for many species of birds, reptile, fish. Pastor et al. (2019) recall that **by 2050, without major policy interventions, human water use and irrigated areas are expected to increase rapidly due to population growth and an increase in food demands; but at the same time, crop yields are projected to decrease by more than 80% in some areas under the highest-emission climate scenario, which is hard to reconcile with the imperative to increase land use to meet the needs of a population that may hit 10 billion by 2050.**

The need for a Great Food Transformation

Food is at the core of all these developments. And it is in food production, distribution and consumption that the most evident and detrimental inconsistencies are to be found. Food consumption, according to the United Nations, is impacting the climate in many ways. A third of the food produced in the world each year (approximately 1.3 billion tonnes at an economic cost of $940 billion to farmers, companies, and consumers) is lost or wasted: **wasted food is responsible for roughly 8% of global emissions.** As recently reported by the EAT-Lancet Commission (2019), "unhealthy and unsustainably produced food poses a global risk to people and the planet". Importantly, **there are more than 820 million people that have insufficient food, but many more consume a diet that is so unhealthy that it contributes to severe health complications and premature death.** Global food production is defined as "the largest pressure caused by humans on Earth, threatening local ecosystems and the stability of the Earth system". Systems of food production release massive amounts of greenhouse gases into the atmosphere: this includes methane and nitrous oxide, which have 56 times and 280 times the global warming potential (over 20 years) of carbon dioxide, respectively.[5]

Some of these processes are at least partly inevitable, which suggests that eliminating all greenhouse gas emissions related to food production is not feasible.
However, **the weight imposed by agriculture and global food production on the planet is such that fixing food means also saving the planet.** According to the EAT-Lancet Commission, dietary shifts are needed, including a greater than 50% reduction in global consumption of red meat and sugar, and a greater than 100% increase in consumption of nuts, fruits, vegetables, and legumes. Such dietary changes are expected to substantially benefit human health, averting about 10.8-11.6 million deaths per year.

What is increasingly clear is that **solving the 'food challenge' will also lead to successfully addressing the climate challenge,** strengthening the awareness of the importance of "Fixing food" for the sustainability of the planet (BCFN 2018). At the same time, healthy diets from sustainable food systems are intertwined with all SDGs, and require for example the provision of high-quality primary health care that integrates family planning and education; as well as **substantial shifts towards healthy dietary patterns, large reductions in food losses and waste, and major improvements in food production practices.** A recent IPCC Report on Climate Change and Land observed that **the per capita supply of vegetable oils and meat has more than doubled and the supply of food calories per capita has increased by about one third since 1961. By 2050, dietary changes could free up several million square kilometres of land, and reduce global CO2 emissions by up to eight billion tonnes per year, relative to business as usual.**

Can technology push planetary boundaries?

Against the background of adverse demographics, and the worrying trends of intensive agriculture, food production and consumption, other trends promise to turn back the clock. On the one hand, the promise of specific technologies such as geo-engineering or carbon capture and storage (which fall outside the scope of this report, dedicated to digital technology) comes with threatening side effects in terms of overall sustainability, and if anything exacerbates the Anthropocene's vocation towards altering the natural course of events.

Conversely, **in the agrifood sector the evolution of digital technology has the potential to play a major role in sustainability.** Key trends such as the acceleration of computing power, the emergence of the Internet of Things (IoT), the rise of 5G connectivity, Distributed Ledger technologies (DLTs) and, above all, sophisticated forms of Artificial Intelligence (AI) promise to shift planetary boundaries, possibly remedying situations that would otherwise appear to have become hopeless. As will be explained in more detail below, modern AI techniques (especially when coupled with robotics and the Internet of Things) can lead to optimising soil management and increasing crop yields, leading to an optimised matching of food supply and demand, massively reducing the use of pesticides and, with the help of adequate data, governance and skills throughout the value chain, empowering farmers and consumers to realise the full promise of the Great Food Transformation. Likewise, DLTs, cloud and edge computing can achieve unprecedented, trusted control of the integrity of value chains. Again AI, in the form of interactive user interfaces such as conversational bots, and in combination with connected devices, can transform the user experience and lead to more sustainable patterns of consumption, for example guiding consumers towards healthier diets. And the power of peer-to-peer (P2P) networks and the collaborative economy can lead to massively reducing the problem of food waste.

Can these digital technologies really turn back the clock? The promise is real, and far-reaching, but also fraught with uncertainty and peril. The governance of digital technologies is still being developed in many legal systems, and while countries like France, Canada, Japan and (possibly) Italy have been working in the direction of leveraging digital technologies for sustainable development, many superpowers such as the US and China appear to be prioritising global competitiveness and areas such as defence and security. This, overall, is not the best precondition for what could, and should become a collective effort towards leveraging technology for good. Moreover, and relatedly, in many countries there are insufficient legal, fiscal and financial incentives for companies to invest in research and development to develop digital technologies that can accelerate the transition towards more sustainable business models, as well as for consumers to prefer healthier diets. In general, policy coherence for sustainable development (PC4SD) is still unknown in many countries, and requires additional, specific effort in terms of regulatory governance (Ashford and Renda 2016). Furthermore, the lack of access to technologies and adequate digital skills risks leaving this outstanding potential untapped, especially when it comes to empowering farmers and consumers.

More generally, the deployment of digital technologies can provide a very powerful contribution to the quest for sustainable agrifood, and at the same time help us address existential risks, such as climate-related ones. However, **technology is not a replacement for strong political will and commitment; and it is no replacement for changes in producer and user behaviour, which are essential in order to trigger a Great Transformation.** Also, as will be explained below in more detail, **digital technologies often contribute to both the problem and the solution.** For example, in a recent paper Strubell et al. (2019) find that sophisticated AI techniques such as Deep Learning depend on the availability of exceptionally large computational resources that necessitate similarly substantial energy consumption. The researchers found that the process of building and testing a model required training 4,789 models over a six-month period, cumulatively emitting around 78,000 pounds of CO2 equivalent, i.e. seven times the annual footprint of the average human. At the same time, companies are using AI to reduce the energy costs of data centres and improve wind farm efficiency, as well as finding new ways of training AI without a heavy carbon footprint.

A holistic agenda: the SDGs as a framework for digital agrifood

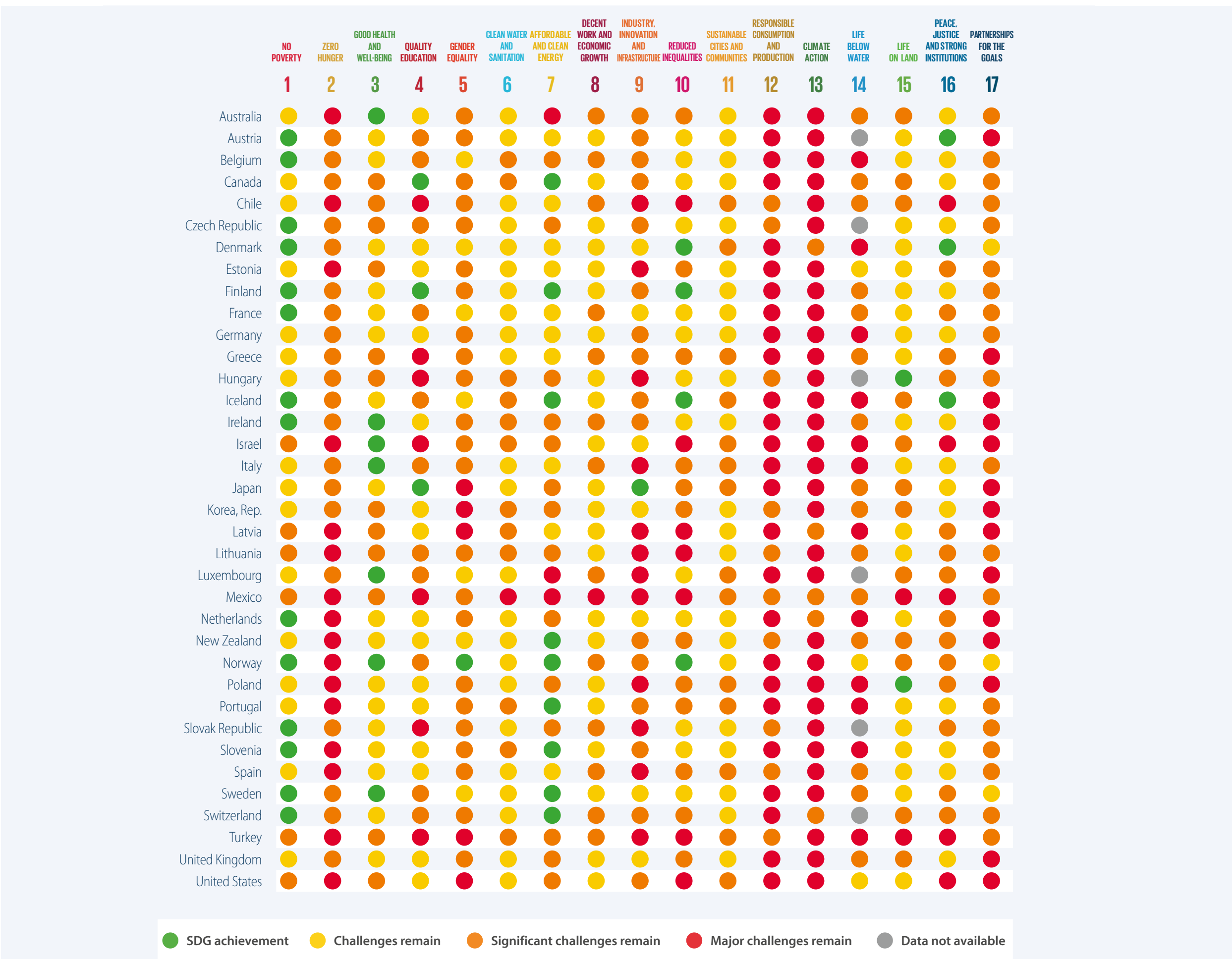
The interconnectedness and complexity of the problems and challenges explored in this report is unprecedented and calls for a common overarching framework that can guide policymakers and businesses in addressing trade-offs, mastering synergies and managing risks. This framework is provided by the SDGs, which incorporate the economic, social and environmental impacts that needs to be achieved in the next decade, in order to bring society back on a sustainable path. However, despite the widespread support that the SDG framework has received since 2015 at the global level, recent reports have confirmed that, with the exception of Scandinavian countries, **all high-income countries are far from a trajectory that would lead them to achieve the 17 goals, and struggle in particular with the four objectives that are most related to agrifood: sustainable consumption and production patterns, climate action, aquatic life and life on land.**

In this context, technology is increasingly at the core of the debate on how to achieve the SDGs. While the possible contribution of digital technologies to the SDGs has initially been limited to the discussion of Goal 9 (industry, innovation, and infrastructure), there is now a well-established understanding that **digital technology can help drive progress for all goals,** and it might be essential to harness this potential to be able to reach the goals by 2030, as time is running out. Untapping this potential requires that policymakers integrate technology developments into a **coherent policy framework.** This is not yet happening, in particular when it comes to emerging, disruptive and pervasive digital technologies that bear the highest potential for achieving the SDGs, such as blockchain and (more generally) DLTs; the Internet of Things; and Artificial Intelligence. Renda (2019), observes that the use of digital technologies along the agrifood chain features an outstanding potential to contribute to the SDGs, and in particular to help combat and eradicate hunger without a massive increase in food production. Current estimates suggest that food supplies need to rise 60-70%[6] by the year 2050 to meet demand for a global population expected to rise to 9.2 billion. It is unlikely that current farming methods can meet this challenge or that the environment can sustain food production on this scale. **Digital technologies can be usefully combined with holistic approaches to the management of the agrifood chain (such as agro-ecology, see Wezel et al. 2009), which also incorporate the social and environmental dimensions.**

Will governments be able to leverage the entire potential of digital technologies? As observed in Renda (2019), **it is important that the focus of governments is not limited to one single technology, but to the whole stack** as presented below in Chapter 1 below. Moreover, the issue of technology diffusion is increasingly essential since most of the technologies that can help achieve the SDGs are already available, yet they fail to spread within and across industries, and are further hampered by additional obstacles such as the lack of policy coherence, incumbency issues and lack of skills needed for a full uptake. **Very often some of the critical players along the value chain are unable to make the most of the data revolution.** In the case of agrifood, small farmers often have limited knowledge of how to use their data, and consumers can easily be nudged into sub-optimal, profit-motivated advice by suppliers.

Moreover, technology needs direction: for example, the use of AI in agriculture is already leading to

Figure 3 – SDG dashboard for OECD countries



Source: SDSN and Bertelsmann (2019).

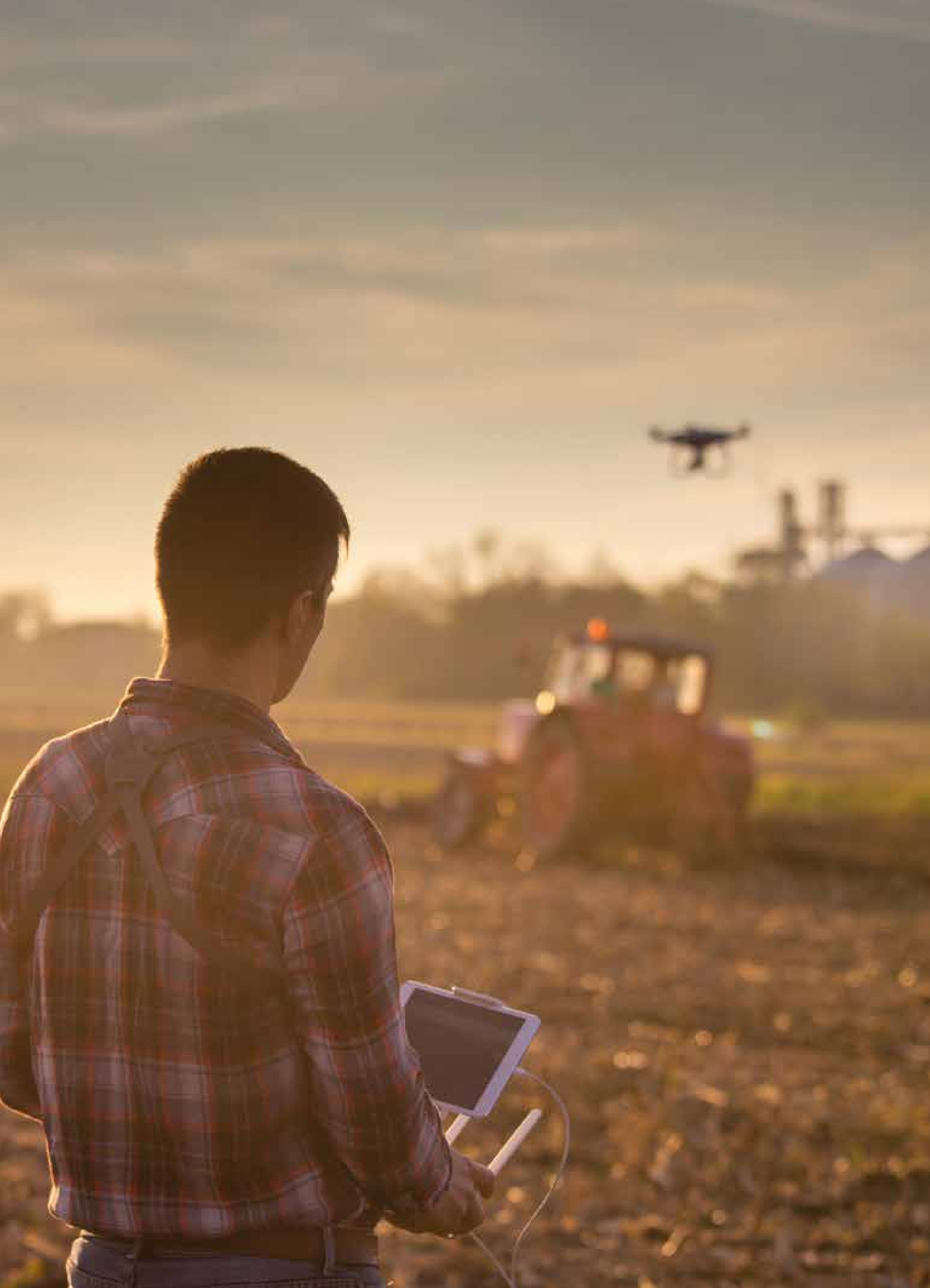
important results in terms of optimisation of processes, prediction of events, detection of diseases, and user empowerment through personalised nutrition: however, **there is a need to establish shared ethical and legal standards** to avoid that AI use impinges on user self-determination and agency, as well as privacy and integrity, leading to cases of discrimination, hyper-nudging of consumers, and intrusive use of personally identifiable information. More generally, **the alignment between technology development and medium-term policy objectives such as SDGs must be ensured if technology is to be used 'for good'.** This includes also an assessment of technology applications that is sufficiently holistic to account for possible trade-offs between SDGs.[7] In line with our reasoning, the Sustainable Development Solutions Network and Bertelsmann (2019) observe that "sustainable land-use and healthy diets require integrated agriculture, climate and health policy interventions". They also observe that "transformations towards sustainable land use and food systems are required to balance efficient and resilient agriculture and forestry with biodiversity conservation and restoration as well as healthy diets".

A reader's guide to this report

This report looks at options for boosting the digital transformation of the agrifood chain, with a view to achieving the SDGs. **The report does not address specifically the application of new technologies to food, nor does it focus on genetically modified organisms. Rather, we explore possible ways in which the emergence of new digital technologies can make the current agrifood chain more efficient, and more sustainable.** Our research is therefore complementary to ongoing academic research, i.a. on the impact of the diffusion of gene editing techniques such as CRISPR in agriculture. The overall impact of a smarter value chain should include also the application of these technologies, as well as policies that adequately mitigate their associated risks, while reaping their benefits.

The drafting of this report benefited from the support of an expert group, which met three times between July and October 2019. We would like to thank all experts for their valuable input, including i.a. Silvia Balmas (European Foundation Centre), Christine Frison (University of Antwerp and Université Libre de Bruxelles), Ana Cuadrado Galvàn (Bio-Based Industries Joint Undertaking), Tim Gentle and Kat Bidstrup (Think Digital), Relja Kosanovic (Ahold Delhaize), Danielle Nierenberg (Food Tank), Cristina Pozzi (Impactscool), Camillo Ricordi (University of Miami), Philipp-Andreas Schmidt (Bayer), Riccardo Valentini (University of Tuscia), Sveatoslav Vizitiu (Wello), Stefano Zamagni (University of Bologna), Marc Zornes (Winnow).

The report is structured as follows: Chapter 1 below introduces the reader to the present and foreseeable future of the digital technology "stack", and the key opportunities and challenges it offers for the agrifood chain. Chapter 2 digs deeper into a number of digital technology use cases in different parts of the agrifood chain: precision farming, data governance to empowersmall farmers, blockchain applications to optimise distribution, consumer empowerment through AI and IoT, and reducing food waste through collaborative economy and AI. Chapter 3 discusses the possible risks and challenges associated with the deployment of digital technologies at scale. Chapter 4 discusses policy actions that would be needed to steer technological developments towards sustainable agrifood, with specific emphasis on the role of Europe, both at the EU and member state level, in promoting the digital transformation of agrifood towardssustainability. Finally, Chapter 5 outlines a number of policy recommendations that emerge from our research, aimed at promoting reform at the global, EU and national level.



NOTES TO THE INTRODUCTION

[1] The 'Anthropocene' is a term widely used since its coining by Paul Crutzen and Eugene Stoermer in 2000 to denote the present geological time interval, in which many conditions and processes on Earth are profoundly altered by human impact. This impact has intensified significantly since the onset of industrialization, taking us out of the Earth System state typical of the Holocene Epoch that post-dates the last glaciation.

[2] https://www.theguardian.com/environment/2019jun/12/hundreds-new-pesticides-approved-brazil-under-bolsonaro; https://www.nytimes.com/interactive/2019/climate/trump-environment-rollbacks.html; https://www.cnbc.com/2019/05/08/california-moves-to-ban-farm-pesticide-that-trumps-epa-has-defended.html.

[3] IPCC, 2014, quoted from the International Conference on Agricultural GHG Emissions and Food Security – Connecting research to policy and practice –, September 2018. https://www.agrighg-2018.org/fileadmin/ghg-agriculture/AgriGHG_Volume_of_Abstracts.pdf

[4] According to the recent IPCC report on "Climate Change and Land", Agriculture, Forestry and Other Land Use activities accounted for around 13% of CO2, 44% of methane (CH4), and 82% of nitrous oxide (N2O) emissions from human activities globally during 2007-2016, representing 23% of total net anthropogenic emissions of GHGs. If emissions associated with pre- and post-production activities in the global food system are included, the emissions are estimated to be 21-37% of total net anthropogenic GHG emissions.

[5] Methane is produced during digestion in ruminant livestock, such as cows and sheep, or during anaerobic decomposition of organic material in flooded rice paddies. Nitrous oxide mainly arises from soil microbes in croplands and pastures and is affected by soil fertility management, such as fertiliser application. Carbon dioxide is released by agricultural land from tillage of soils and during burning to clear land of plants, soil, organic matter, and agricultural residues, and from burning fossil fuels by farm machinery, for production of fertilisers, and in transport of agricultural products. Carbon dioxide is also released when converting natural ecosystems, especially forests, to agriculture.

[6] George Silva, Michigan State University, 2018. Accessed 21/06/19, https://www.canr.msu.edu/news/feeding-the-world-in-2050-and-beyond-part-1

[7] For example, automation of jobs and the carbon footprint of data centres very often challenge the achievement of important SDGs such as limited or zero carbon footprint (SDGs 7 and 13); inclusive growth, full and productive employment, and decent work for all (SDG 8); quality education (SDG 4); and the promotion of women's empowerment (SDG 5). In this respect, proposals to steer AI development in a direction that is fully consistent with SDGs appear to be more likely to achieve this form of policy coherence than proposals merely based on GDP and competitiveness.


Grow
75%
Expose
Greenhouse
100%

CHAPTER 1
The digital technology stack: a primer

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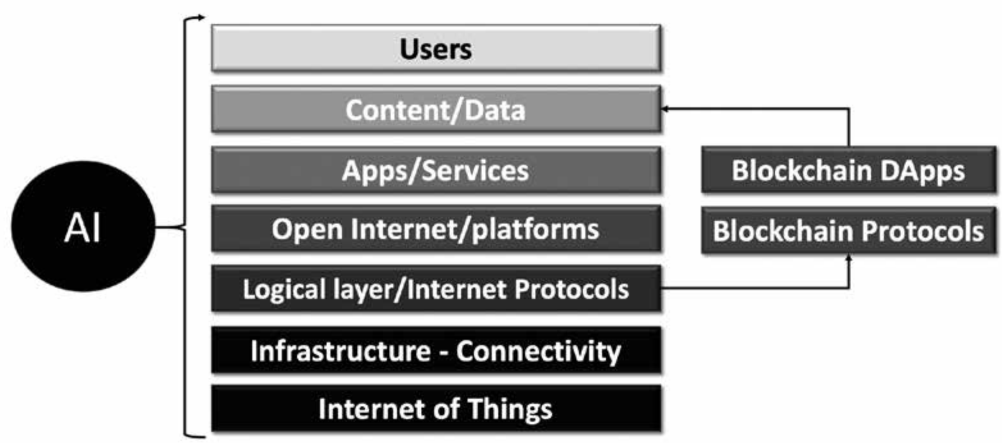
The digital technology stack: a primer

The past few years have been characterised by the rise of a new wave of technological developments, which promise to revolutionise the digital economy, bringing it towards an era dominated by dramatically superior computing power and connectivity speeds; a skyrocketing number of cyber-physical objects connected to the internet (the Internet of Things, or IoT, powered by nano-technology and by 5G wireless broadband connectivity); and the pervasive spread of Artificial Intelligence into almost all aspects of personal and professional life. This new stack will be composed of powerful hardware, including faster and smaller processors; distributed computing capacity through edge (or fog) computing; new, distributed and decentralised platforms such as blockchain, able to keep audit trails of transactions and other asset-backed values; and a pervasive presence of AI-enabled solutions, mostly in the form of data-hungry techniques such as smart analytics, deep learning and reinforcement learning (Renda 2018; 2019). Focusing on all layers of this emerging

Figure 4 – The emerging digital technology stack



Source: Author's extrapolation.

stack is extremely important when it comes to scaling up these technologies to the benefit of society: merely focusing on one element, such as AI or blockchain, would not harness the full potential of this emerging world.

Figure 4 above portrays the digital technology stack. The IoT layer generates an unprecedented amount of data, requiring sensor technology, nano-tech, enhanced connectivity through 5G or satellite, and devices like drones or robots, able to generate live data remotely.[8] Regardless of the way in which data are generated, stored and exchanged, the use of AI will be ubiquitous in most supply chains. At the top of the supply chain, end users very often constitute the weakest link, due to the need to equip them with adequate skills in using digital technologies (Renda 2019).

Although no real estimate of the combined impact of these technologies on the future economy exists, several studies have already been published on the economic impact of AI, as well as on the impact of IoT in specific sectors. For example, recent reports by Accenture/Frontier Economics, McKinsey and PWC conclude that **AI will be a game changer for total factor productivity and growth, by gradually rising as a third pillar of production, together with labour and capital.** PWC (2018) concluded that by 2030, global GDP will be 14% higher due to AI development and diffusion; the Accenture study (Purdy and Dougherty 2018) finds that growth rates will be doubled by 2035 thanks to AI. The latter study also shows an industry-by-industry breakdown, which includes agriculture, forestry and fisheries: this sector is expected to **more than double its growth rate by 2030,** from 1.3% to 3.4% on a yearly basis thanks to AI. Similarly, the Internet of Things is expected to massively contribute to future growth: by 2020 approximately 30 billion devices are expected to be connected to the internet, and according to one recent forecast the number will soar to 125 billion in 2030. ARM, a big semiconductor firm recently acquired by Softbank, predicted that there will be as many as one trillion connected devices in 2035 (Renda 2018). Finally, DLTs are expected to complement these developments by solving various market failures along the supply chain, as well as empowering end users in their consumption choices; some commentators go beyond these expectations, and foresee a revolutionary impact of blockchain in many sectors, including agriculture and food, as will be explained in Chapter 2 below.

A number of important technological and organisational trends are transforming the digital economy, leading to a transformation that gradually permeates all sectors, including the agrifood chain. They include the **'platformisation'** of the ecosystem, which implies the emergence of large online digital intermediaries; the increased **virtualisation** of various parts of the ecosystem and of functions in the internet architecture; the emergence of **cloud computing and new, more distributed forms of computing** such as edge and fog computing; the rise of open and collaborative business models, often involving (at the higher layers) open IP strategies such as open source software and open patent portfolios; the growing prominence of **big data and data-driven innovation; the rise of AI** as a family of digital technologies that pervades all layers of the technology stack; and the increasing attractiveness of **distributed and decentralised architectures** such as Distributed Ledger Technologies.

Platformisation, virtualisation, servitisation

More in detail, **the emergence of platforms as a new, extremely efficient form of governance was initially a peculiarity of the internet ecosystem.** The fact that overly abundant information can be captured, organised, and conveyed to end users in a way that helps them navigate cyberspace has led to the rise of 'superstar' firms (tech giants) as extremely powerful and almost unrivalled players in the digital (and increasingly, in the real) economy. The centripetal forces featured by the internet, powered by network effects, and the ongoing digitalisation of many sectors of the economy has led to disruptions in many markets, and the potential entry of digital giant firms into traditional sectors, such as banking, energy, insurance, transportation, and of course agrifood. The economies of scale and scope enjoyed by these platforms are such that smaller traditional companies, if not adequately supported by policymakers, end up exiting the market, or being acquired. This, as will be explained below, calls for attention by policymakers, in particular when it comes to ensuring that the value created by companies in traditional markets is not entirely captured and extracted by digital players (Mazzucato 2018). The platformisation trend today affects also governments:[9] administrations today can provide application programming interfaces (APIs) to trusted intermediaries as way to open up their infrastructure to "private sector services and entrepreneurs, reduce the burden on and costs of government itself, and increase program effectiveness" (World Bank 2016).

These platforms' models often have a local outreach, but some exhibit some of the same characteristics of existing large online intermediaries, some of which create challenges for policymakers. In particular, the digital nature of transactions and the move from a property-based to an access-based economic model lead to legal and regulatory challenges such as the **dilution of liability, the deterioration of bargaining power for employees and independent contractors, and ultimately the distancing between corporate responsibility and sustainability impacts.** As a matter of fact, the sustainability of digital platforms is difficult to measure and, if needed, regulate, since platforms, themselves, are often much smaller (in terms of size of the corporation) than the economy that they coordinate and orchestrate. This is summarised with the expression "scale without mass" (Renda 2019): companies like WhatsApp could conquer hundreds of millions of end users with only 50 engineers, and a fistful of administrative staff. And companies like Amazon, already hitting the trillion-dollar market cap mark, are moving transactions that are worth much more (a recent McKinsey report estimates that more than 30% of global economic activity, approximately $60 trillion, could be mediated by digital platforms in six years' time).[10] However, **these large tech companies are currently not responsible for the sustainability of the businesses they host, or promote, on their platforms:** in other words, marketplaces and other online platforms normally convey only a very synthetic signal to their end users, consisting in the main characteristics (including price) of the products, as well as customer ratings. This implies that **a large and growing amount of market transactions, absent other public policy interventions (e.g. taxation, subsidies), takes place with total uncertainty about the impact on the sustainability of the players involved.**

A second, important trend evident in the evolution of the digital economy is the ongoing **virtualisation of a growing number of functions,** again made possible by technological evolution and underlying standardisation. With this standardisation come significant cost reductions and the disruption of existing business models. Perhaps the most evident trends in this respect are cloud computing and software-defined networking. With cloud computing, **technology has made it possible for small companies to avoid buying or leasing hardware and downloading software and applications: these traditional transactions were replaced by 'everything as a service',** which led to enormous advantages both for individuals and businesses.[11] The transition towards a 'cloud era' has led personal devices to become increasingly 'light', as users are able to lease software located in the cloud, as well as access their files stored somewhere in cyberspace, and managed by a cloud provider: to put it more simply, a limitless 'office LAN' where the main server is not located downstairs, but potentially on the other side of the globe.[12] An industry report defined "cloud implementation" as "an elastic execution environment involving multiple stakeholders and providing a metered service at multiple granularities for a specified level of quality (of service)”.[13] The most fast-growing, innovative parts of the ICT ecosystem include the emergence of the collaborative economy and distributed architectures. In particular, **the open, collaborative economy is emerging in many more sectors than the often-mentioned taxi (Uber, BlaBlaCar) and hotel/accommodation (Airbnb) sectors.**[14] As we will see in Chapter 2 below, agriculture is no exception.

The data-driven economy and the rise of AI

Another important trend that bears consequences for the evolution of the ICT ecosystem is the breath-taking surge in the **availability of data, coupled with the already-mentioned dramatic reduction in the cost of data storage and processing.** Worldwide Big Data market revenues for software and services are projected to increase from $42 billion in 2018 to $103 billion in 2027, attaining a compound annual growth rate (CAGR) of 10.5%. As part of this forecast, Wikibon estimates the **worldwide Big Data market to grow at an 11.4% CAGR between 2017 and 2027, growing from $35 billion to $103 billion.**

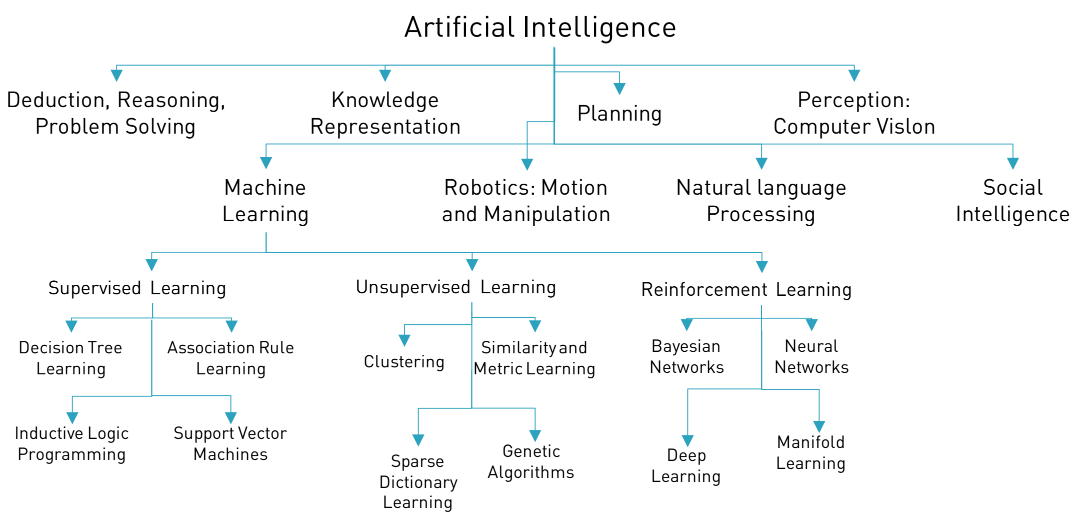
The power of big data analytics, according to many experts, still has to be fully discovered, especially if one considers that the overwhelming majority of data available for analytics (some say, 99%) has been produced in the past two years; or, as others have observed, “the amount of data generated in two days is as much as all data generated in human history before 2003”.[15] Coupled with the already existing move towards access-based services, the use of big data can lead to important changes in the value chain of almost every sector, from retail (e.g. ‘intelligent shelves’) to healthcare, insurance, and agriculture. As already demonstrated by projects such as PredPol, now implemented and adopted in some European cities after its first experiments in California, police enforcement can also make extensive use of big data to improve its nowcasting abilities.[16] The list of sectors is much longer – as long as the economy is wide. In agriculture, real-time data collection enables precision farmers to adjust water and fertiliser on the spot. Real-time data collection also allows for feedback to manufacturers and retailers on what consumers are buying and when – as in the case of intelligent shelves in supermarkets.

Big data applications are encompassing many sectors of the economy, but also many forms of innovation, including, increasingly, open innovation[17]**.** Powered by massive data availability, Artificial Intelligence (AI) is already being massively used in a number of areas. AI techniques include, i.a., search and planning; knowledge representation and reasoning;[18] machine learning, which has led to AI breakthroughs in fields such as search and product recommendation engines, speech recognition, fraud detection, image understanding, etc.; multi-agent systems; robotics; machine perception, including computer vision and natural language processing; and more.[19] In particular, **machine learning accounts for the largest portion of current investment in AI-related R&D:** it extracts patterns from unlabelled data (unsupervised learning), or efficiently categorises data according to pre-existing definitions embodied in a labelled data set (supervised learning). Machine learning is used i.a. in Google’s search algorithm, digital advertising, and online personalisation tools (e.g. the Amazon and Netflix recommendation engines; or the Facebook newsfeed). Machine learning also extends into quantitative processes such as supply-chain operations, financial analysis, product pricing, and procurement-bid predictions. **Today, nearly every industry is exploring or utilising machine-learning applications.** Within this domain, Deep Learning uses additional, hierarchical layers of processing (loosely analogous to neuron structures in the brain) and large data sets to model high-level abstractions and recognise patterns in extremely complex data. Deep Learning has made speech understanding practical on our phones and in our kitchens, and its algorithms can be applied widely to an array of applications that rely on pattern recognition. These tools are today made available by large corporations (Google's TensorFlow, Microsoft's Control Toolkit, and many other AI tools are free and open source) and operate on common computer hardware.

Use cases are quickly emerging in many specific sectors, beyond the internet economy, from autonomous transportation to home/service robots, healthcare, entertainment and education. AI can also potentially help development and cooperation by empowering low-resource communities, and by enabling more effective policing and, more generally, public safety. As a general-purpose family of technologies, **AI will pervade all sectors of the economy, and all aspects of professional and daily life. At the same time, it will have to be used responsibly:** many commentators also argue that AI, if badly governed, can represent an existential risk for our society;[20] whereas others observed that AI can make catastrophic events such as a nuclear war more likely.[21] While this threatening narrative should not overshadow the positive disruption that AI will bring to our future society, it is important to map possible risks, which will be as essential as opportunities in forming the basis for future AI policy and regulation. As a matter of fact, while biases already exist in society, the use of algorithms may in some cases exacerbate bias, amplify it, or create it de novo.

AI, and more specifically machine learning, is also a likely game changer when it comes to tackling climate change, including through revolutionising agriculture. Recently, Rolnick et al. (2019) map 13 solution domains in which machine learning can make a difference. In the same publication, Alexandre Lacoste takes stock of possible uses of machine learning in agriculture, focusing in particular on computer vision, reinforcement learning and control, and transfer learning. As will be explained in more detail in Chapter 2 below, such applications in agriculture include: the remote sensing of emissions through the combined use of hyperspectral cameras, standard satellite imagery and machine learning algorithms able to fill the gaps in data and obtain more precise information about emissions; the use of robots in the field, equipped with hyperspectral cameras and able to perform activities such as mechanical weeding, targeted pesticide application, and vacuuming of pests;[22] machine learning-enabled macroeconomic models aimed at predicting crop demand and deciding what to plant at the beginning of the season;

Figure 5 – Classification of AI approaches and domains



Source: Nazre and Garg (2015).

intelligent irrigation systems that can save large amounts of water while reducing pests that thrive under excessive moisture; can improve crop yield prediction, disease detection, weed detection, and soil sensing. These solutions often feature minimal hardware requirements, such as the use of Unmanned Aerial Vehicles (UAVs) with hyperspectral cameras. More generally, machine learning can be used to improve deforestation tracking through satellite imagery and computer vision, even helping law enforcement through the use of algorithms for detecting chainsaw sounds. Machine learning is also used in the development of techniques aimed at nudging consumers towards more sustainable consumption choices.

Against this background, **AI needs direction.** Just as it can help save the planet, it can also facilitate the deployment of controversial techniques such as solar geo-engineering and carbon farming, which imply very uncertain long-term consequences for the planet. Further, when used to 'nudge' end users, AI can often lead to excessive manipulation of end users, leading to losses in individuals' self-determination and agency. This is why many governments around the world have been working on defining adequate ethical principles for AI. And this is why we dedicate one full section to the challenges of AI, below, in Chapter 3.

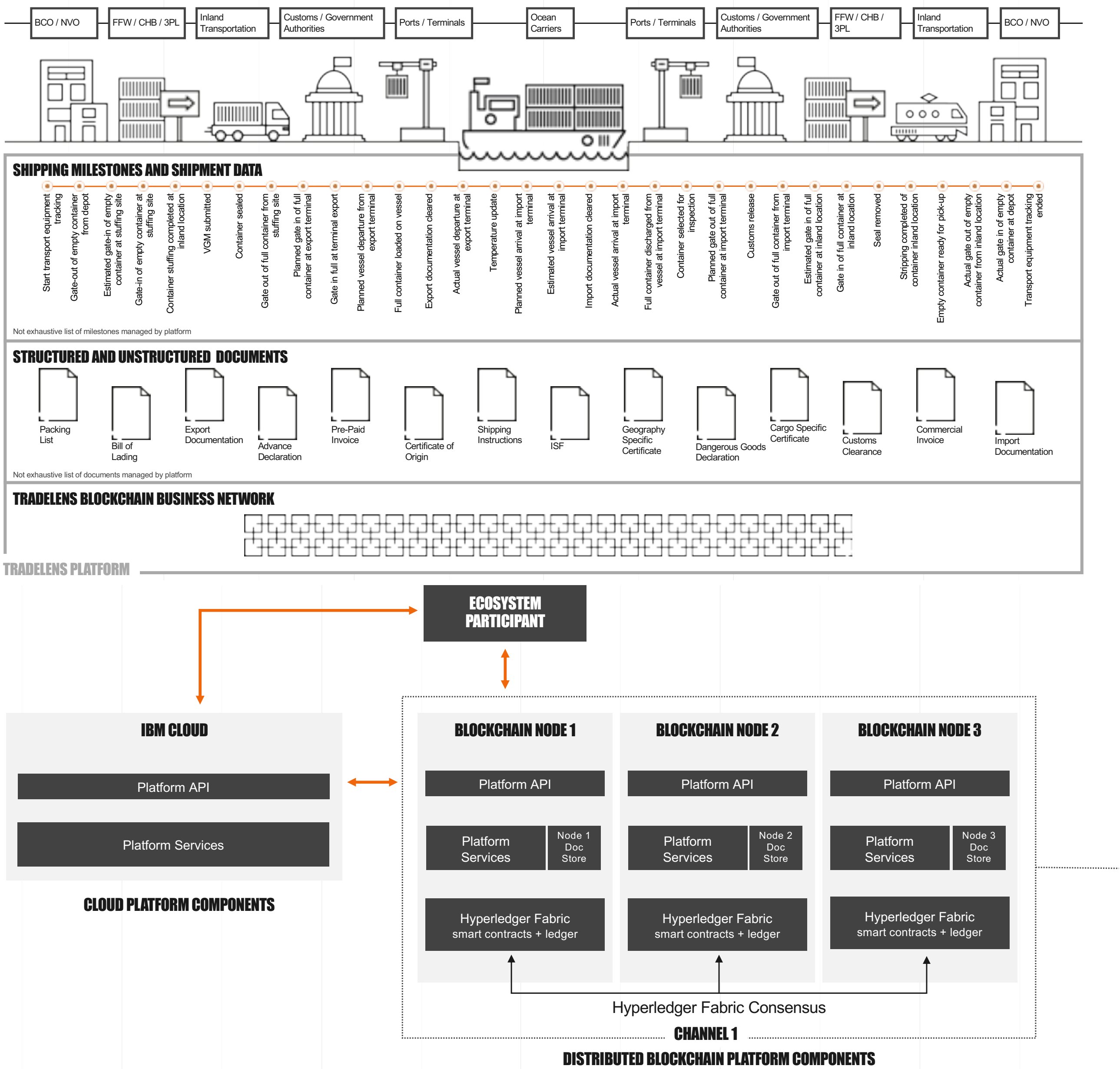
Centralised, distributed or decentralised? The proliferation of alternative governance modes

In 2008, an obscure personality known as Satoshi Nakamoto revived the hopes and enthusiasm of those that dreamed about a dis-intermediated internet by proposing a decentralised ledger architecture for the realisation of seamlessly interoperable transactions, known since then as the blockchain, and supporting the use of a crypto-currency known as Bitcoin.[23] The idea behind Bitcoin was to create a decentralised electronic transaction system, in which individuals could store and transfer value between one another without the need for central authorities. The title given by Nakamoto to 'his' 2008 paper already clarified that the technology underlying Bitcoin reproduced the same peer-to-peer features of many other technologies that had been used since the early days of the Web, such as Napster, and the early Skype (Barkai 2001).[24] Computer engineers have long been aware of the fact that peer-to-peer technology possesses formidable features, but also limits, in particular when it comes to scalability: this is why very often they resort to alternatives to the 'pure' peer-to-peer model, to embrace 'hybrid' peer-to-peer models often implying 'supernodes', or even apparent oxymorons such as 'centralised peer-to-peer' systems.[25]

The emergence of global value chains significantly affected the original dilemma of corporations on whether to revert to a more pluralistic, or a more proprietary business model. As observed by academics like Ronald Coase in his seminal work on the nature of the firm (1937), the decision whether to bear transaction costs related to market transactions, or the administrative costs related to the setting up of more hierarchical structures such as firms, determines the heterogeneity of governance structures observable today. A more nuanced view was offered by Ian MacNeil and later Oliver Williamson (1975; 1979), who distinguished possible governance arrangements as falling into more short-term market transactions ("classical contracting"), more long-term recurrent transactions based on repeated performance ("neoclassical contracting"), and more structured, integrated structures that form quasi-integrated relationships, often coupled with dispute resolution schemes and deeper governance arrangements ("relational contracting").

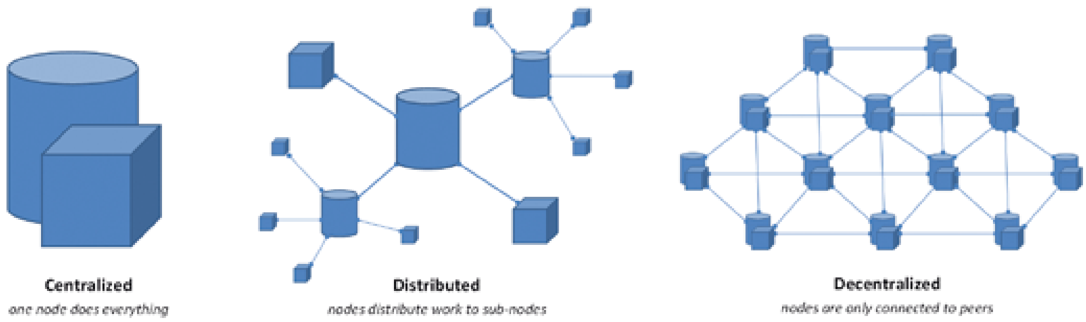
Supply chain governance and outsourcing of specific phases of the value chain are typically accompanied by various governance arrangements, aimed at reaping all the benefits of specialisation while at the same time mitigating the

Figure 6 – TradeLens architecture



Source: TradeLens.

Figure 7 – Centralised, distributed and decentralised computing



risk of relying on a nexus of contracts rather than on a more hierarchical structure. These schemes, along value chains, already presented some risks for the parties, including the emergence of superior bargaining power and abuses of economic dependency, but also contractual risks of non-performance by players located in jurisdictions with faulty rule of law.

This trend towards the hybridisation of contractual relationships on the value chain was later affected by several trends. Ongoing globalisation of exchanges led to unprecedented possibilities to offshore production across the globe, but also exacerbated associated contractual risks and information asymmetries. This is problematic since not only the authenticity, but also the 'credence qualities' of many goods and services are increasingly important in guiding consumer choice: for example, the fact that clothes have been produced in compliance with workers'rights in all phases of the production chain; that food has been locally sourced; or that all players along a supply chain are compliant with environmental standards are often decisive elements in guiding consumers' willingness to pay: the lack of verifiability and clarity on these aspects of goods and services can lead to problems such as adverse selection ('market for lemons'); and moral hazard, which further reduces the quality of available products, since competing on quality is not a winning strategy.

Can blockchain and DLTs help remedy some of these problems? In principle yes, as testified by the fact that several companies and intermediaries are developing ambitious projects to improve the integrity and efficiency of complex supply chains. **A notable example is the TradeLens project recently launched by IBM and Maersk,** which applies blockchain to the world's global supply chain, through shipping solutions designed to promote more efficient and secure global trade. As many as 94 organisations are actively involved or have agreed to participate on the TradeLens platform built on open standards, including more than 20 port and terminal operators across the globe, global container carriers, customs authorities in five countries, custom brokers, cargo owners, freight forwarders, transportation and logistics companies.[26]

Using blockchain smart contracts, TradeLens enables digital collaboration across the multiple parties involved in international trade. The project attracted the attention of other consortia, which launched alternative platforms (e.g. GSBN, powered by Oracle in cooperation with Evergreen Marine, CMA CGM, Cosco Shipping, and Yang Ming, representing about a third of total global container ship capacity).[27] **These schemes, however, come with important governance challenges.** According to some commentators, the fact that Maersk owns a stake in TradeLens and the intellectual property associated with the joint venture creates conflicting interests in the governance of the platform, in particular when it comes to attracting members that are also competing with platform owners. Commitment to profit-sharing and an open IP policy would probably remedy current problems.[28]

More generally, **the lessons learnt from the first steps of blockchain/DLT applications in the supply chain are numerous. First, the potential is great, but the impact so far is still small.** Projects like TradeLens and GSBN show the commitment of industry giants, and the lack of trust between main players, who show scepticism when looking at a major initiative led by the largest shipping company in the world. Similar dynamics may be observed in the near future in other industries with complex supply chains. Most of these investments will focus on supply chain integrity and traceability, as well as on financial transactions. Similar emphasis is being placed by governments: recently the government of South Korea announced that part of its $4.4 billion plan to boost the digital economy will be devoted to blockchain applications for the supply chain. Interesting recent developments include the creation of a Blockchain in Transport Alliance; the tests on traceability of pork and mangoes run by Walmart; and the tracking of i.a. tuna along the supply chain offered by companies like Provenance.

Second, it must always be recalled that **DLT applications for the supply chain cannot entirely solve the problem of information asymmetries, lack of verifiability of credence qualities, and opaque supply chains.** Blockchain and DLTs only record transactions: they do not entail the creation of an 'Internet of Value'. This means that while they offer key advantages in terms of verifiability and traceability of information related to products as appended to the ledger, they do not guarantee that such information was not false in the first place.

Third, **what is commonly called blockchain in the supply chain world is effectively a permissioned DLT,** in which several parties agree to share a ledger. *Rather than dis-intermediating the supply chain, and thus removing costly intermediaries, these applications effectively re-intermediate the supply chain*, with large potential efficiency gains, but no 'permissionless' environment. Supply chain solutions are particularly important as an example, since they illustrate some of the key problems that may emerge in the future when the EU tries to create a pan-European distributed ledger: the current technological constraints, which prevent decentralised blockchains from scaling up, should not become an alibi for leaving future DLT-enabled solutions in a few, private hands; otherwise the solution chosen may end up being captured by individual interests, and unable to fully scale up into a public blockchain.

Connecting cyber-physical objects: the IoT age

Perhaps the technological development that promises to revolutionise the agriculture sector most deeply is the Internet of Things (IoT). When deploying this technology, data, devices and machines ('things') are equipped with two types of sensor technologies (Zhang et al. 2018, page 510). Local sensors are installed on the ground level to, for example, measure relevant indicators such as humidity, temperature or nitrate levels, while distant visual sensors on satellites, airplanes, or unmanned aerial vehicles (UAVs) generate image data to, for example, estimate the need for irrigation or fertilisation (Zhang et al. 2018, page 513). After data collection, the individual data points are transmitted to a centralised system, such as a cloud platform. To this end, the 'things' are equipped with antennas to transmit data with specific protocols. The choice of protocol therefore depends on which protocol is most appropriate to transmit data in a given use case (Yang et al. 2019, page 5).

More specifically, an IoT system is essentially organised around four main layers: directly attached to the 'things' are sensors, antennas and actuators, which can take a wide variety of forms; these devices must be connected to a network layer, which allows the aggregation and basic control of data; above these layers (or, as commonly said, above the 'edge') are a first layer of intelligence (Edge IT), which provides analytics functions and pre-processing of data; and the cloud, in which data are stored, analysed, and processed for ultimate action and decision-making.

The first element to be considered in a full-fledged IoT system is of course the 'things'. Objects of all sorts, including toys, furniture, clothes, implanted devices, wearables, buildings and living objects such as plants, human beings and animals must be known and identified in the system. This is done by attributing to each of them an IP address and/or a universal unique identifier (UUID), which makes the orchestration and integration of things into large-scale networks much easier.[29] Things are then integrated into IoT eco-systems through a variety of technologies, which include RFID, wireless sensor networks (WSN), and mobile computing. RFID, WSNs, and mobile computing contribute significantly to the development of IoT sensing systems.

But things often need technological enhancements that enable them to gather information from the outside world, and implement decisions adopted by either humans, AI, or a combination of both. This is why IoT systems typically feature sensors, transmitters and actuators.[30] Local sensors are installed to, for example, measure soil humidity in agriculture or to record location data in logistics. Distant visual sensors on satellites, aerial vehicles (UAVs), or simple cameras generate image data to, for example, estimate the need for irrigation or to count crowds in public transportation during rush hour. **There is a plethora of different sensor technologies, but the aim is always the same: to create digital data about the physical world.** As there are different types of IoT sensors, optimal scheduling and planning algorithms for power and computing resources are needed urgently. The existence of heterogeneous sensing networks also requires seamless information exchange and data communication through different protocols to achieve a high level of interoperability.

After data collection through sensors, the data needs to be transmitted to a centralised system, such as a cloud service. To this end, the 'things' are equipped with antennas to transmit data with protocols such as Bluetooth, WiFi, NFC, LoRaWAN, ZigBee or cellular (5G and earlier generations of cellular network technology). Each protocol has its own advantages and downsides with regards to range, data transmission rates and cost, which means that there is no single, silver bullet solution that dominates the others. The choice of protocol depends on which protocol is most adequate to transmit data in a given use case (Yang et al. 2019, page 5):[31] Bluetooth is commonly used for short-range in-vehicle networking and wearable sensing applications, whereas ZigBee is the most popular WSN protocol with low energy consumption, being well suited to ubiquitous sensing; Z-wave is suitable for smart home and health applications; NFC is commonly used in contactless payment via smart phones; and while these protocols are used for short-range communication (5 cm to 100 metres), there are long-range and wide-area network protocols such as SigFox, Neul, LoRaWAN, and cellular communication technologies that are commonly used for smart city and environmental applications to transmit data over ranges from 2 kilometres to 200 kilometres. Independently of the choice of specific transmission technologies, the key is to transmit the disparate data from different 'things' into a central system where they can be stored, cleaned and analysed.

Once the data have been transmitted, they need to be stored, processed and made available for analysis. This normally entails the use of cloud solutions such as Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform, GE Predix, ThingWorx, IBM Watson, or C3 IoT among others. These platforms provide the software infrastructure to enable physical things and cyber-world applications to communicate and integrate with each other. They enable a variety of solutions such as cloud computing, embedded systems, augmented reality integration, data management, software applications, machine learning, and analytical services.

Once data have reached the location where they will be stored and analysed, they have to be processed and prepared for analytics. As a matter of fact, data scientists spend around 80% of their time on collecting and preparing the data, and only 20% of their time is actually spent on data analysis (Bowne-Anderson 2018).[32] Data needs to be cleaned and merged with data from different sources to achieve a common format suitable for analysis, such as tabular format ('data wrangling').[33] Once these activities have been performed, different data analytics methods, such as AI algorithms, can start crunching the data collected by the IoT application. The most well-known type of Artificial Intelligence is *machine learning*,[34] a family of algorithms capable of learning patterns from labelled data sets to classify new data (supervised machine learning) or capable of extracting patterns from unlabelled data (unsupervised learning) (Renda 2019).[35] These algorithms have one thing in common: they need large amounts of data, digitally available in an organised format. They are therefore highly dependent on the 'lower layers' to correctly perform their tasks: sensors, transmitters, connectivity and adequate data cleaning and wrangling.

Combined with good quality data, machine learning can lead to unprecedented results. Self-driving cars, for example, depend on machine-learning models, trained on large amounts of sensor data, allowing the car to autonomously recognise objects around them. At the same time, they also chiefly rely on the work of sensors (e.g. Lidar sensors, cameras) and good data transmission to the layer at which analytics take place. In the domain of agriculture, satellite sensor data can be used to train machine-learning models, which more accurately predict weather conditions for farmers – helping them to increase their yield and avoid risks. At the same time, in certain circumstances machine learning necessitates real-time data, which means that data transmission cannot afford high levels of latency. This, as will be explained in more detail in the next Chapter, is leading to important changes in the way IoT systems are being designed.

In most circumstances, the working of IoT systems is designed to support human control and decision-making, even if in principle IoT systems could be designed to be fully autonomous. The level of interaction of the system with humans varies depending on the circumstances, ranging from mere ex post oversight of autonomous systems by humans (or human-on-the-loop) to cases in which the human is fully 'in the loop', and data collection and analysis are performed to support a decision to be adopted by a human. To support human decision-making, insights must be presented in an understandable, actionable format such as dashboards, which provide a graphical user interface that enable monitoring useful key performance indicators (KPIs) quickly and generate reports for decision support.[36] When actions are entirely automated (in particular when IoT devices are equipped with actuators and data reception technology), the user interface will be limited to enabling oversight of key indicators and data visualisation, without providing decision-making tools. A farmer could, for example, decide that his irrigation system should be automatically switched on once the moisture sensors indicate a certain level of dryness. The central system can send a signal to the irrigation system and the actuators can then trigger irrigation. These types of human-machine interfaces can help companies save money and time.

CHAPTER 1
Main findings

Digital technologies are revolutionising agrifood through a combination of connected cyber-physical objects, big data analytics, pervasive Artificial Intelligence, distributed ledger technologies and collaborative economy platforms.

The combined implementation of digital technologies is an essential precondition for achieving sustainability in agrifood: however, policymakers need to adopt a holistic view, which includes infrastructure, technology diffusion and skills.

The potential is huge along the whole agrifood chain, from improving land management to reducing the use of pesticides, tackling food waste and promoting healthier diets. AI alone promises to double growth rates in the next few years. Trends such as platformisation, virtualisation and servitisation promise a future in which the benefits of technology are accessible to all.

However, the platformisation of the economy may also bring dilution of liability, the deterioration of bargaining power for employees and independent contractors, and ultimately the distancing between corporate responsibility and sustainability impacts.

More distributed architectures appear more likely to achieve sustainability, as they increase trust and empower a larger number of actors along the value chain.

NOTES TO CHAPTER 1

[8] Data can be stored in various ways, including through remotely accessible, cloud-enabled solutions; through distributed databases; or through distributed ledger technologies such as blockchain. Some of these technologies are key enablers of value chain integrity, monitoring and trust, since they produce 'audit trails' that enhance the verifiability of transactions and contractual performance across the value chain.

[9] O'Reilly (2010), http://chimera.labs.oreilly.com/books/1234000000774/ch02.html (Note that in the UK "Government as a Platform" itself is often used in a completely different sense, to refer to the use of standard PaaS services.

[10] https://innovator.news/the-platform-economy-3c09439b56

[11] Cloud architectures are conceived to be very simple for end users but feature a very complex architecture 'behind the curtain'. As an example, Apple's iCloud allows the syncing of various devices with the cloud, such that the end user always enters the same environment regardless of the device used to connect to the network. Similar strategies have been pursued for the end user market by Google (Android), Microsoft (Azure) and Amazon (AWS). The most widely acknowledged taxonomies of cloud computing are those that relate to the basic cloud 'modes' (i.e. Public, Private, Hybrid); and the main cloud 'types' (i.e. Saas, AaaS, IaaS, PaaS). The provision of platform as a service (PaaS), for example, leaves more control of the configuration to the client than mere application as a service (AaaS) or software as a service (SaaS) modes. At the same time, private clouds are certainly more customized to the client's needs than hybrid or public clouds, which however enjoy clear economies of scale.

[12] Cloud computing is a general-purpose technology of the IT field which became widely available in the late 2000s. VAQUERO et al. (2009) define it as "a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized Service Level Agreements"."

[13] The most widely used definition of cloud is that provided by the US National Institute for Standards and Technology (NIST) in 2009: "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction".

[14] Bank of America Merrill Lynch recently valued the worldwide sharing economy at $250 billion but estimates that $6 trillion in commerce could be disrupted by the sharing economy across sectors such as transportation, travel, food, retail, and the media. This, representing approximately 8% of global GDP, is supported i.a. by the fact that eight of the world's 10 largest start-ups based on valuation are in fact sharing economy businesses. Merrill Lynch research report. See https://www.zerohedge.com/news/2017-07-24/primer-global-sharing-economy-20-charts

[15] https://www.uschamberfoundation.org/sites/default/files/Data%20Report%20Final%2010.23.pdf

[16] See www.predpol.com for more information. For a non-technical introduction, see the article published in The Economist on predictive policy, "Don't even think about it", available at http://www.economist.com/news/briefing/21582042-it-getting-easier-foresee-wrongdoing-and-spot-likely-wrongdoers-dont-even-think-about-it

[17] The OECD (2014) reports the example of Ushahidi, a non-profit software company based in Nairobi, Kenya, which develops free and open-source software for data collection. Ushahidi's products are provided as open source cloud computing platforms that allow users to create their own services on top of it. They are free services that enable programmers to collect information from multiple sources (i.e. 'crowd-sourcing') to create timelines and provide mapping services. In addition, a key component of the website is the use of mobile phones as a primary means to send and retrieve data.

[18] IBM's Watson program, which beat human contenders to win the Jeopardy challenge in 2011, was largely based on an efficient scheme for organizing, indexing, and retrieving large amounts of information gathered from various sources.

[19] Some of the most sophisticated AI systems use a combination of these techniques: for example, the AlphaGo program that defeated the human champion at the game of Go used multiple machine learning algorithms for training itself, and also used a sophisticated search procedure while playing the game.

[20] Centre for the Study of Existential Risk; FLI, etc.

[21] RAND

[22] E.g. RIPPA, university of Sydney.

[23] S. Nakamoto (2009), Bitcoin: A peer-to-peer electronic cash system". https://bitcoin.org/bitcoin.pdf

[24] https://en.wikibooks.org/wiki/A_Bit_History_of_Internet/Chapter_6_:_Peer-to-peer

[25] In terms of architecture, a computer system can feature several organisational arrangements. It can be centralised, and as such host information and processing at the central level, without sharing the process or the information with other systems. It can be decentralised, and as such have various components that operate on local information to accomplish goals, rather than the result of a central ordering influence. A system can be federated, i.e. be a cohesive unit formed of smaller sub-units which collaborate to form the whole, but which retain significant local autonomy. Or it can be distributed, and hence be a system in which computation is distributed across components, which communicate and coordinate their actions by passing messages, and components interact

with each other in order to achieve a common goal. Finally, a system is said to be peer-to-peer if it features a set of equally privileged nodes, which are equipotent participants in the pursuit of collaborative goals. The OECD (2015; 2017) has approached this issue in a slightly different way: rather than adopting a binary definition of closed versus open data, it identifies degrees of openness on a continuum ranging from closed or limited access (only by a data controller) to open and public access to enable more differentiated approaches to data sharing and reuse. See OECD, Going Digital in a Multilateral World (2018).

[26] https://newsroom.ibm.com/2018-08-09-Maersk-and-IBM-Introduce-TradeLens-Blockchain-Shipping-Solution.

[27] https://www.supplychaindive.com/news/ocean-carriers-new-blockchain-cosco-cma-cgm/541630/

[28] https://www.forbes.com/sites/andreatinianow/2018/10/30/how-maersks-bad-business-model-is-breaking-its-blockchain/#476280234f4d

[29] As the number of 'Things' connected to the internet is increasing rapidly, the scalability of the internet protocol has emerged as a major challenge. Currently, IPv4 is the 32-bit address system that is on the verge of being incapacitated, i.e. using up all the IP addresses. IPv6 is the new 128-bit address system that has a capacity of approximately 2128, or 3.4×1038 addresses. IPv6 enables every IoT 'thing' to have a unique IP address on the global internet.

[30] Zhang, L.; Dabipi, I., Brown, W. Jr (2018), Internet of Things Applications for Agriculture. The Institute of Electrical and Electronics Engineers Inc., John Wiley & Sons, Inc. http://iranarze.ir/wp-content/uploads/2018/10/E9758-IranArze.pdf

[31] Yang, H., Kumara, S., Bukkapatnam, S., Tsung, F. (2019), The Internet of Things for Smart Manufacturing: A Review. IIE Transactions. Available online: https://www.researchgate.net/publication/330408457. Dali Ismail, Mahbubur Rahman, Abusayeed Saifullah (2018), Low-power wide-area networks: opportunities, challenges, and directions. Conference Paper, Workshops ICDCN '18, January 4–7, 2018, Varanasi, India. Available online: https://www.researchgate.net/publication/323986231_Low-power_wide-area_networks_opportunities_challenges_and_directions. And see Zhijin Qin, Frank Y. Li, Geoffrey Ye Li, Julie A. McCann, and Qiang Ni (2018): Low-Power Wide-Area Networks for Sustainable IoT. arXiv. Available online: https://arxiv.org/pdf/1810.10761.pdf

[32] Bowne-Anderson, Hugo (2018), What Data Scientists Really Do, According to 35 Data Scientists. Harvard Business Review. Available online: https://hbr.org/2018/08/what-data-scientists-really-do-according-to-35-data-scientists

[33] Grolemund, Garrett, Wickham, Hadley (2017), R for Data Science. Available online: https://r4ds.had.co.nz/introduction.html. Data cleaning is still largely a human activity, while AI is increasingly able to engage in wrangling: this requires 'multimodal deep learning', in which machines are trained to learn features over multiple modalities (e.g. audio and video).

[34] It must be noted, however, that artificial intelligence / machine learning is only one tool in the data scientists tool kit – and it is not necessarily the favourite tool: they often cite classical statistical tools such as logistical regressions, because of their better interpretability and lower complexity. The adequate analytical tool highly depends on the specific puzzle a project tries to solve.
See DataCamp (2019), DataFramed Podcast. https://www.datacamp.com/community/podcast

[35] Renda, Andrea (2019), Artificial Intelligence – Ethics, governance and policy challenges. Report of a CEPS Task Force. Available online: https://www.ceps.eu/ceps-publications/artificial-intelligence-ethics-governance-and-policy-challenges

[36] For example, Azure supports a user-configured dashboard that can include a number of resources from the marketplace such as IoT events, time series insights, stream analytics, log analytics, cost analytics, and reports. Most of these are general-purpose platforms, which are often replaced by domain-specific ones, for example for manufacturing and healthcare.

CHAPTER 2
Key use cases in the agrifood chain

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The agrifood value chain is complex and spans industrials, farming, logistics, wholesale distribution, processing and manufacturing, and finally retail distribution to the consumer. Agrifood Technology (AgTech) industry participants can be divided into two groups: upstream, AgTech players involved in food production, and downstream, tech-enabled players that operate closer to the consumer. Both the upstream and downstream sides of the value chain have important roles to play in making the agrifood chain more sustainable, efficient, and productive. The greatest use of resources and environmental degradation occurs on the upstream side, and as such, offers the greatest potential for conservation and efficiency gains, while food waste prevention is more closely related to the downstream activities of consumers.

Digital technologies are particularly relevant for digital farming applications on the upstream side and are represented in the graphic below by novel farming systems, midstream technologies, farm robotics/mechanisation, farm management software and sensing/IoT applications which generate vast quantities of data that can be analysed and modelled for more effective decision support on resource allocation and usage. On the downstream side, in-store retail and e-grocery applications can help both retailers and consumers to mitigate food waste by better matching supply with ready demand. Home and cooking tech can assist consumers in tracking their purchasing habits so that food is not wasted simply because consumers mistimed their food purchasing requirements. Sensor technology could help reduce food waste by assisting consumers to better judge when foods will spoil in the refrigerator, allowing them to avoid unnecessary purchases.

Digital technology is driving a global renaissance in entrepreneurship with large sectors of the global economy being reimagined, disrupted, and disintermediated by companies offering new products, services, and business models. The agrifood chain, which has been slow to respond to this trend, is not immune to the impacts of digital technology and the changes it brings with it. According to a recent report by Agfunder, the global agrifood sector is a $7.8 trillion[37] industry, representing about 9% of global GDP (based on World Bank 2018 data) and employing about 28% of the world's population,[38] yet it remains one of the least digitised of all major industries, which engenders huge inefficiencies and with it, food loss and insecurity for more than 820 million people globally.

At its core, agriculture technology – AgTech – is about using advanced monitoring and data analysis tools to do more with less – to find ways to increase yields without further burdening diminishing resources such as land and fresh water or using more pesticides and fertilisers. Below, we explore a number of use cases in agriculture, the reduction of food waste, and nutrition. Changes triggered by digital technology in the agrifood sector can be located in a number of areas, ranging from empowerment of small farmers and farmer-centric apps to precision farming, shifts in business models, support for the circular economy with more effective management of food waste, the promotion of supply chain integrity and traceability, and better signalling of food quality to the end users.

Revolutionising agriculture: empowering small farmers, deploying IoT and sharing data

The use of IoT in combination with various AI techniques is revolutionising agriculture. The promise of precision agriculture lies in the power to make the modern farm more efficient and productive through automated data collection and decision-making at the farm level, increasing the resource efficiency of the agriculture industry, lowering the use of water, and even more that of fertilisers and pesticides, with ensuing benefits to the ecosystem. With continuous data-driven feedback provided to farm systems, farms can automatically adapt to changing conditions and therefore produce better quality products. AI-augmented farms connected to smart marketplaces could automatically adjust crop quantities, based on supply and demand data coming from food retailers and foodservice providers on the downstream.

Figure 8 – AgTech category definition

Upstream	Downstream
Ag Biotechnology On-farm inputs for crop & animal ag including genetics, microbiome, breeding, animal health.	**Innovative Food** Cultured meat, novel ingredients, plant-based proteins.
Agribusiness Marketplaces Commodities trading platforms, online input procurement, equipment leasing.	**In-Store Retail & Restaurant Tech** Shelf-stacking robots, 3D food printers, POS systems, food waste monitoring IoT.
Bioenergy & Biomaterials Non-food extraction & processing, feedstock technology, cannabis pharmaceuticals.	**Restaurant Marketplaces** Online tech platforms delivering food from a wide range of vendors.
Farm Management Software, Sensing & IoT Ag data capturing devices, decision support software, big data analytics.	**eGrocery** Online stores and marketplaces for sale & delivery of processed & un-processed ag products to consumer.
Farm Robotics, Mechanization & Equipment On-farm machinery, automation, drone manufacturers, grow equipment.	**Home & Cooking Tech** Smart kitchen appliances, nutrition technologies, food testing devices.
Midstream Technologies Food safety & traceability tech, logistics & transport, processing tech.	**Online Restaurants and Meal Kits** Startups offering culinary meals and sending pre-portioned ingredients to cook at home.
Novel Farming Systems Indoor farms, aquaculture, insect, & algae production.	**Miscellaneous** (Upstream+Downstream) e.g. fintech for farmers

Upstream
Downstream
Upstream+Downstream

Source: Agfunder, Agrifood Tech Funding Report: Year Review 2018.

Farmers would be able to capture more value for their output by having near real-time signalling from the market as to which crops are being demanded and at what prices. Better matching of supply and demand would also help to reduce food waste and loss.

Precision farming: the promise of smart agriculture

The World Economic Forum (2018) observed that smart agriculture has the potential to "fundamentally change agriculture even more than 20th century mass farming methods did"; and these changes "may spread more rapidly than previous ones"; in particular, Artificial Intelligence could enable farms to become almost fully autonomous (WEF 2018). Farmers will be able to grow different crops symbiotically, using machine-learning solutions to spot or predict problems and to take appropriate corrective actions via robotics. For example, should a corn crop be seen to need a booster dose of nitrogen, an AI-enabled system could deliver the nutrients. This kind of production could be more resilient to earth cycles.

A recent paper by Liakos et al. (2018) explores various uses of AI in agriculture. For example, by applying machine learning to sensor data, farm management systems can evolve into real-time AI-enabled programs that provide rich recommendations and insights for farmer decision support and action. The key fields of application include: crop management, including applications on yield prediction, disease detection, weed detection, crop quality, and species recognition; livestock management, including applications on animal welfare and livestock production; water management; and soil management. More specifically:

- In crop management, there are several fields of application. They include most notably yield prediction, which impacts key activities such as yield mapping, yield estimation, matching crop supply with demand, and crop management to increase productivity. Use of AI also massively improves disease detection, particularly in the area of pest and disease control, where the use of machine learning allows much better targeting of agro-chemicals input in terms of time and place, thus avoiding the uniform spraying of pesticides; and breakthroughs in image processing and recognition can enable real-time control of plant infection, as well as real-time plant classification. IoT enabled systems can help farmers manage diseases and pests more sustainably. Here again, imaging data from remote sensing technology can help identify and classify diseases and pests.

- Another area in which digital technology is dramatically changing agriculture is in the management of livestock, and in particular in protecting animal welfare and livestock production. In the field of animal welfare, AI is helping in the monitoring and classification of behaviour based on data from cameras and drones, the recognition of the impacts of dietary changes (in cattle), and even the automatic identification and classification of chewing patterns (in calves) thanks to data collected by optical sensors. In the area of livestock production, studies have led to the accurate prediction and estimation of farming parameters to optimise the economic efficiency of the production system. Researchers are increasingly able to avoid using RFID tags to recognise and monitor animals, and this removes a source of stress for the animal itself, at the same time reducing costs.[39]

- Digital technologies can help agricultural firms in water and soil management. For example, machine learning is being applied to the estimation of evapotranspiration, important for resource management in crop production; and to the design and management of irrigation systems, and the prediction of daily dew-point temperature. For what concerns soil management, machine learning leads to a more accurate estimation of soil drying, condition, temperature, and moisture content, at the same time dramatically reducing costs. Using high-definition images from airborne systems (e.g. drones), real-time estimates can be made during cultivation period by creating a field map and identifying areas where crops require water, fertiliser or pesticides, with consequent resource optimisation.[40]

- In the agrifood chain, the evolution of the technology stack possesses a unique set of features and challenges. For example, cloud-based solutions face a number of challenges in smart agriculture, related to security (since IoT networks enlarge the 'attack surface'); speed (data collection and transfer is extremely time-consuming); and cost (cloud computing expenses typically depend on the amount of data generated by the "things" and transferred through the network). Edge computing potentially offers a solution to these challenges. The result is an enhanced possibility to deploy 'agribots' that behave 'intelligently', for example by calculating most efficient paths to cover the required area taking into account the type of task performed, number of vehicles currently in the field, size of implements, etc.; and rerouting automatically in case of unexpected obstacles. Similarly, greenhouses or even entire farms can be put on autopilot using IoT edge computing, and regardless of the connection to the main server, taking decisions

How GAIA is disrupting the viticulture industry

A revolutionary new AgTech product named after the Greek goddess of nature, GAIA is a web application which automatically identifies, locates and monitors micro-level, high-value crops at continent-scale. GAIA's primary intention is to provide pervasive geospatial insight to growers, regulatory bodies, and biosecurity organisations alike in every season, delivering both crop mapping and intelligent analytics. In order to enable GAIA to successfully scale, Consilium Technology has developed several key features, including satellite imagery that provides GAIA with global coverage of high-value crops; machine-learning algorithms that allow GAIA to automatically locate crop boundaries; and crop health imagery that is automatically updated when new satellite images become available. [42 43]

In a global first, the team behind GAIA at Consilium Technology has partnered with Wine Australia in order to deliver a technical solution for accurately collecting and analysing the continent's vineyard data. Having completed Australia's National Census of Vineyards, GAIA has mapped and measured every vine row within Australia.

Using machine-learning algorithms powered by artificial intelligence technology, GAIA scanned high-resolution satellite images of Australia's viticulture regions to reveal with high accuracy that there are 146,128 hectares under vine across Australia's 65 wine regions.[44] The information GAIA produces is critical for deploying timely emergency biosecurity responses, as well as for precisely regulating wine labelling requirements based on where grapes are grown. GAIA also measures vine row length, allowing planting densities by region to be analysed and improved for the first time.

How does GAIA differ from previous approaches to crop mapping? The combination of artificial intelligence-powered crop mapping and automatedcrop health monitoring allows GAIA to provide crucial data and insights that are impossible to provide through traditional approaches. These insights are then made easily accessible on all popular web browsers on any device. Manual surveying on the other hand, (as previously used to conduct Australia's National Census of Vineyards), has limited accuracy as a result of low response rates and infrequent collection of data due to the labour-intensive and costly nature of manual data collection. In terms of examining free satellite imagery for crop information, the method has proved insufficient as it lacks the resolution required for precision agriculture, micro-level analytics, and individual insights.[45] Finally, drones and/or aircraft technology have limited repeatability; have not been feasible at a continent-scale due to sensor range constraints, weight and power limitations; have limited access to historical imagery archives; and have more expensive per kilometre due to labour costs.

How does GAIA deliver value? GAIA's value proposition differs according to the target market. For regulatory bodies, GAIA provides accurate, nationwide crop location data that allows for industry regulation and better analysis of market trends. For grape growers and winemakers, employing GAIA as a tool allows for highly precise, cost-efficient, and regular assessments of crop health. Finally, for biosecurity organisations, GAIA's monitoring, detection, and classification capabilities allow for better prevention and management of disease outbreaks, especially on a national scale. Automatically programmed and easily scalable, GAIA offers a solution based on high-quality satellite imagery that reduces data collection and analysis costs; increases accuracy of data collection; reduces crop health monitoring expenses; increases frequency of data collection (continual monitoring); and provides additional crop insights.[46]

To provide empirical evidence in support of GAIA's value, a team at Consilium Technology conducted two case studies of two client vineyards in 2018-2019 that show decreases in costs and increases in profit. The first chart reflects the improvements associated with the utilisation of GAIA by the Brown Family Wine Group for their Tamar Ridge vineyards (whose 133 hectares produce premium Pinot Noir).[47] Profitability is limited by variability in the vineyard's vigour and yield, which were both being impacted by the region's hills, different soils, varying slopes, and range of microclimates. GAIA crop monitoring and spatial imagery identified the areas of greatest variability in the Tamar ridge

Table 1 – Estimated changes in return per hectare of Tasmanian Pinot Noir due to tree removal and targeted marc application, based on GAIA's insights

	OPERATING COSTS* $ / ha	YIELD T / ha	PRICE $ / T	RETURN $ / ha	PROFIT $ / ha
CURRENT PRACTICE	$17, 000	6	$3, 000	$18, 000	$1, 000
REDUCED VARIABILITY WITH GAIA	$17, 200	6.6	$3, 100	$20, 460	$3, 260
GAIA'S ADDITIONAL BENEFIT	**$200**	**0.6**	**$100**	**$2, 460**	**$2, 260**
Based upon 50% increase in yield on 20% of the block (10% total) and 3% increase in price due to small portions of the fruit being graded higher. Costs are regional estimates.					

vineyards, highlighting areas of high and low vigour as well as other irregularities. GAIA also went a step further by demonstrating the effects of these issues on vigour and yield. In the end, GAIA helped the Brown Family Wine Group analyse and curtail variability within their vineyards, as well as inform strategic decisions in management and resource deployment.

In the second case study, GAIA was used by De Bortoli Wines in order to better understand how their irrigation system was functioning, with the overarching objective being the optimisation of water operations. GAIA's spatial imagery providedvisual representation of the vigour variability within the Semillon block of grapes De Bortoli Wines used for its premium wine, Noble One with the company's total 270 hectares of wine grape vineyards. GAIA's imagery provided direct feedback on the effect of irrigation practices, identifying that the last 150 metres of each row were being underwatered. The management changes recommended by GAIA analyses were expected to minimise variability across the entire vineyard, reduce water costs, and increase fruit yield and value per tonne.[48]

Beyond improving crop monitoring and health, GAIA can also help manage pest and disease control, as well as enable better understanding of market trends in order to prevent oversupply and waste of resources. These effects can have a significant impact on increasing efficiency and sustainability of agrifood supply chains, especially as Consilium Technology looks to expand GAIA's reach to the global scale.[49]

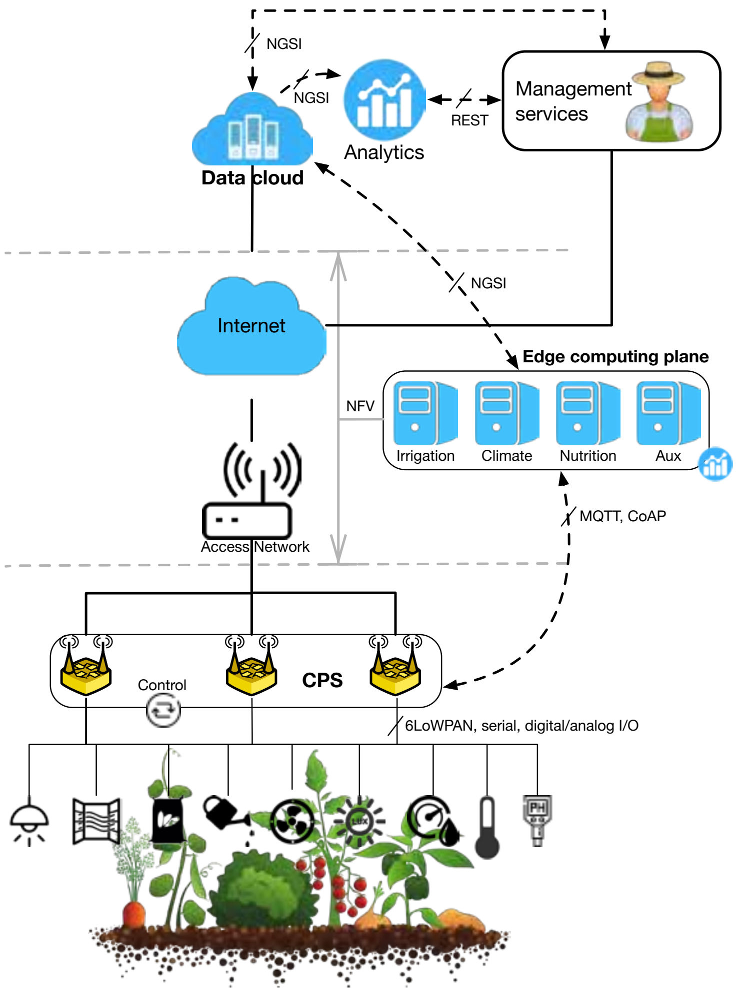
Source: Consilium Technology.

locally, based on the data from local sensors. This has the potential to improve processes' reliability and reduce waste, making agriculture more sustainable. Finally, with edge computing, agriculture IoT systems can take informed decisions about potential environmental hazards or natural disasters.[41]

The precision agriculture stack

Zamora-Izquierdo et al. (2019) explore the new architecture based on IoT, cloud and edge computing. They describe a system distributed into three main planes: crop (local) cyber-physical systems tier, edge computing tier, and data analytics and smart management at the cloud. The cyber-physical systems (CPS) and cloud planes are designed to be respectively deployed at the local crop premises and remote data servers. The intermediate layer for edge computing comprises a set of virtualised control modules in the form of Network Functions Virtualisation (NFV) nodes that can be instantiated along the network path, from the field facilities to the cloud plane on the internet. This increases versatility in the deployment

Figure 9 – Overall architecture of the precision agriculture platform



Source: Zamora-Izquierdo et al. (2019).

of the solution, at the same time connectivity performances with the CPS layer are met. At the crop premises, sensors and actuators for automation are deployed and connected with CPS nodes.[50] Additionally, there are emergency reactive actions locally implemented in the CPS nodes that require real-time operation and can be launched without human or edge plane supervision. An example of these are the opening of windows and turning on of ventilation if the greenhouse inner temperature reaches a predefined threshold. The data cloud serves as the interface between users and the core platform, which is where the current status of the crop and configuration parameters are maintained. Moreover, as can be seen in the diagramme, special analytics coupled with concrete service needs are performed using the cloud as data source.

Earth observation data and its impact on precision farming

Earth observation (EO) is the science of measurement of all aspects of the Earth system, including its physical, chemical and biological processes. The use of AI and more specifically, machine learning, to yield predictive value, which is crucial in precision agriculture, requires enormous amounts of data to create models, including from weather patterns. Rain and sunlight are essential inputs that impact the taste and quality of foods, and the yield of farms.

Weather patterns are global and can be observed and measured from space. Additionally, earth observation images from space can yield high specificity on land fertility by estimating moisture content, soil erosion, parkland forest cover, pest infestation, crop health, irrigated landscape mapping, and potential crop yield. Earth observation data, coupled with models, and clouding computing resources, and data gathered on the ground from sensors and cameras, is a powerful decision support tool on a site-specific basis allowing farmers to decide which crops to plant, how to optimise their yields, reduce crop loss, increase crop quality, reduce pollution, and reduce the need for nitrogen-based fertiliser.

Radiant Earth – Geo-diverse open training data as a global public good [51]

Radiant Earth was founded as a non-profit,based in the US and funded by Omidyar Network, the Bill and Melinda Gates Foundation, the McGovern Foundation, and Schmidt Futures. It is also a beneficiary of the Amazon Sustainability Initiative, supported by the AWS Cloud Credits for non-profits and the AWS Public Datasets Program. Radiant Earth is focused on delivering open geospatial data and analytics to the global development community (GDC) in support of their mission to address the Sustainable Development Goals (SDGs) and other key targets. Radiant Earth supports GDC by aggregating open geospatial data and providing access through its cloud-based platform, generating open Earth Observation (EO) machine learning tools and training data libraries, and creating new metadata standards through its MLHub Earth initiative.[52] Additionally, the organisation offers training resources to support capacity development and expertise in the geospatial and remote sensing sciences.

To effectively leverage open EO data and analytics in support of the SDGs, Radiant Earth turns raw EO data into insights that can guide the decisions required to support sustainability. Machine learning is an important part of that process but has one major drawback – the lack of geo-diverse training datasets. This is a gap that Radiant Earth is actively working to fill.

Developed countries can rely on long-term datasets thanks to open data policies of satellite missions from National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) in the US, the European Space Agency, and the Group on Earth Observations (GEO) as well as extensive ground truth data gathered by different agencies such as United States Department of Agriculture (USDA)'s National Agricultural Statistics program. During the last decade, many of these ground truth and satellite data have been processed and compiled as training data to foster the application of Earth observation data. In comparison, **countries in the Global South are experiencing a deficiency of data**, especially high-quality data needed to measure progress towards meeting the SDGs. Machine-learning techniques can be used with Earth observation data to build models for monitoring SDGs; however, existing training data catalogues are skewed towards developed countries, leading to machine-learning models that give biased or incorrect results. In other words, a model built on training data from one part of the world cannot be applied in a different ecosystem.

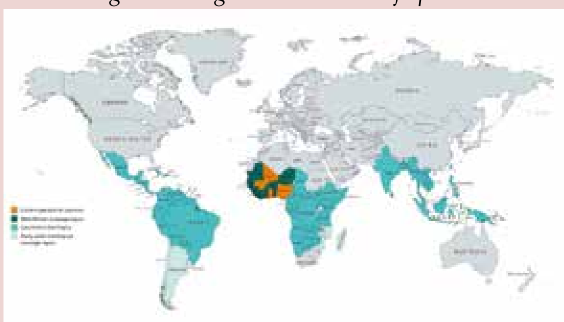
This lack of data could be addressed through a number of international projects, in particular focusing on generating thematic training datasets through a collaborative effort by aggregating existing ground truth data, augmenting these data with machine-learning predictions, and taking advantage of transfer learning methods. This is what the GEO, a Geneva-based intergovernmental organisation, is trying to develop by working to improve and coordinate global Earth observation systems and promoting broad, open data sharing.[53] GEO's flagship initiative is its Global Earth Observation System of Systems (GEOSS) which has made more than 400 million data and information resources freely available via the GEOSS Portal. Open data policy has gone from the exception to the global norm since the inception of GEO, and following work by organisations including the G20 and the OECD.

However, despite the broad recognition of the

Ignitia: Precision weather forecasts for the tropics

With an estimated 40% of the world's population (Wilkinson 2014)[54] and 1 billion small scale farmers being impacted by the weather in the tropics, precise tropical weather forecasting provides a huge commercial opportunity and moral imperative. The Swedish start-up Ignitia is trying to tackle this problem by building a proprietary weather forecasting model specifically tailored for tropical weather analytics, which produces predictions with an accuracy of 84% in the tropical region - twice as precise as global models, Ignitia claims. Ignitia buys raw satellite data from EUMETSAT, NASA and other providers and feeds them into a proprietary version of the Weather Research and Forecasting Model, specifically tailored for the tropics. Ignitia's computing hardware then calculates high-resolution (3-9 km) weather forecasts for the coming 48 hours, one month and the upcoming season. Tailored forecasts are then sent to farmers via SMS, based on their GPS location or the location of the closest cell phone tower, enabling them to take informed farming decisions.

Figure 10 – Ignitia's countries of operation



Through this method, Ignitia provides an effective **solution for regions with very low capital endowment.** Most farmers cannot afford internet enabled smart phones, but only simple 2G phones. Most forecasts are therefore delivered via SMS and if the GPS location of a farmer is not available, the location can be approximated via the closest cell phone tower. In addition, Ignitia does not install expensive IoT hardware to collect data on the ground in their countries of operation. **Buying satellite data is cheaper, more flexible, scalable and is independent of local geographical, infrastructure and regulatory conditions.** This is particularly important in tropical regions where the geography (e.g. long distances, adverse weather conditions), the local infrastructure and the regulatory environment are more difficult. Moreover, the literacy rate among farmers is low. Forecasts are therefore delivered in simple language with seven keywords which illiterate farmers can recognise.

Ignitia's primary product, the SMS forecasting service called Iska, is a paid subscription service for farmers and has more than 1 million subscribers. Ignitia's pricing model varies from country to country depending, in part, on what the telecom provider's SMS charges to subscribers are. Ignitia also sells its forecasting service to NGOs and companies like agricultural suppliers, financial institutions or consumer good companies, which can use the forecasts to, for example, mitigate climate risks or optimise logistics. Ignitia is currently working on 'Iska Plus', transferring the forecasts to internet-enabled devices with more interactive features. Moreover, Iska is working on an internet-based dashboard called Ojo, which is more targeted towards civil society organisations like the Red Cross and their activities in the tropics.

Due to these benefits, Ignitia claims that its forecasts have a measurable positive impact on farmer's yield and their bottom line: **farmers can make back 80 times the initial $6 investment in Ignitia's service, which can amount to $480 of additional yearly income for a farmer living on $2 a day. Furthermore, farmers who used Ignitia's forecast could increase their average crop yield by 65%.**[55] Ignitia is currently active in Ghana, Mali and Nigeria, but thanks to its relatively flexible and scalable technology, it is planning to expand to other West African countries and other tropical climates in the coming years. Based on the stock of weather data and expertise accumulated over the past years it is also exploring further increasing its forecast accuracy through machine learning. First deployments of machine-learning models are scheduled for 2020.

Ignitia's current accuracy is already encouraging: according to a study completed in 2019 by Björn Claremar at Uppsala Universitet, Iska rainfall probability forecasts outperformed both global model GFS and Weather Underground in terms of accuracy, false alarm rates and overall reliability (see table below).[56]

Table 2 – Results of evaluation of ISKA forecast performance

Weighted statistical indices for the grid points in which subscribers exist for the years 2017–2018. "Best" values are indicated in bold.

Parameter	ISKA0.1°		ISKA0.5°		GFS0.5°		Wunderground	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Percent Correct	0,90	0,89	**0,93**	**0,93**	0,75	0,76	0,53	0,50
Hit rate	**0,99**	**0,98**	**0,99**	0,96	0,48	0,63	0,96	0,98
False alarm rate	0,20	0,32	**0,16**	**0,28**	0,50	0,49	0,47	0,51
Critical success index	0,80	0,67	**0,83**	**0,70**	0,32	0,39	0,51	0,49
Bias	1,24	1,45	1,18	1,34	**0,94**	**1,23**	1,82	1,99
Heidke Skill Score	0,79	0,72	**0,85**	**0,78**	0,32	0,40	0,04	0,01
Brier Skill Score	0,19	0,20	**0,17**	**0,19**	0,23	0,23	0.30	0,31
AUC	0,75	0,69	**0,77**	**0,72**	0,66	0,67	0,51	0,50
Integral Reliability	85	81	**90**	**86**	66	67	62	57

Source: Björn Claremar, Uppsala Universitet, 2019.

importance of data openness and sharing, less than 50% of GEO member governments have established national Open Data regulations and policies to enable agencies to share Earth observation datasets nationally and internationally. This lack of data sharing poses a particular risk of introducing inaccuracies, omissions, and bias in Earth observation models.

Empowering small farmers through data and connectivity

If adequately put in the driver's seat, small farmers could benefit from the digitalisation and 'datification' of agriculture even more than the mobile revolution benefited trade in agricultural products in least developed countries over the past two decades.[57] One way to use these tools for smallholder farmers is to create probabilistic models for seasonal forecasting, by merging into one dataset several variables including soil nutrients, seed bed preparation, germination rate,

IoT and precision irrigation

Agriculture accounts for around 70% of global freshwater withdrawals (FAO 2017: 1). Optimising the use of water is therefore crucial to "increase water-use efficiency across all sectors and ensure sustainable with drawals and supply of freshwater" (SDG target 6.4, UN 2015). IoT-enabled precision irrigation systems can help achieve just that, in roughly three steps: First, identifying the right data and indicators; Second, building an IoT infrastructure to collect the relevant data; Third, integrating the data into the broader system to analyse it and make it actionable (Zhang et al. 2018: 512 - 516).

1. Identifying relevant data: One way of measuring a crop's water demand is the Crop Water Stress Index (CWSI), an indicator for a crop's surface temperature and therefore a proxy for water demand. In order to calculate the CWSI, two types of data need to be collected: crop canopy and air temperature. Combining these two types of data in the CWSI provides farmers with a numeric indicator of the optimal time for irrigation.

2. Data collection: The IoT inventory of 'things' offers different means to collect this data. First, a local temperature sensor, such as a connected thermostat, measures the air temperature. Second, thermal infrared cameras deployed on satellites or drones can measure the plant canopy.

3. Data integration and action: these data are then transmitted to a central system, such as a cloud platform, which allows for the storage, analysis and visualisation of the data. Once the CWSI is calculated in the central system, it can alert the farmer of the ideal time for irrigation via a user terminal such as a smart phone app. Alternatively, the system itself can 'take action' by triggering automated irrigation systems once the CWSI reaches a trigger value.

The outcome: The precision irrigation system allows farmers to increase water-use efficiency by only using water when it is truly necessary (SDG 6.4). Furthermore, the systems enable farmers to find the ideal time for irrigation in order to increase crop yield, therefore increasing agricultural productivity (SDG 2).

irrigation, cultivation, minerals, microorganisms, pests, and disease.

Projects related to digital agriculture for small farmers are being developed in various parts of the world. In India, companies like Microsoft are providing several solutions, from basic technological support (i.e. automated voice calls to inform farmers whether their cotton crops are at risk of a pest attack, based on weather conditions and crop stage) to providing governments with AI-powered price forecasts and informing farmers on the optimal sowing date based on large datasets.[58] In Africa, small farmers have the prospect of significantly profiting from index insurance thanks to the advanced use of satellite imaging and remote sensing. This reduces their vulnerability due to climate-related risks, which typically strike farmers in the same area and at the same time, making most risk management approaches unfeasible. A project implemented in Senegal by the Weather Risk Management Facility (WRMF) showed that the potential of these instruments is significant, but is also constrained by lack of high-quality data and adequate skills in government and among farmers (IFAD 2017).

Some of these projects also look at the development of farmer-centric apps. For example, the **Govi Mithuru mAgri** service works to provide a platform wherein farmers can conveniently and cost effectively receive information and connect with local farming communities to quickly learn better agricultural practices, share knowledge and information, and achieve greater market access (FAO and ITU, E-agriculture in Action, 2017). In addition to information meant to improve productivity, the service also provides information on the nutritional value of crops, preventative health practices, and hygiene standards in order to improve overall quality of nutrition and health (FAO and ITU, E-agriculture in Action, 2017).

Similar projects have consistently concluded that data and skills are major obstacles to the empowerment of small farmers. Data can be used by farmers in many ways along the chain, and in particular for planning, monitoring and assessment, event management and intervention, and autonomous action through ICTs. It is therefore very important that projects are developed in order to tackle the specific challenges of each data use, in a way that is tailored to the needs of small farmers. This includes i.a. aggregating farmer data and services through joint action that empowers and gives voice to farmers; developing platforms and mechanisms that enable open data sharing; and reaching international agreements to facilitate data access, ownership and flows.

WeFarm: a social network for farmers

A London-based start-up, WeFarm has created the world's largest knowledge sharing network and marketplace for small-scale farmers without an internet connection. WeFarm provides an SMS-based questions and answer service with 280,000 thousand monthly contributors and 1.5 million messages sent per month. WeFarm estimates that one in five farmers in Kenya and Uganda are part of their network, and they have recently expanded to Tanzania. Their promise: connecting poor farmers via new technologies empowers them to improve their livelihoods, while also providing for a functioning business model.

A farmer can send a question via SMS to WeFarm, reading for example: "small red insects are attacking my tea plants, please help." The message is automatically processed, stored and analysed in WeFarm's servers, where thanks to machine learning, Wefarm categorises the message by language, intent and content. A matching algorithm is then used to match the message with other farmers who are most likely to provide suitable answers to the question based on their profiles and historical data in WeFarm's database. The original question on red insects and tea plants is then forwarded to 10-12 other farmers in the WeFarm network who might, for example, also cultivate tea plants and had previously provided useful responses on small red insects. These responding farmers can then send advice back to the central system via SMS, which are then forwarded to the asking farmer. The farmer can then rate the answers as useful or not and take informed action based on the crowd-sourced advice.

WeFarm is basically a two-sided marketplace, similar to platforms like Facebook, but dedicated to small-scale farmers without an internet connection. Farmers get a free SMS Q&A service and they provide data in return, such as the crop they use or their location. Based on this data, WeFarm then connects farmers to a broad range of discounted products, services through their marketplace. WeFarm provides vouchers for products or services, which farmers can redeem at a local retailer via their mobile phones. WeFarm receives a commission for every voucher redeemed. The products offered on WeFarm's marketplace range from agricultural products to cooking stoves, to micro-insurance to ultimately loans and a market for their produce. Similar to other digital platforms, WeFarm's biggest selling point is its access to its users (farmers) and the trove of data it is collecting on the smallholder market.[59]

It is hard to quantify the impact of the knowledge generated by WeFarm, as the actual actions taken by the farmers do not leave a digital trace. WeFarm conducted two surveys among its users and 77% provided positive feedback, 21% reported an increase in yield or profit and 56% reported improved farming. An external study conducted on behalf of the Global Resilience Partnership (GRP) by Picture Impact concludes that WeFarm's platform generates actionable responses. The study also concludes that the service faces challenges such as low literacy and that the technological limitations of SMS impose limitations on the service. In addition, WeFarm has to overcome language barriers. The company has built Natural Language Processing (NLP) libraries from scratch for local languages like Swahili, Runynakole and Luganda. As WeFarm continues to scale into new counties, new countries and new continents their data team will continue to build on these libraries, so that language is not a barrier to farmers being able to access the service. The service must therefore be adapted if a new region with a new language is targeted. To extend its functionality, WeFarm plans to bring its service to internet-enabled devices, which will increase the functionality beyond the limits of SMS and which will prove more and more valuable as the internet infrastructure gradually improves.

While the evidence is limited, research has previously shown the positive impact of knowledge on productivity (Onphanhdala 2009;[60] Lockheed et al. 1979).[61] Even in the EU, only 8.5% of farmers have received full agricultural training, and 70% have only practical experience (Augère-Granier 2017).[62] The need for knowledge in agriculture in sub-Saharan Africa can be expected to be much higher. It is important to note that the challenges mentioned above are not specific to WeFarm, but rather general problems in sub-Saharan Africa where human, technologicaland financial capital is scarce. WeFarm has developed an interesting solution which uses new technologies to tackle these challenges in a difficult region that is normally neglected by technology investors.

Connecting small farmers to the market through blockchain

One of the key opportunities offered by digital technologies in the agrifood chain is the possibility to empower small farmers by allowing them to access and share data with the (often more powerful) other actors of the value chain. This can be done through distributed ledger technologies that configure a so-called permissioned blockchain.

These technologies, as already explained, allow all authorised nodes to append tran actions on a shared ledger: this can at least partly reduce transaction costs in identifying and locating counterparties in commercial relations, as well as address problems of trust during the business relationship. Examples like Indonesian platform HARA (see case study below) are extremely promising, provided that all actors in the value chain are adequately skilled and aware of the opportunities offered to them by data. As a proof of the systemic nature of the challenge, it must be recalled that the desired result cannot be achieved without adequate connectivity and adequate quantities of good quality data generated by sensors, drones, satellite images, and devices.

HARA, an integrated, blockchain-based data platform

A good example of emerging integrated blockchain-based applications is HARA, a data exchange platform belonging to Indonesian company Dattabot that aims to provide farmers and all other agricultural players with access to reliable data and transactions. By building an integrated, blockchain-based platform, HARA aims to address a number of existing problems in the value chain: giving financial institutions access to new, underserved customers; enabling insurance products that better leverage climate forecasts and soil information; making it possible for data companies to build sophisticated credit scoring models for underserved borrowers; empowering retailers to provide customers with traceability information; providing certification agencies with information to enable real-time certification; providing price transparency to all players; accelerating the evolution in microbiology and supporting effective substitutes for toxic farm inputs; providing smallholders with agronomical data, online-advice and market information, such as prices and off-take volumes.

The markets that HARA will focus on are developing countries located near the equator, characterised by long growing periods (many are year-round), and where mobile phone service is available. Dattabot has identified eight countries that possess these attributes, representing nearly one third of all smallholder farmers in the world: Bangladesh, Indonesia, Vietnam, Thailand, Uganda, Kenya, Mexico and Peru. The data included in the platform are shown below.

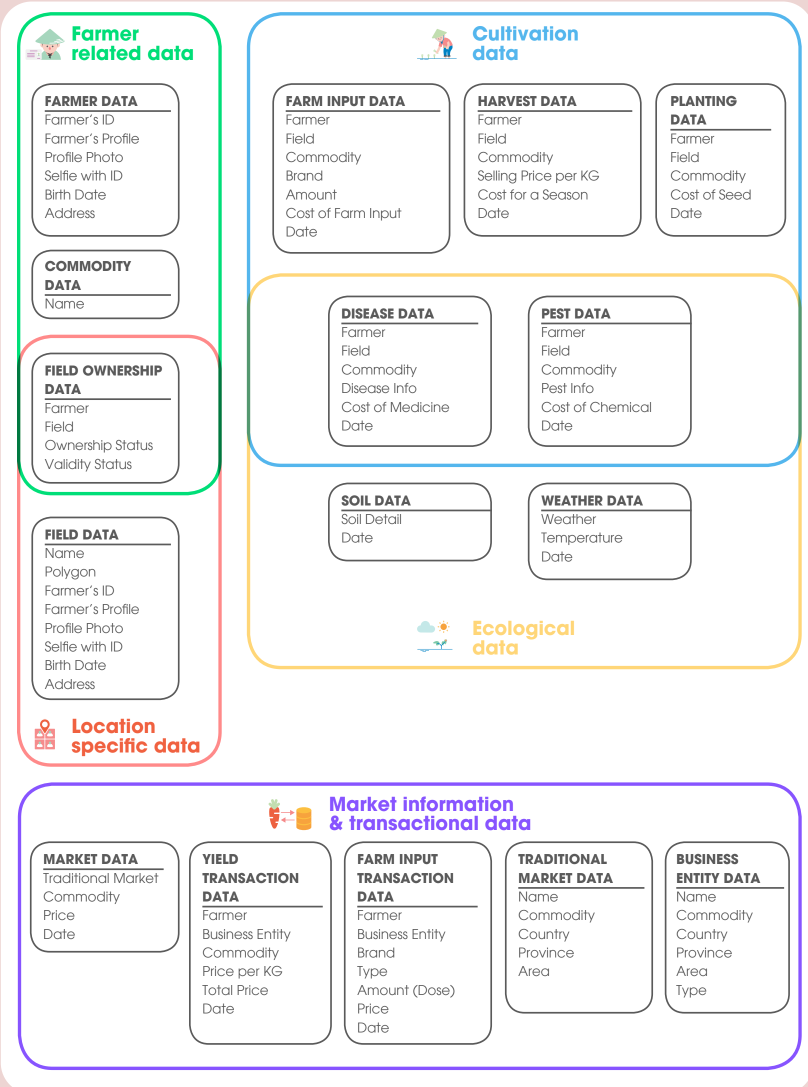
Through a field validation process over the past few years, HARA has found that a combination of four stakeholders is needed to create a sustainable ecosystem on its platform. The four stakeholders play different roles:

- **Data providers** include individual data contributors, data companies, cooperatives, NGOs, field agents, and governments. They can use the data exchange to assess the quality of their data and monetise it by exchanging it for tokens.

• **Data qualifiers** add value to the ecosystem by providing verification in the form of proof of work. They act as a crowd-sourced indicator of data quality, which overtime, will help improve the overall robustness of the data and help generate healthy, ongoing demand. Data qualifiers will receive tokens based on their efforts related to the tasks they perform in verifying data on the exchange. Data qualifiers can be any HARA token holders.

• **Data buyers** include enterprises such as banks, insurance companies, retailers, agriculture input suppliers, NGOs, and government – all the way down to local communities or even individuals.

Figure 11 – Data included in the HARA platform



• **Value-added Services** include companies and institutions that access and process raw data from HARA Ecosystem and resubmit it as 'enriched data'. These can be academic institutions, brands, data analytics, financial technology and agriculture technology companies. They create value-added insights from the raw data and share in the proceeds with the original data providers by submitting the cleansed, organised, and structured data back to the HARA Ecosystem.

The resulting ecosystem is depicted below.[63]

Figure 12 – The HARA ecosystem

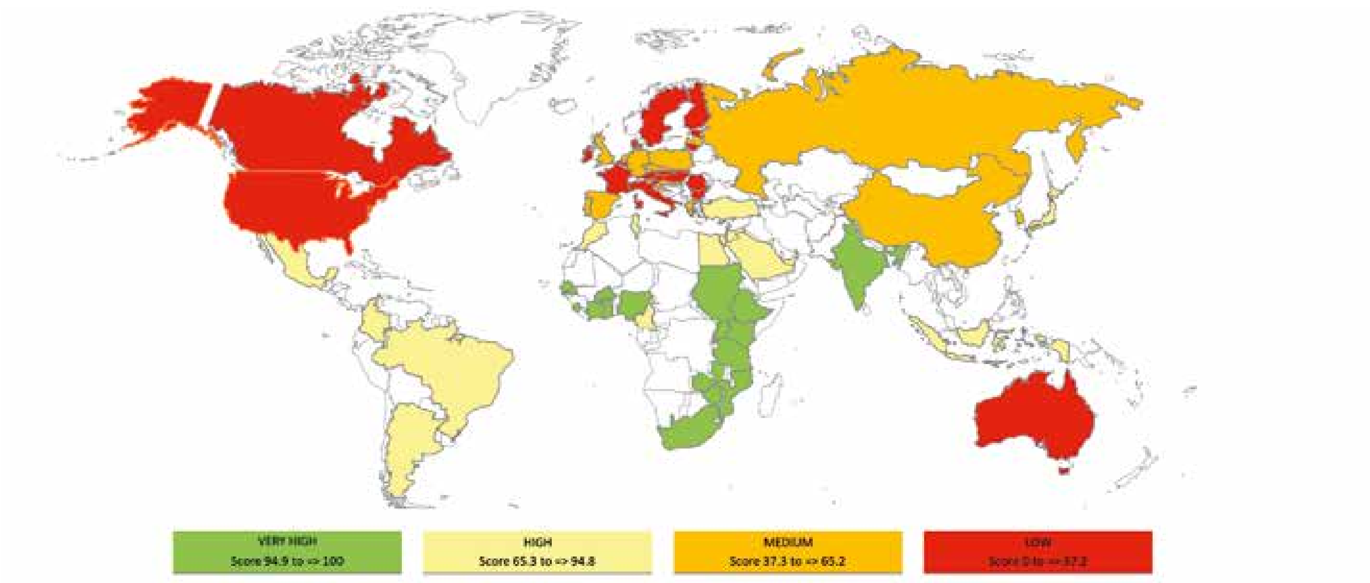
Reducing food waste and minimising loss

According to the United Nations, 820 million people lack access to the food necessary to lead a healthy lifestyle today, 98% of whom live in developing countries and 75% in rural areas.[64] In stark contrast with this figure, a third of the food produced in the world for human consumption, approximately 1.3 billion metric tonnes, gets lost or wasted every year. Digital technologies can help overcome this mismatch in many ways: better matching supply and demand, helping to identify and target exactly where waste occurs and what is being wasted, and helping consumers better judge spoilage. Figure 13 below displays the global per capita food waste at the end- user level, measured in kilogrammes per person per year, as observed in some of the key findings from the 2018 Food Sustainability Index. The map clearly shows that consumers in the developed world including North America, most of Europe, and Australia are wasting the most food. Among households, the causes of food waste have to do with excessive purchasing, poor planning, and consumer preferences for unblemished fruits and vegetables.

Additionally, confusion around expiry dates on products can lead to unintentional waste. In commercial settings, kitchens routinely overproduce due to poor forecasting or contractual constraints. In retail outlets, again over-purchasing and poor forecasting, coupled with strict expiry dates lead to an inability to move the merchandise resulting in wastage.

storage link of the supply chain, largely due to lack of reliable electricity and in turn, cold storage. The distinction between food waste and loss is important because the root causes are different, and therefore conservation methods and their related impacts will also differ. In advanced economies, conservation efforts need to focus more on strategies for raising awareness and engagement

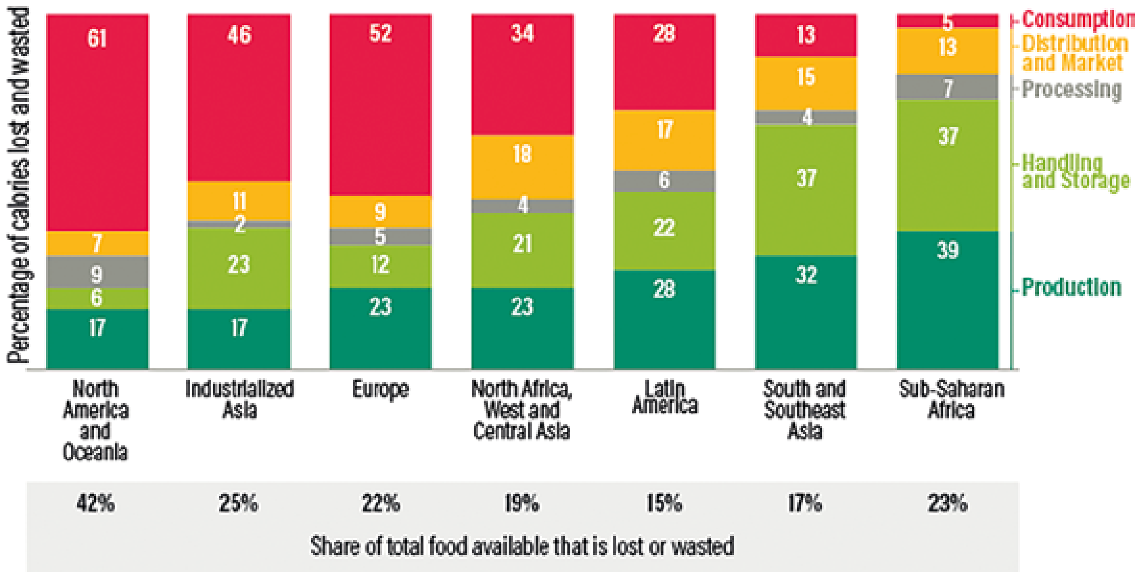
Figure 13 – Per capita food waste per year



Source: Barilla Center for Food and Nutrition, Economist Intelligence Unit 2018.

While the map above illustrates where food waste per capita is most prevalent, the graph below shows that different regions of the world need different solutions to food waste and loss. Perhaps predictably, in advanced economies where consumers have greater disposable income and more complex demands for different food types, supply chain losses occur most significantly at the consumer level, which is properly considered to be food waste. In developing economies, the greatest food losses occur at the handing and among downstream (consumer) actors. The problem in developing countries, by contrast, is the opposite where poor levels of public infrastructure in roads, railways, electrical power grids, and customs cause the greatest losses on the upstream side. In developing countries, DLTs could help the implementation of "cold chains", i.e. temperature-controlled supply chains, which ensure that distance travelled by food does not inadvertently lead to damaged goods and food loss.[65]

Figure 14 – Where food loss and waste occurs along the food chain



Source: WRI analysis based on FAO data 2011.

Digital technologies offer promising solutions for tackling food waste and loss, depending on the part of the value chain being considered. For example, some authors estimate that 15-20% of food waste happens after harvest and before it reaches consumers (Shacklett 2018). To reduce this waste, companies can use geo-location systems to optimise logistics and bring food to consumers before it spoils; smart thermostats can ensure an uninterrupted cooling chain during the transportation phase (Nirenjena et al. 2018); tracking sensors can be deployed to track and prove the origin of products; or applications can be used to nudge consumers towards more sustainable consumption. Better supply and demand signalling gained from AI-powered applications described in the discussion of precision farming could reduce overproduction on the supply side which would have a ripple effect all the way through to the consumer. Other AI-powered applications deployed in a retail setting, such as the one designed by the Albert Heijn supermarket chain, encourage consumers to buy edible food before it spoils.

Albert Heijn offers discounts with dynamic pricing to fight food waste

Albert Heijn is a Dutch food retail brand belonging to the international food retailing group Ahold Delhaize, based in the Netherlands. The group operates 6,769 stores in the US and Europe, serves more than 50 million customers per week, and reported revenues of €62.8 billion in 2018. [66]

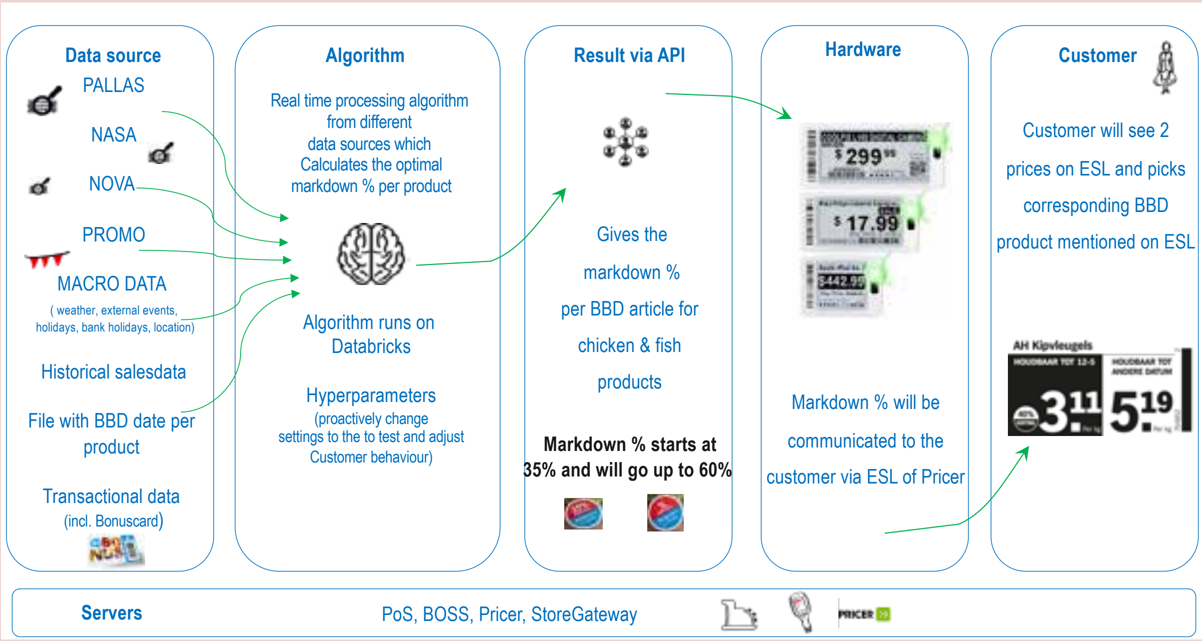
The company's core principles to support its sustainability strategy and vision revolve around enabling their customers and associates to eat healthier every day, contributing to the global goals to reduce food waste, and providing a healthy and inclusive workplace for associates. With regard to food waste, the company has committed to reducing total waste in operations by 20% from 2016 to 2020, and to maximising the recovery of unsold food to reduce hunger in the community. Ahold Delhaize measures food waste by: tonnes of food waste per sales, i.e. 'shrink' as a percentage of total food sold; percentage of food waste recycled (i.e. diverted from landfill); and tonnes of food donated.

Dynamic discounting - how it works

In May 2019, advised by Tel Aviv-based Wasteless, a company that has developed a machine-learning pricing engine enabling dynamic pricing based on a series of variables, Albert Heijn conducted a test experimenting with dynamic discounts on chicken and fish products at a store in Zandvoort in the Netherlands. The products are automatically reduced in price based on their sell-by date, with a higher discount for items with the shortest remaining shelf-life. The algorithm developed by Albert Heijn calculates the best discount by taking several factors into account: the expiration date, weather conditions, location, bonus offers, historical sales performance, and in-store stock. The products are displayed using electronic shelf labels (ESL) with two prices: the regular price and a discount at a specific expiration date. The dynamic price tags are also accompanied by T-stands with an inspirational message such as "40% discount because waste is a shame", designed to get the customer's attention. The prices are displayed before 10 a.m. and are adapted during the day based on actual sales. The application pulls data, both proprietary and macro, and feeds it into an algorithm which calculates the discount that appears via the API on the ESL where the customer is alerted to the item on offer.

Results

Albert Heijn achieved encouraging results with the test which resulted in positive media coverage and increased favourable brand perception by customers. Food shrink figures stayed under the Albert Heijn national average on the same products during the test period and improved in the final phase. The pilot determined that dynamic markdown solution is scalable and the company plans further pilot testing in 10 stores to better estimate the benefits and optimise processes and infrastructure in order to roll out the ESL solution nation-wide. The ESL is an elegant and more scalable solution than manual stickering of mark-downs which may result in more edible-but-expiring foods being sold rather than wasted.



Source: Albert Heijn proprietary research, 2019.

Blockchain applications and food waste

Blockchain, and DLTs more generally, have the potential to integrate supply chain transactions in real-time, as well as identify and audit the origin of goods in every link of the chain (Renda et al. 2019). When applied to the agrifood supply chain, critical product information such as origin and expiration dates, batch numbers, processing data, storage temperatures, and shipping details get digitised and entered into the blockchain at every step along the chain. Using smart-phones to read QR codes to get details on the source of meat, including an animal's date of birth, usage of antibiotics, vaccinations, livestock harvest, dispatch and shipping can easily be traced. Increasingly, companies are now developing infrastructure to leverage blockchain to make supply chains more robust, efficient, and traceable.

In early 2017, food giants like Wal-Mart, Nestlé, and Unilever (among others) started to collaborate with tech companies to apply blockchains to global agrifood supply chains. A recent report by Forbes highlighted that while by conventional methods Walmart took more than 6 days to trace the exact farm location of mangoes being distributed in its stores, using blockchain the same task can be completed in under 3 seconds.[67] Projects being developed by start-ups like FreshSurety, AgriDigital, HarvestMark, FoodLogiQ and Ripe.io all move in the direction of increasing the transparency and traceability of the value chain. Another ICT-based agrifood service that relies on information is Trace-Verified, the first electronic traceability service in Vietnam. Not only does TraceVerified help consumers by enabling them to access more transparent information about foods on the market, it also benefits farmers and good producers by creating an opportunity for them to build their credibility and competitiveness in the market (FAO and ITU, E-agriculture in Action, 2017). Importantly, TraceVerified was intentionally designed to be a web-based and smartphone-enabled IT service so that anyone with access to web technology can use it.

A mapping of these projects (Ge 2017) concluded that the key areas of application include: the registration of holdings, animal, plant and transactions; the tracking and tracing of products with credence attributes (i.e. qualities that are not directly observable by users or end consumers,); true pricing that aims to convey information on the externalities of food production; transfer of import and export certificates; inclusive development by ensuring access of smallholders to better market and better payments or financing possibilities (e.g. FairFood, AgriLedger); creating opportunities for automating business processes triggered by a conditioned transaction.

Blockchain can also help in more downstream phases of the food waste cycle, by helping reallocate leftovers and foods that are nearing expiration but are still edible, as well as foods that are perfectly fit for consumption but are deemed second quality in appearance. This is what companies like Goodr in Atlanta do to arrange the distribution of leftovers from restaurants to local charities through an app. Estonian company Delicia is using blockchain to create a global, decentralised platform for retailers like grocery and convenience stores to sell food that is nearing expiration to local buyers like restaurants or consumers. These services can easily be coupled with AI-enabled dynamic pricing: companies like Wasteless help retailers to dynamically price and sell products based on their freshness; the automatic tracking of unsold inventory allows effective decisions leading to the most optimal financial outcomes and less food waste (e.g. Spoiler Alert). Coupled with IoT, blockchain can provide an even more compelling solution: for example, a start-up named Blue Ocean is attempting to deploy a radical business model that would leverage identity verification systems, algorithms, IoT, smart sensors, and blockchain to develop a system in which connected smart bins identify who, when, what and how participants within the ecosystem are behaving. This, in turn, allows the system to immediately reward users for placing food leftovers in the recycling trash bin.[68]

Machine learning and food waste

Outside the blockchain universe, the use of AI to reduce food waste, mostly in the form of machine learning, is growing rapidly. For example, Hitachi partners with hospitals to use AI to monitor food waste, improving meal preparation while also relieving the burden on nurses to check these leftovers. The system works by using a camera mounted on a trolley that collects trays, taking pictures of the leftovers. Hitachi systems can recognise patterns in the leftovers that humans otherwise could not see. Similarly, start-ups like Winnow (a food waste computer vision technology for restaurants) and Kitro (smart bin that can identify, manage and monitor the sources and quantities of food waste) are developing solutions that combine data collection and sensing with AI. AI-enabled algorithms are being used also to improve food inspections using images taken by a mobile phone (AgShift), hyperspectral images (Impact Vision) and sensor data.

Winnow: Helping chefs around the world waste less in the kitchen

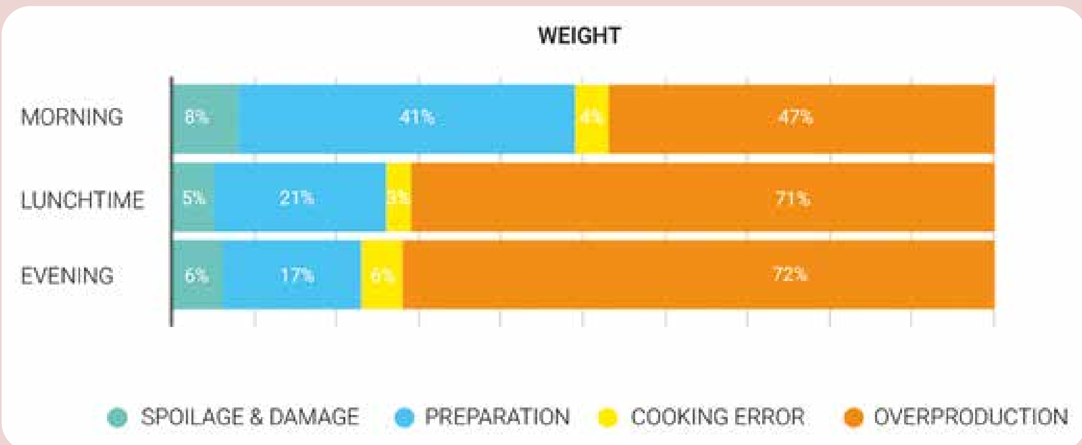
Food waste is a huge problem globally, but it is especially acute in the hospitality and foodservice industries. This has significant social and environmental costs, which digital technology can help mitigate for commercial kitchens by identifying patterns of waste and aiding in meal planning to prevent overproduction, the key cause of waste. In cook-to-order restaurants, most waste is 'plate-waste' left behind by diners who did not finish their meal. This is actually a small amount relative to all waste in commercial kitchens. In commercial canteen environments, overproduction is essentially a forecasting problem. For example, in order to ensure that there is enough food of sufficiently appealing quality for customers, a buffet on cruise ship or in a hotel must constantly replenish stocks as diners fill their plates. In contract catering, the foodservice provider is contractually bound to produce a certain level of food. Both of these cases tend to favour overproduction in order to be assured of meeting supply. In neither of these cases are there any consequences for oversupply – except for the profitability of the provider.

Where and why food waste occurs

According to data collected by Winnow from over 450 sites in 25 countries, kitchens that prepare food in advance waste between 8-20% of total food costs due to overproduction, kitchen errors, spoilage and damaged produce, and food left on customer plates. In some facilities, this level of waste can be as high as 40%.[69] Often this amount can be equal to, or more than, total net profits. By dissecting the data, it is evident that, within the total amount of waste, overproduction is the main cause: over 60% of food waste by weight is thrown away because kitchens prepare more food than customers are able to eat (below), particularly in the dinner hour. In fact, the data show that over 70% of all food waste happens before it reaches the customers' plates (pre-consumer waste), compared with less than 30% of food waste coming from the plate itself (post-consumer waste).[70]

The majority of these kitchens have demonstrated that, through the use of quality, granular data, coupled with strong leadership and high levels of staff engagement, it is possible to cut the level of overproduction waste by 40% or more, without impacting the quality of service.[71] The old adage, "what gets measured gets managed", has never been more true than in a kitchen environment, where high staff turnover, changes in menus and variances in costs can have a significant impact on the profitability of the kitchen. By measuring and managing both the weight and value of food waste on an ongoing basis, kitchens have an opportunity to greatly enhance the efficiency and productivity of their operations.

Figure 15 – Where food waste occurs in hospitality and food service



Source: Winnow Proprietary Research.

Winnow Vision – how it works

Winnow uses a form of AI called computer vision, which is the act of taking the information in an image, breaking it down in detail and then having the computer analyse that information to understand what the image is. Winnow Vision employs a camera, positioned directly above the bin, that takes images of what is being discarded. As food goes into the bin, the system performs three machine-learning based tasks:

1. **Bin detection:** Locates the bin in view of the camera, and crops the photo to show just the contents of the bin.
2. **Change detection:** Compares the new photo with the photo from the previous transaction, the system detects where the new food is in the bin and outlines that area.
3. **Food recognition:** Focusing on the identified area, the system uses a food recognition model to classify the food.

The benefits

Winnow Vision is a breakthrough because it offers a pathway to improved data quality, and the automation of a process that was at worst impossible, and at best a time-consuming task for kitchen teams. The product has already surpassed human levels with an accuracy rate of over 80%[72] in identifying food that has ended up in the trash. Busy kitchen teams average between 70-75% data accuracy.[73] When recognition capability is turned on, a state of semi-automation is reached where users are only required to confirm the suggested food. Eventually, as the system gets smarter, full automation will not require any input from the team. By accurately identifying and quantifying what is being thrown away, kitchens are better able to forecast what quantities of food to prepare in the first place, vastly reducing pre-consumer waste. Winnow helps their users to reduce food waste by 40-70% in the first six to twelve months of implementation and reduce their costs between 2-8%. Since its founding, the company has helped its users reduce carbon emissions from food waste by 36,000 tonnes collectively.

Winnow's business model

Winnow uses a Software as a Service (SaaS) business model. The company charges a monthly fee for analytics generated by the system, based on the size and complexity of the kitchen. Winnow's internal estimates are that customers achieve anywhere from a 2 to 10 times return on investment (ROI) by implementing Winnow Vision.[74]

Results: IKEA's journey to cutting food waste by 50% [75]

In 2017, IKEA launched its "Food Is Precious" initiative, committing publicly to cutting its restaurant waste by 50% by the year 2020. IKEA UK & Ireland was one of the first commercial deployments of Winnow Vision, and has played a crucial role in the product's evolution. Winnow Vision is now live in all 23 IKEA stores in the UK & Ireland.

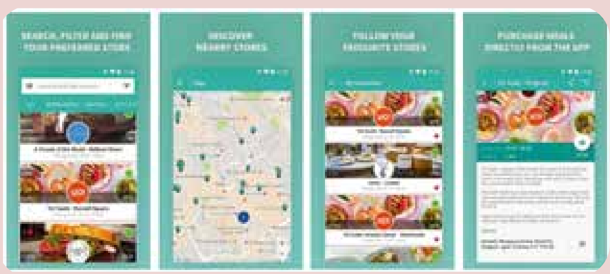
In addition to food-tech solutions as discrete applications, alternative retail formats dedicated to preventing food waste could be envisioned to address downstream consumption, using innovative ways of reaching consumers. One such example coming from Denmark is Too Good To Go, an app that connects consumers to sources of edible, surplus food at a discount.

Too Good To Go: Finding an after-market for leftovers

Too Good To Go is a Danish start-up founded in 2016 that is fighting food waste by creating a movement. The company's mission is to engage consumers in food waste prevention through their everyday actions. The company has identified four pillars against which they have set ambitious targets to meet by 2020. The pillars include: households – with a target of reaching 50 million people; businesses – with a goal to recruit 75,000 onto the platform; education – with the intent to inspire 500 schools; politics – with the goal of advancing anti-waste legislation in five countries.

How it works

Too Good To Go's solution works by providing a marketplace for connecting businesses, through a mobile app, that have surplus food to sell on discount, with consumers who want to rescue food and find good deal at the same time. Consumers never know exactly what is on offer from food retailers or restaurants – the element of surprise helps to drive user engagement. Customers order a "magic bag" of surplus food through the app and collect it from a dedicated pick-up window at the seller's location. Customers can filter for dietary restrictions or a type of cuisine, or even follow their favourite restaurants and stores, but cannot select specific menu or retail items. The app detects a consumer's location by using the phone's GPS system while they are using the app and after opting-in. Once the user closes the app, it no longer tracks any of their activities or location. The app is powered by an algorithm designed to optimise its performance and performs some behaviour tracking to learn a user's preferences in order to display available food to users.



Business model and current results

The food establishments offer users a magic bag of goods at a heavily discounted price. Too Good To Go takes a percentage, usually in the range of 30-33% of the bag price for arranging the sale and payment through their app. For the seller, being able to earn any revenue at all is worthwhile, because otherwise they would have to throw the food away, which is both a cost and loss of revenue for them. As for results so far, the company has: 16 million registered users, saved 22 million meals, saved more than 55,000 tonnes of CO_2, launched in 13 countries, and partnered with more than 30,000 restaurants and retailers.[76]

Nutrition: empowering consumers and protecting their health

Towards the end of the agrifood supply chain, digital technologies can have a substantial impact on the way individual consumers manage and approach their consumption behaviour and decisions. This is, again, due to a combination of technologies in the 'agrifood stack', including connectivity, IoT, blockchain and AI. One good example is the use of blockchain to enable more transparent and reliable decision-making by end users when deciding which food to purchase and consume. As already mentioned, the use of blockchain can solve some of the problems associated with 'credence qualities' in food, which can otherwise create problems of adverse selection. Since opacity and lack of trust in the value chain can limit the trustworthiness and observability of quality attributes of food, consumers end up choosing cheaper products as they do not trust the signals provided by the distributor. With blockchain, and supported by adequate data, end users could trace the origin of food by themselves, and may then decide to place more value on quality signals. This can address the issue of high-quality food being otherwise excluded from the market, thus restoring the allocative efficiency potential of market exchange, as well as incentives to invest in quality on the side of producers and distributors.

The importance of quality signals has been validated now that Walmart's original proofs of concept with IBM on mangoes and pork have been scaled up to a large coalition of retailers and producers, including Kroger, Wegmans, Tyson, Driscolls, Nestlé, Unilever, Danone, McCormick, and Dole (Yiannas 2018). More recently, in November 2018, Auchan, the world's 13th largest food retailer, announced the implementation of TE-FOOD's blockchain-based farm-to-table food traceability solution in France, with further international roll-outs expected to follow in Italy, Spain, Portugal and Senegal.[77] Moreover, French retail giant Carrefour has taken similar steps to Walmart by integrating IBM's tailored blockchain data system known as Food Trust with a view to improving food safety.[78]

Needless to say, the implementation of blockchain technology for traceability and integrity in the agri-food supply chain also has important consequences for the SDGs, and in particular to avoid the spread of diseases such as, i.a. the recent Romain lettuce e.coli outbreak in the US and Canada.[79] In particular, blockchain can assist in tracing the cause of the outbreak to a specific distributor, farm or grower in the supply chain. This prevents blanket warnings which affect everyone even when the cause is limited to a particular origin. This positive effect is also one of the reasons why food safety regulators have started to consider using the technology on a large scale. In October 2018, the US Food Standards Agency announced the successful completion of a blockchain trial to track beef from the slaughterhouse to the end consumer. The expansion of the use of DLTs in agrifood is by now considered to be likely, and promising: however, the governance attributes of existing projects are constantly evolving, and the need for a distributed, if not decentralised structure is often evoked as the only way to avoid that the re-intermediated sector falls into the hands of large corporations, creating problems of competition and also reducing the possibility for public authorities to fully observe the data being stored on the chain.

How AI can empower and nudge end users 'for good'

AI can empower end users in many ways. These range from purely technological solutions to behavioural assistance in consumption decisions. For example, a new dataset of common grocery store items was recently developed by Klasson et al. (2018), using a smartphone camera and photographing 5,125 images of various items in the fruit and vegetable and refrigerated dairy/juice sections of 18 different grocery stores. The dataset contains 81 fine-grained products, which are each accompanied with an iconic image of the item and a product description including origin country, the estimated weight and nutrient values of the item from a grocery store website. Such a system can reportedly help visually impaired people when they shop in grocery stores, and can complement existing visual assistive technology, which is confined to grocery items with barcodes. More generally, still on the technical side, image recognition and computer vision can enable more trust in remote shopping, where an enhanced ability to recognise the conditions and quality of the food being purchased is needed. If coupled with remote sensing through IoT in the future, these systems can improve on the experience of purchasing food directly in the store, at the same time distancing consumers from their direct, hands-on experience.

Think Digital – FarmVR: virtual and augmented reality technology in agriculture education

Do people feel connected to farmers and to food? With increasing industrialisation and globalisation of agricultural supply chains, consumers are finding themselves more and more distant from their food – physically, psychologically and emotionally. Surveys conducted in industrialised nations around the globe have found low levels of 'agricultural literacy' among consumers. In the US alone, 16 million people indicated that they believe chocolate milk comes from brown cows (Farmbillfairness). The US survey also showed that orange juice was considered the nation's most popular 'fruit', and potatoes (in chip and fry form), were the nation's most popular 'vegetables'.

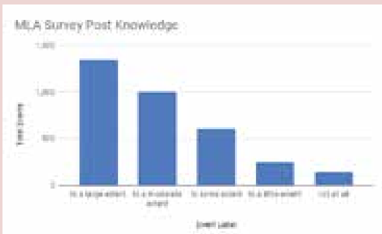
The amount of processing and length of distance that food travels before getting to consumers partly explain why consumers feel so detached from it. The farming and food production sectors have moved to the periphery of industrialised societies, with only a very small percentage of people actively involved in the growing, harvesting, and raising of agricultural goods and commodities.

This is where Think Digital's augmented and virtual technology comes in. An Australian tech company, Think Digital, builds immersive education platforms, FarmVR and FarmAR, for the agriculture industry that are designed to educate people on where their food comes from, increase agricultural literacy amongst consumers, and encourage people to consider careers in agriculture. Think Digital's products and services allow consumers to connect with users all over the world to participate in traditional agricultural activities such as sheep-shearing, chemical safety tests, artificial insemination and tractor driving simulations.[80]

Think Digital has produced a number of innovative technologies, including virtual reality hardware as well as virtual and augmented reality software and mobile applications. Their diverse product suite includes a series of platforms, compatible with both Android and iOS, that are available on the Apple, Android, Steam and Oculus app stores.[81] Their audiences and clients range from school students, to educators, to industry groups and producers.

What are the benefits of employing virtual and augmented reality technology in agriculture education? Virtual reality makes it possible to providein depth, personal, and precise education and training experiences that are either impractical, burdensome, or too costly to simulate in a traditional classroom setting. Just short of experiencing an aspect of the agriculture industry first-hand, the immersive content places the learner into the situation, providing greater comprehension and engagement with the material. By requiring the learner to use more senses, ThinkDigital's technology enables increased retention of key material, while simultaneously approaching agricultural education in a new, efficient, and innovative way. [82]

In terms of measuring the impact of ThinkDigital's software, hardware, and mobile applications, the company has shown demonstrated improvements in consumer understanding of agricultural supply chains by means of their augmented and virtual reality technology. At a recent agricultural show in Australia, Think Digital's FarmVR team collected over 4,500 responses from people who engaged in the Lamb Paddock to Plate VR Experiences that illustrate the shifts in the consumer's perception of Australia's lamb industry.



While Think Digital concedes the different terminology used in the pre- and post-surveys taken before and after consumers immersed themselves into the FarmVR Lamb Paddock to Plate experience, a decrease of roughly two-thirds can be seen in consumers who perceived their knowledge of the livestock, specifically lamb, industry in Australia. A significant increase can also be seen in the number of consumers who registered an 'excellent' or 'to a large extent' understanding of the Australian lamb-raising industry and supply chain. By bringing the consumer directly into the industry, Think Digital is increasing transparency, efficiency, and creativity in people's approach to food and agriculture.

Besides purely technical solutions, there is reason to expect that the real revolution brought about by AI in the short term will be in personalised services in nutrition. Food giants like Nestlé are now launching ambitious programmes to boost personalised diet advice through AI, coupled with new technological breakthroughs such as instant DNA testing. In Japan, this already led more than 100,000 users of the 'Nestlé Wellness Ambassador' programme send pictures of their food via the popular Line app that then recommends lifestyle changes and specially formulated supplements. This requires the use of voice assistants powered by natural language processing and machine learning, and ends up as 'mass customisation of food', such as the creation of personalised tea capsules based on individual characteristics and preferences.[83] As the understanding of human dietary needs improves in the coming decades, these services will become commonplace, with significant impact on SDGs related to health, hunger and malnutrition. For example, the absence of balanced food and nutrition security leads to health problems such as diabetes, obesity, and malnutrition. Personalised approaches can be effective since responses to dietary intervention vary across the population, according to variables such as genetics, age, gender, lifestyle, environmental exposure, gut microbiome, epigenetics, metabolism nutrition derived from diet, and foods.

The combination of user data, DNA and genetic testing and analysis, big data, computer vision, data on environment, healthcare records, data from wearables and implanted devices and advanced AI solutions can generate enormous advantages, but also important risks, for humanity.[84] For example, closely monitoring conversations on social media, companies can use AI to analyse consumer data and identify sentiments or behaviour that are crucial not only in building positive experiences but also in the development and design of new product lines. Herranz et al. (2018) study food analysis powered by AI and focus i.a. on recommender systems, which require collecting feedback and user preferences, and in particular, taking health and nutritional aspects in the recommendation. As demonstrated in large randomised controlled trials on personalised nutrition such as Food4Me, such systems can be extremely effective in promoting healthy diets; but can also easily nudge users towards specific food consumption, enabling a new, more season of granular, extremely effective AI-enabled marketing, which can even compromise human agency and self-determination (Verma et al. 2018).

Recent studies demonstrated successful application of providing personalised dietary advice at an individual level. Although the prediction method used by Zeevi et al. demonstrated the effectiveness of personalised diet regimes to reduce levels of glucose, the results failed to connect to health outcomes. A web-based pan-European, Food4Me study aimed to evaluate whether personalised advice caused more changes in dietary behaviour as compared to a 'one size fits all' approach. An automated dietary feedback system was used to deliver personalised dietary advice and its comparison with manual system demonstrated complete agreement. The study demonstrated that personalised nutrition advice was more effective compared to a population-based nutritional advice.

Nutrino: data-driven meal recommendations

Israeli digital company Nutrino is a personal, data-driven meal recommender for healthier diets. Nutrino combines two important data sources for its meal recommendations. First, on the food side, it has developed a large nutritional database on the micronutrients of different foods and meals and on nutritional recommendations. Second, on the user side, it allows user to input personal data such as daily food consumption, activity, sleep and medical data into their system.

Nutrino then combines these data and applies data analytics tools such as AI and machine learning to better understand dietary impacts on the user's health. It terms this data process as the user's "Food-Print". Since Nutrino's 2018acquisition by Medtronic, a medical device manufacturer, Nutrino mostly focuses on diabetes. Take the following example: users can log their food into Nutrino's application by taking a picture of each snack or meal. Then the AI-powered program matches each food entry with the user's glucose levels following the meal. Every six days Nutrino's app is synced with the patient's glucose measuring device and creates a Pattern Snapshot report and a FoodPrint report. The snapshot report shows users their glucose level, target range and patterns. The FoodPrint report shows users all of their recorded meals with an accompanying score of A, B, C, D or F, based on the user's glucose reaction to that meal. The resulting recommendations can help patients improve their dietary choices. Nutrino claims that hypoglycemic events could be brought down by up to 18% for diabetic patients using the application daily (Nutrino 2017).[85]

Towards a more systemic view on health – an interview with Prof. Ilaria Capua

Prof. Ilaria Capua is a virologist and former Italian politician. She is currently the director of the One Health Center of Excellence at the University of Florida. Based on her combined experience as a scientist and politician, we interviewed Prof. Capua on the challenges and opportunities linked to digital technologies.

Question: What is your experience when it comes to the application of digital technologies in the domains of agriculture, food loss and waste or nutrition in the developed world?

Answer: Particularly in some sectors of agriculture, I see resistance when it comes to the adoption of digital technologies. The digital divide plays an important role in this. The average farmer in Canada and the USA is almost 60 years old. Farmers tend to prefer using the old ways they have always used. It takes a while for them to accept that digital technologies can actually facilitate their life. Paradoxically, in developing countries there is less resistance but fewer opportunities.

Question: This ties into our second question. What are the greatest challenges for digital technologies in this domain?

Answer: Digital technologies have to help farmers optimise their work. As a farmer who is, on average, male and 60 years old, I have to optimise my time. If I have to figure the technology out on my own, there is no optimisation and I will not use it. For digital technologies to be useful, farmers have to be able to access them fast and they have to provide useful answers to their problems. Commercial companies are making inroads into this area. A major opportunity exists to leverage these initial technical platforms to reflect a wider data package that is personalised and both economically and environmentally relevant.

The facilitation of interventions that result in health status improvements in animals and crops will inevitably affect human health, and is a key deliverable moving forward.

Question: What, on the other hand, is the greatest potential of digital technologies in this domain?

Answer: I am a scientist and I work on public health. The greatest potential is in the combination of the information that digital technologies generate. For example, if digital technologies help us to monitor crop health, they can help us detect diseases earlier and avoid costly and unhealthy treatments. Healthy crops mean healthier water, soil and people. We have to start seeing health as a system, interacting in real time and in a real space and not as a series of disjointed pillars.

Thanks to digital technologies, we will soon be drowning in data. We can use this data to join up things that we previously thought separate pillars. From the 'pillars' point of view, agricultural scientists look at soil, veterinarians look at animals, etc. But when antibiotics are fed into animals, they pass into the water, soil and eventually humans. The growing amount of data will enable us to develop a more integrated view of these problems. When we understand the problem clearly, a solution will surely follow.

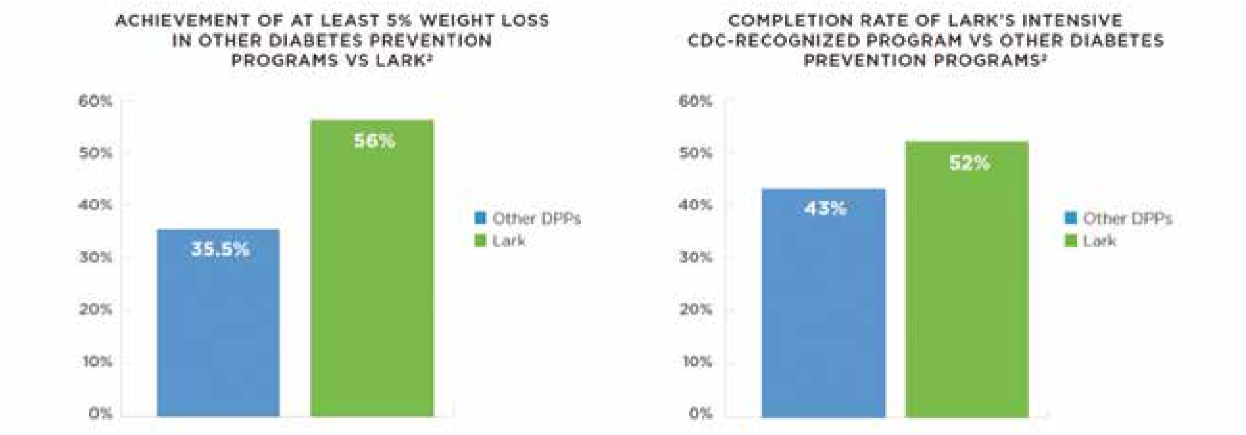
Question: Based on your experience in the Italian Parliament, what are your policy recommendations?

Answer: We need to bridge the digital divide and empower producers. We need to empower large companies to be more transparent and sustainable. We need to harness the power of the individual to inform and influence sustainable policy formulation. I believe that rules facilitating greater transparency are one of the most important components of this overall policy solution. Acting more transparently and ethically allows producers to develop closer relationships with consumers and assists politicians in acting in a more supportive way for citizens. The optimisation of rules on transparency is therefore a key goal if political structures are to influence, in an ever developing positive spiral, what we are discovering as the connected framework of 'Circular Health'.

Several AI-enabled apps have entered the market recently. Lark is a health app that describes itself as a 24/7 Health Coach. It promises "a holistic, customised plan", delivered by AI, with a chatbot that acts as a virtual, personal trainer and nutritionist coach. The program was developed by health and behaviour researchers at Stanford University and Harvard Medical School, with input from experts on nutrition, fitness, sleep, and chronic disease prevention and management. Apple voted it one of the "Top 10 Apps of 2015", and Vogue described it as a cheerleader that "ultimately feels like a friend". Various versions of Lark are for wellness, weight loss, diabetes prevention if you have prediabetes, and managing diabetes and hypertension.

Lark's Digital Nutrition Therapy delivers disease-specific nutrition counselling based on different care plans in real time. Utilising FDA guidance for serving sizes and the nutritional information for each food item allows Lark to estimate the food's nutritional breakdown with accuracy. Lark, based on input from its medical advisory board comprised of the leading behavioural and nutrition experts from Harvard and Stanford, has broken down foods beyond the traditional calorie-focused, one dimensional approach to nutrition into a 12-dimensional analysis, then

Figure 16 – Lark's Results on Prediabetic Users



Source: Lark company website https://www.lark.com/outcomes.

attached thousands of interventions to those outputs. This allows highly personalised interventions for each disease state, and each with the granularity and personal context of the individual struggling with a chronic condition.

Yum-me is a meal recommender developed by researchers at Cornell. Its distinctive feature is that it learns fine-grained food preferences without relying on the user's dietary history.[86] It leverages people's apparent desire to engage with food photos to create a more user-friendly medium for asking visually based diet-related questions. The recommender learns users' fine-grained food preferences through a simple quiz-based visual interface and then attempts to generate meal recommendations that cater to the user's health goals, food restrictions, as well as personal appetite for food. It can be used by people who have food restrictions, such as vegetarian, vegan, kosher, or halal. Particularly, Yum-me focuses on the health goals in the form of nutritional expectations, for example adjusting calories, protein, and fat intake. This also includes one of the first interfaces and algorithms that learn users' food preferences through real-time interactions without requiring specific diet history information.

For such an online learning algorithm to work, one of the most critical components is a robust food image analysis model called FoodDist. Researchers evaluated the online learning framework in a field study of 227 anonymous users: results showed that it is able to predict the food items that a user likes or dislikes with high accuracy.

CHAPTER 2
Main findings

Digital technology can revolutionise agriculture, address food waste, and support healthier diets, achieving sustainability

Agriculture represents 9% of global GDP but has been slow to digitise and remains inefficient.

Precision agriculture achieves efficiency and sustainability through the smart use of AI, sensors and IoT, cameras, robotics, blockchain, and data in various use cases.

Small farmers can benefit enormously from the digitalisation of agriculture connecting them to markets; information and services through blockchain platforms can resolve trust and traceability challenges.

AI-powered apps tackle food waste and create personalised nutrition services by incorporating a variety of user data.

Precision agriculture

Ignitia: an AI-powered weather analysis and prediction platform, leveraging Earth observation data.

WeFarm: a farmer-centric app for exchange of advice between poor farmers in the global south via SMS.

GAIA: a web app which identifies, locates and monitors micro-level, high-value crops at continent-scale.

Food Waste

Albert Heijn: global food retailer trialling an AI-powered, dynamic digital price tag solution.

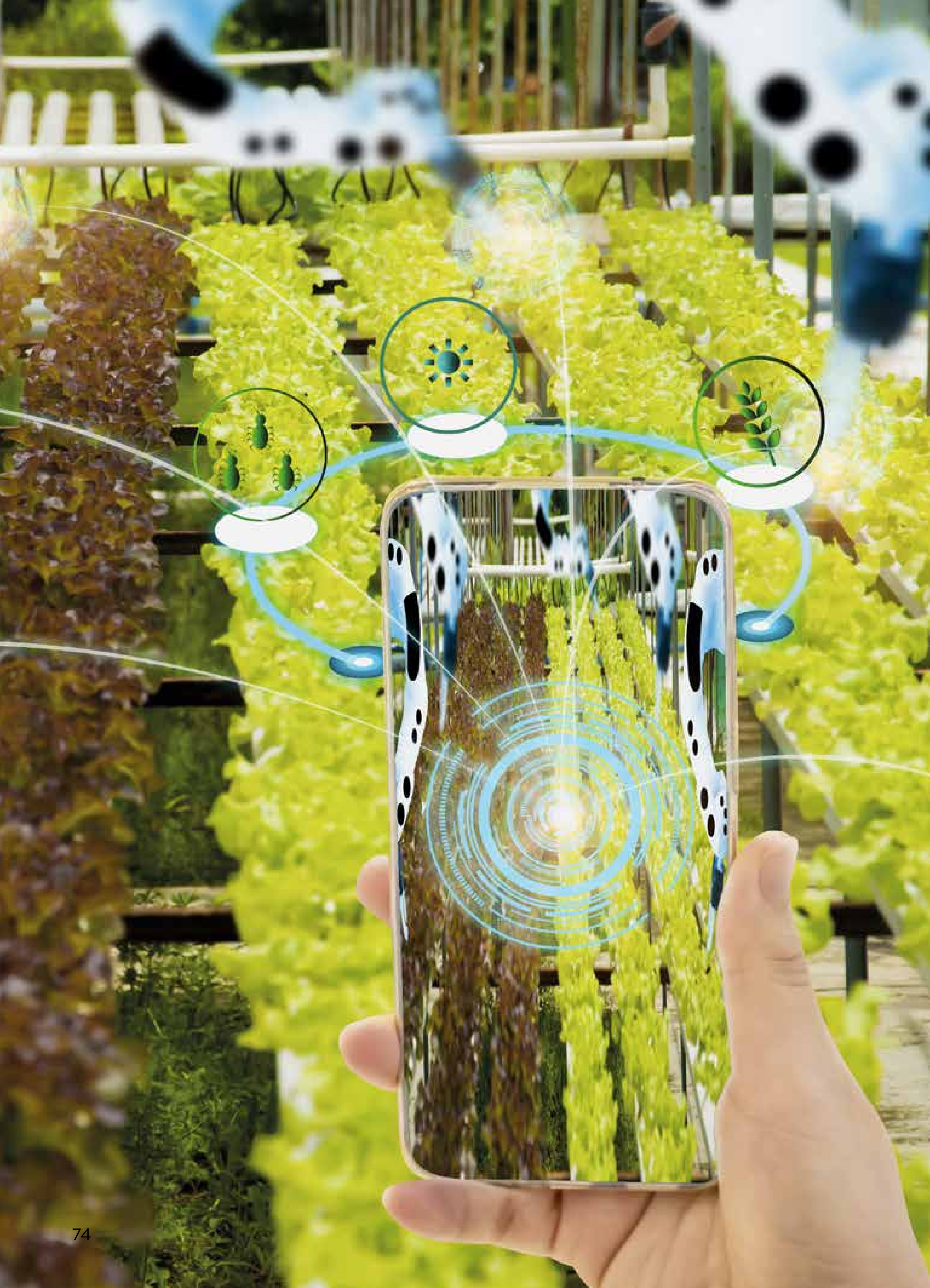
Too Good To Go: an app matching unconsumed supply with unmet demand using alerts to subscribers.

Winnow Solutions: a computer vision tool helping commercial kitchens identify where waste food occurs.

Nutrition

Nutrino: a nutrition insights platform, and creator of Foodprint, analysing a person's physical response to foods.

Think Digital - Farm VR: augmented and virtual reality technology designed to increase agricultural literacy.



NOTES TO CHAPTER 2

[37] Agfunder Research, (2018), Agrifood Tech Funding Report: Year Review 2018, p.4. Available online: https://agfunder.com/research/agri-food-tech-investing-report-2018/

[38] ILO (2019): World Employment and Social Outlook: Trends 2019. [web pdf], p. 14. Available online: https://www.ilo.org/global/research/global-reports/weso/2019/WCMS_670542/lang--en/index.htm

[39] Smart animal farms can use sensors to measure air quality, temperature, humidity, lightning, distress level and weight. This data can then be analysed to find the right environmental conditions to increase animal growth and therefore productivity. For example, smart cow farms can equip cows with localisation and vital sign sensors or monitor their behaviour with cameras to spot diseases and patterns reducing their milk yield, fertility or longevity. In smart aquaculture, sensors can be deployed to measure water quality, and fish behaviour to determine optimal conditions for growth. (Shi et al. 2019: 12; Zhang et al. 2018: 519 – 522; Alreshidi 2019).

[40] Fertilisers are both a blessing and a curse for the SDGs. They are crucial for supplying crops with necessary nutrition to increase output (SGD 2). At the same time, excessive fertilisation threatens public health (SDG 3), clean water (SDG 6), and biodiversity (SDG 15). Precision fertilisation can help farmers use the right amount of fertiliser to reap their benefits and avoid their hazards. One example is the use of aerial or satellite imagery to estimate the Normalised Difference Vegetation Index (NDVI), an indicator for crop health, vegetation vigour, and density. Combined with geo mapping and GPS, this approach can create a differentiated map of fertilisation requirements, informing farmers where fertilisers must be applied and where it is unnecessary. These maps can be fed to automated vehicles, which can automatically apply fertilisers where necessary, avoiding the cost and hazards of bulk fertilisation (Zhang et al. 2018: 516-518).

[41] Aleksandrova, Mary, "3 Edge Computing Use Cases for Smart Farming," Available online: https://easternpeak.com/blog/3-edge-computing-use-cases-for-smart-farming/, (April 5, 2019)

[42] Hibbard, Sarah, "How GAIA Disrupted the Viticulture Industry," https://consilium.technology/how-gaia-disrupted-the-viticulture-industry/, (December 10, 2018)

[43] See Project GAIA (2019), available online https://projectgaia.ai/

[44] Hibbard, Sarah, "GAIA Delivers Australia's National Vineyard Scan," https://consilium.technology/gaia-delivers-australias-national-vineyard-scan/, (June 12, 2019)

[45] Hibbard, Sarah, "How GAIA Disrupted the Viticulture Industry," https://consilium.technology/how-gaia-disrupted-the-viticulture-industry/, (December 10, 2018)

[46] Hibbard, Sarah, "GAIA Delivers Australia's National Vineyard Scan," https://consilium.technology/gaia-delivers-australias-national-vineyard-scan/, (June 12, 2019)

[47] Project GAIA (2019), "Case Studies", available online https://projectgaia.ai/case-studies/

[48] Project GAIA (2019), "Case Studies", available online https://projectgaia.ai/case-studies/

[49] Hibbard, Sarah, "Consilium Technology Wins Trifecta at AIIA's SA/NT iAwards," https://consilium.technology/consilium-technology-wins-trifecta-at-aiias-sa-nt-iawards/, (June 21, 2019)

[50] Examples of sensors are solar radiation, humidity, temperature, CO2, pH meter, electrical conductivity, liquid consumption (flow meters) or pressure sensors, while some of the actuators considered are soil and water nutrition pumps, valves and activation of devices (watering and ventilation devices, lighting, or automated windows).

[51] Narrative taken from AWS website, available online: https://aws.amazon.com/blogs/publicsector/geo-diverse-open-training-data-as-a-global-public-good/

[52] The MLHub is a central repository of open labelled training data, models, and standards for machine learning and EO. The goal is to establish a community focused on advancing the application of EO data to solve the challenges in the Global South using machine learning techniques. Radiant Earth is currently developing two datasets to be hosted on the MLHub Earth. The first is a crop type training dataset for major crops in Africa. The second one is a global land cover training dataset of labels from a geographically representative set of regions. Both datasets are being built using the European Space Agency's (ESA) Sentinel-2 multi-spectral optical imagery at 10 m resolution hosted on AWS through the Public Data Set Program. The MLHub catalogues is hosted on Amazon Simple Storage Service (Amazon S3) storage with an API to enable the public to search for training datasets and access them with a creative commons license. Radiant Earth uses a variety of resources on AWS including clusters of Amazon Elastic Compute Cloud (Amazon EC2) machines to read the Sentinel-2 data from the public buckets, process them, generate the training data catalogues, and store the training data on the MLHub bucket.

[53] GEO consists of 105 Member countries, the European Commission, and 129 participating organizations that work collaboratively to solve global challenges. This includes addressing the SDGs and its eight specific "Societal Benefit Areas" which are: Biodiversity and Ecosystem Sustainability, Disaster Resilience, Energy and Mineral Resources Management, Food Security and Sustainable Agriculture, Public Health Surveillance, Sustainable Urban Development, Infrastructure and Transportation Management, and Water Resources Management. GEO's engagement priorities include: the UN 2030 Agenda for Sustainable Development, the Paris Climate Agreement, and the Sendai Framework for Disaster Risk Reduction.

[54] Wilkinson, Allie (2014): Expanding tropics will play greater global role, report predicts. Available online: https://www.sciencemag.org/news/2014/06/expanding-tropics-will-play-greater-global-role-report-predicts

[55] These numbers are based on a Preliminary SWFF Monitoring & Evaluation Study from 2018. Ignitia did not share the study, so potential biases in the research design could not be verified. Given the importance of weather forecasts for the agricultural timing problems explained above, the benefits of the service are plausible.

[56] Claremar,B. (2019), Evaluation of ISKA forecast performance, Uppsala Universitet, p. vi. Available online: http://uu.diva-portal.org/smash/get/diva2:1297112/FULLTEXT01.pdf.

[57] For example, the CGIAR Platform for Big Data in Agriculture employs biologists, agronomists, nutritionists, and policy analysts to use Big Data tools to create AI systems that can predict the potential outcomes of future scenarios for farmers. The ultimate goal is to seamlessly integrate real-world data from farms around the world into algorithms that generate critical insights that can then be shared back with farmers. The CGIAR Platform is already showing results of potential benefits for smallholder farmers, such as for the Colombian Rice Farmers Federation. After multiple seasons of challenging rain patterns, rice farmers in Colombia were struggling to know when to plant their crop. Depending on whether there was going to be above average or below average rainfall, farmers would need to decide whether to plant earlier or later in the season. If there was going to be too much rain, they might decide not to plant at all that season.

[58] To calculate the crop-sowing period, historic climate data spanning over 30 years – from 1986 to 2015 – for the Devanakonda area in Andhra Pradesh was analysed using AI. To determine the optimal sowing period, the Moisture Adequacy Index (MAI) was calculated. Available online: https://www.business-standard.com/article/companies/microsoft-ai-helping-indian-farmers-increase-crop-yields-117121700222_1.html

[59] When asked about the criticism that WeFarm has an incentive to cater more to the interest of advertisers than to their farmers, WeFarm responds that embedded within their core company values is the commitment to making farmer trust deserved and that they ensure the quality of the products offered in their market place through a careful, continuous vetting process. Many farmers struggle with fake products and limited access to cheap products and services and WeFarm claims that it can solve this problem by only working with trusted partners.

[60] Onphanhdala, Phanhpakit (2009), Farmer Education and Agricultural Efficiency: Evidence from Lao PDR. Available online: http://www.research.kobe-u.ac.jp/gsics-publication/gwps/2009-20.pdf

[61] Lockheet, Marlaine; Jamison, Dean; Lau, Lawrence (1979), Farmer Education and Farm Efficiency: a Survey. Available online: http://www.research.kobe-u.ac.jp/gsics-publication/gwps/2009-20.pdf

[62] Augère-Granier, Marie-Laure (2017), Agricultural education and lifelong training in the EU. European Parliamentary Research Service, Briefing. Available online: http://www.europarl.europa.eu/thinktank/mt/document.html?reference=EPRS_BRI(2017)608788

[63] See: HARA Token White Paper, https://haratoken.io/doc/HARA_Token_White_Paper_v20190325.pdf

[64] UN News (2019), "Over 820 million people suffering from hunger; new UN report reveals stubborn realities of 'immense' global challenge" July 15, 2019. Available online https://news.un.org/en/story/2019/07/1042411.

[65] Id. With blockchain, vendors can remotely record a wide variety of predetermined measurements, including storage temperature, at each juncture in the supply chain. If temperature at point B varies dramatically from the temperature at point A and C, product managers can extrapolate this data to pinpoint problem areas and allocate resources accordingly.

[66] Ahold Delhaize company factsheet. Accessed 25/09/19, https://www.aholddelhaize.com/media/9681/22345_ad_factsheet_q2_2019_digitaal.pdf.

[67] Aitken, Roger (2017): "IBM Forges Blockchain Collaboration with Nestlé & Walmart In Global Food Safety," August 22, 2017. Available online: https://www.forbes.com/sites/rogeraitken/2017/08/22/ibm-forges-blockchain-collaboration-with-nestle-walmart-for-global-food-safety/#3e9c1b843d36.

[68] Abudheen, Sainul (2018), "This IoT, blockchain startup rewards you every time you drop the food leftover into the waste bin," October 18, 2017. Available online https://e27.co/ai-waste-management-startup-blue-ocean-20181011/.

[69] Winnow company research, "Addressing Food Waste in the Hospitality and Foodservice Sector," p.2, accessed 29/09/2019, https://info.winnowsolutions.com/insight-report-food-waste-hospitality-foodservice.

[70] Id.

[71] Id.

[72] Winnow company website, https://www.winnowsolutions.com/vision, accessed 01/10/2019.

[73] Id.

[74] David Jackson (CMO at Winnow Solutions), company interview, October 2019.

[75] Narrative and data taken from Winnow company report, "How Will AI Tranform the Hospitality Industry?," accessed, 01/10/2019, https://info.winnowsolutions.com/how-will-ai-transform-the-hospitality-industry

[76] Too Good To Go company website, https://toogoodtogo.com/en, accessed 07/10/2019.

[77] This follows an extended pilot in Vietnam, where more than 6000 companies are using it, including leading international food conglomerates like AEON, CP Group, Lotte Mart, Big C, Japfa, and CJ. https://www.foodingredientsfirst.com/news/globalized-blockchain-auchan-implements-food-traceability-technology-on-international-scale.html

[78] Kamath, Reshma (2018), Food Traceability on Blockchain: Walmart's

Pork and Mango Pilots with IBM. The Journal of the British Blockchain Association. 1. 1-12. 10.31585/jbba-1-1-(10)2018.

[79] Lamb, Catherine (2018), "After More Romaine Recalls, Is Blockchain the Missing Link in Preventing Outbreaks?," November 21, 2018. Available online: https://thespoon.tech/after-more-romaine-recalls-is-blockchain-the-missing-link-in-preventing-outbreaks/

[80] Think Digital (2019), "Software", available online: https://think.digital/software-development/

[81] FarmVR (2019), "Apps". Available online https://farmvr.com/farmvr-apps/

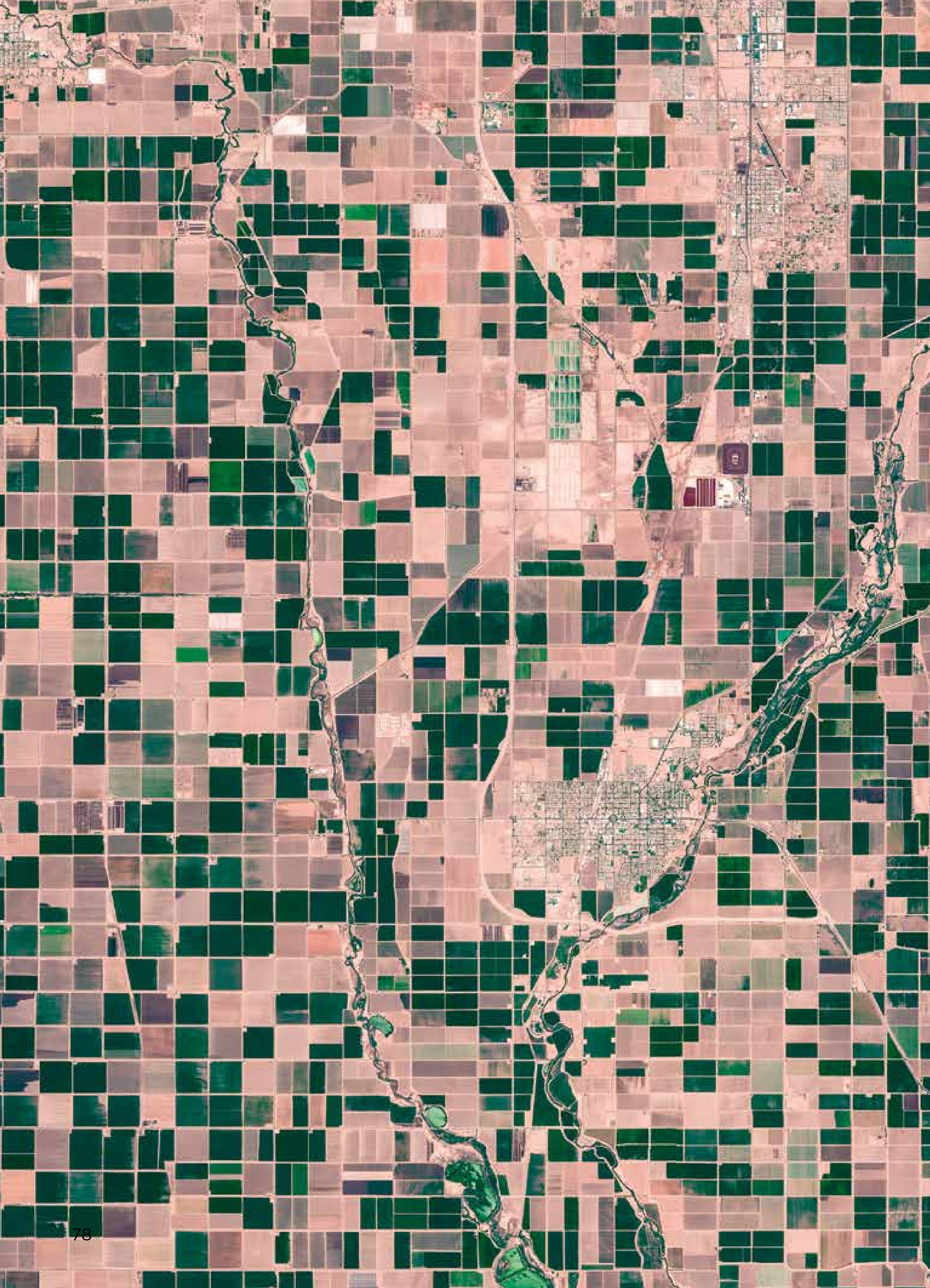
[82] FarmVR (2019), "Immersive Education Strategy". Available online https://farmvr.com/immersive-education-strategy/

[83] Du, Lisa (2018), "Nestle pivots to health research with artificial intelligence and DNA testing for personalized diets," September 2, 2018. Available online: https://www.independent.co.uk/news/science/nestle-dna-artificial-intelligence-health-personalised-diet-japan-nutrition-a8519626.html

[84] Verma, M., et al (2018), Challenges in Personlized Nutrition and Health. Available online: https://www.frontiersin.org/articles/10.3389/fnut.2018.00117/full#B7

[85] Nutrino (2017), Nutrino Demonstrates Significant Reduction of Hypoglycemia in Patients with Type 1 Diabetes Who Use Nutrition Support "FoodPrint" App. Available online: https://nutrino.co/foodprint-users-see-18-reduction-hypoglycemia-frequency/

[86] As is typical of systems relying on user-generated data, food journaling suffers from the cold-start problem, where recommendations cannot be made or are subject to low accuracy when the user has not yet generated a sufficient amount of data. For example, a previous study showed that an active food-journaling user makes about 3.5 entries per day. It would take a non-trivial amount of time for the system to acquire sufficient data to make recommendations, and the collected samples may be subject to sampling biases as well. Moreover, the photo food journaling of all meals is a habit difficult to adopt and maintain and therefore is not a generally applicable solution to generate complete food inventories.



CHAPTER 3
Beyond opportunities: a look at the challenges and risks posed by digital technologies for sustainability

CHAPTER 3
Beyond opportunities: a look at the challenges and risks posed by digital technologies for sustainability

While digitising the agrifood chain may lead to undoubted benefits, and possibly create the preconditions for addressing existential risks such as climate change, in reality not all that glitters is gold: digital technologies come with a plethora of potential 'dark sides', risks that should be adequately addressed to avoid the cure ending up as worse than the disease itself. They include the creation or persistence of digital divides and inequality of opportunities, both from a geographic perspective and across societal groups; the environmental footprint of some of the digital technologies; the problem of e-waste; the possible negative impacts on the job market; and the peril of a rise in market concentration. Below, we discuss these challenges and risks, and propose corresponding mitigating measures, which will then become part of our policy recommendations in Chapter 4.

Bridging digital divides and opportunity gaps

As politicians and governments alike are heralding ICT as the key to unlock social and economic progress, it is important to also recognise potentially divisive aspects associated with these new technologies and the 'information age', particularly issues of inequality. A digital divide exists that reflects various digital differences among and within countries. This divide is defined by three primary factors: the availability of telecommunications infrastructure (connectivity); education and skills; and financial resources – all of these gaps need to be bridged in order to close the digital divide (see for example OECD, Understanding the Digital Divide).

The connectivity gap

According to the ITU, 3.9 billion people (approximately half of the world's population) were using the internet at the end of 2018. But while four out of five people in developed countries are online, less than half are using the internet in developing countries, and the percentage goes down to 20% in the world's 47 least developed countries. According to the GSMA, almost half of the world's population will still be offline by 2020 and 40% will still be offline by 2025 (ITU 2018; Smith 2018).[87] Even in the EU, rural broadband deployment varies significantly: by the end of 2017, only 47% of rural areas were covered by fast broadband connectivity, resulting in some rural communities not being able to reap the benefits of the social and economic integration that digitalisation brings (Draft Declaration on "A smart and sustainable digital future for European agriculture and rural areas", 2019).

The skills gap

Lack of digital skills is another important obstacle, particularly in developing countries. A third of individuals lack basic skills such as being able to copy files or folders using copy and paste tools; only 41% have standards skills, such as installing or configuring software, or using basic spreadsheet formulas; and most drastically, only 4% master specialist computer languages to write computer programs (ITU 2018). Even in the EU, the lack of digital skills is striking.

In Europe, 31% of farmers are older than 65 years of age, while only 6% are younger than 35. In addition, most farmers in the EU have not been formally trained in agriculture: 70% only have practical experience, 20% have received basic training and 8% have attended a full agricultural training course (EPRS 2016).

In light of these data, it is clear that there are still significant gaps in digital proficiency, and therefore access to opportunity, within the EU as well as internationally. Socio-economic status and other factors still impact the use of ICT in many areas of the world, demonstrating that digital inequality persists and needs to be accounted for in ICT policy and innovation initiatives.

Costs and the funding gap

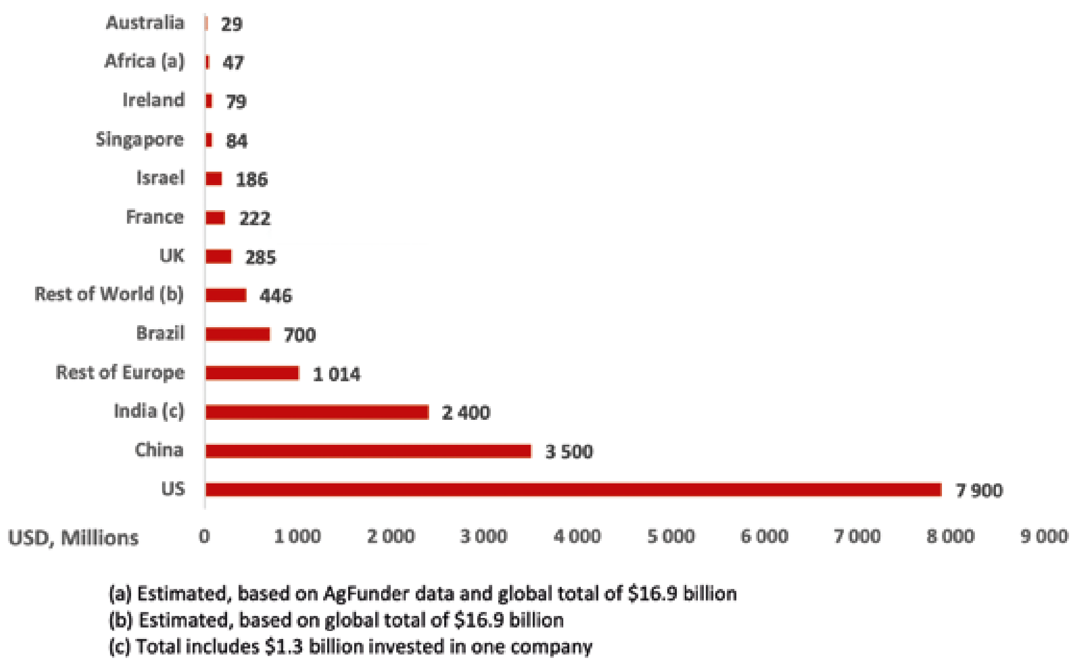
From the perspective of individual farmers, digital technologies in agriculture entail considerable costs in order to set up the complex pipeline from data collection, to (cloud) infrastructure, to analysis and action/task execution. In order to collect digital data, for example, farmers have to invest in IoT hardware. These complex steps can be partially outsourced to service providers, but the maintenance services imply recurring costs for farmers.

Moreover, from a macro perspective, investment data show the enormous disparities between venture capital availability in different parts of the world. Funding is a critical input to innovation and the funding stage is also important: early funding is key to getting start-ups out of incubation and later stage funding essential to scale a company into a market leader.

The US and China are attracting the lion's share of the $16.9 billion in venture capital going into AgTech (AgFunder 2018). Europe, despite having a far larger population than the US, attracts only 10% of global AgTech investment, while the US attracts 47%. Africa has a population nearly as large as that of China and 60% (Lutz et al. 2019) of Africans are employed in farming, yet investment in the continent's AgTech sector is negligible. India, on the other hand, has a similar-sized population and level of employment in agriculture to Africa, but investment in AgTech is competitive with that of Europe. These differences are likely explained by state-level policy coherence on innovation, level of market fragmentation, level of development of physical and judicial infrastructure, and human capital development.

Europe has long lagged behind the US in venture capital flows generally, and this has led many European start-ups to leave the continent for the US and increasingly, Asia, where they can access the capital they need to scale. The problem exists along the entire spectrum of funding from early stage seed rounds to late stage rounds to accelerate growth. The lack of late stage funding also has led to European founders exiting their start-ups earlier than their American competitors, through acquisition by larger, more mature and better funded rivals in the US and even Asia.

Figure 17 – Global AgTech Investment 2018



Source: Data from AgFunder 2018 Agrifood Tech Investing Report; CTA/Dalberg D4Ag Investment Tracker, Disrupt Africa, CEPS analysis.

There are a few critical differences between the VC markets of the US and Europe, which also carry over to AgTech investment. The VC sector in Europe does not attract the same level of institutional money from pension funds, endowments, and corporations as in the US. The majority of European venture capital comes from government and public entities in the form of grants, soft debt, and early stage equity. By contrast, US limited partners (LPs)[88] have a higher tolerance for risk and are willing to be patient for 10 or so years to realise a return. Europe has also traditionally been a fragmented market compared to the US. The euro as a currency has only been around since 1999 and the European Single Market came into force a short time before in 1993. There are relatively fewer barriers to doing business, investing in and scaling companies in the US compared to the EU, even with the single market. European policymakers have recently begun to address these impediments by supporting new pan-European fund-of-funds investment vehicles to increase the size of venture capital funds as well as attracting more institutional, private capital. Additionally, the European Commission has amended European venture capital regulation as part of its Capital Markets Union plan to make it easier for VCs to make cross-border investments within the EU and increase the breadth of companies they can invest in.[89]

The energy consumption of ICT

One of the risks posed by digital solutions for sustainability is the massive energy consumption associated with the deployment of certain technologies at scale. For example, it is estimated that data centres use 200 terawatt-hours each year for the manufacturing and operation of ICT infrastructure, or 1% of global electricity demand.[90] As ICT is being incorporated into an ever-increasing number of products and services, residential and business energy use is growing rapidly. While emphasis falls on the efficiency capabilities of ICT, production of **ICT infrastructure is actually energy intensive, uses large amounts of water for rinsing and cooling purposes, and contributes significantly to greenhouse gas emissions.** It is important to also account for ICT's associated rebound effects: ICT can enable energy and environmental efficiency in a number of sectors through better management of time, money, resources, labour, and infrastructure, leading to new capacities that will inevitably be used. However, if the time, money, resources, etc. that were saved by means of ICT efficiency are used in environmentally damaging ways, no energy was saved in the end. In fact, energy efficiency can easily lead to trends of increased consumption. In order to **avoid rebound effects that would 'balance out' the positive impact of ICT on energy savings**, rebound effects related to ICT must be identified, evaluated, and mitigated (Gossart 2014).

Blockchain and machine learning currently cause similar concerns. For mining Bitcoin alone, the annual electricity consumption was estimated at 70.1 TWh for 2018 (higher than the yearly electricity consumption of Austria) and each Bitcoin transaction is estimated to consume over one thousand KWh, similar to the yearly electricity consumption per capita in countries like Jamaica or El Salvador.[91] Similarly, a recent paper found that **AI models that use neural architecture search emit the carbon dioxide equivalent of nearly five times the lifetime emissions of an average American car** (Strubell, Ganesh and McCallum 2019). If externalities were fully internalised by AI developers, the need to account for the negative impacts on the environment would most likely tilt the balance in favour of other AI techniques. This, too, needs to be taken into account when deploying AI solutions in the agrifood chain. Absent major progress in the reduction of energy consumption, different techniques and more decentralised solutions may become more attractive, and more sustainable. For example, IoT technology may rely on connecting different servers and data centres together, and thereby optimising energy consumption. Ashwar et al. (2019) find that a **distributed architecture, by not using intra-data centre networks and large-size cooling systems, consumes between 14% and 25% less energy than fully centralised and partly distributed architectures respectively.**

Tackling e-waste

With the use of ICT on the rise, the amount of electronic and electrical waste, this so call e-waste is one of the fastest-growing sources of waste according to the ITU. According to the United Nations University's second Global E-waste Monitor, 44.7 million metric tonnes (Mt) of e-waste was generated worldwide in 2016. At its current rate of growth, it is estimated that the e-waste stream will reach 50 million Mt in 2018.[92] In addition, ICT not only produces waste when being thrown away, but also during production. The manufacture of different ICT components, such as micro-chips, or batteries cause significant amounts of air emissions (acid fumes and volatile organic compounds) and water emissions (solvents and silicon) (EPA 2015).

The consequences for human health are alarming: exposure to e-waste has led to increases in spontaneous stillbirths and premature births, reduced birth weights and birth lengths, DNA damage, adverse changes in cellular expression and function, and differences in temperament and behaviour (Grant et al. 2013). Informal e-waste management can lead to contact with hazardous substances and materials such as lead, cadmium, chromium, flame retardants; inhalation of toxic fumes; and accumulation of dangerous e-waste elements in soil, food, and sources of water.[93] These findings are particularly worrying for developing countries where e-waste is treated by the informal sector without adequate waste management systems. These issues can be tackled by investing in environmentally sound waste treatment infrastructure, which can simultaneously assist in the creation of jobs and 'greening' the economy (UNEP 2011).

Automation and jobs: should we fear job displacement in agrifood?

Another form of negative externality that may emerge from the implementation at scale of digital technologies in the agrifood chain is the loss of employment, in particular low-skilled labour. The picture, however, is not black and white.

In the coming years, many of the aforementioned technologies are expected to become more autonomous. Smart agriculture may evolve through a combination of remote sensing and observations (e.g. through drones and computer vision, as well as satellite images); and proximity sensing. For example, remote sensing in soil testing requires sensors to be built into airborne or satellite systems, whereas proximity sensing requires sensors that can help to automatically analyse the soil. The history of mechanisation in agriculture also includes some positive examples of jobs created in the manufacturing and services (Acemoglu, Restrepo 2019).[94]

The pace and extent of automation and the lack of adequate skills are, however, likely to create tensions in the job market in the coming years and reinforce the shift from labour to capital. For example, Rotz et al. (2019) highlight three key tensions: rising land costs and automation; the development of a high-skill/low-skilled bifurcated labour market;[95] and issues around the control of digital data. They emphasise that "the current enthusiasm for digital agriculture should not blind us to the specific ways that new technologies intensify exploitation and deepen both labour and spatial marginalisation"; and argue that "policy and research must further examine how to shift the trajectory of digitalisation in ways that support food production as well as marginalised agricultural labourers".[96]

Market concentration and 'data hoarding'

Another challenge that policymakers may have to address in order to ensure that digital technologies produce sustainable benefits is market concentration. The capital-intensive nature of some of the technological solutions available in agriculture and distribution, and the AI- and data-intensive nature of digital technology in consumption and nutritional advice, may lead to a rise in economies of scale, especially in data aggregation. Rotz et al. (2019) observe that data-producing technologies such as smart tractors require a system of data management to transform the data into useful outputs for farmers. The rise of farm data management platforms such as Climate Field View imply that, "while farmers still own the fields, they are effectively renting their data". They observe that "farmers and farm workers continue to carry the material risks and bear the livelihood impacts of agriculture while the capital gains of digitalisation are, largely, extracted by data management companies". Meanwhile, larger farmers in particular have noted the value of remote sensors and irrigation for maximising efficiencies as well as the leverage that real-time market and weather data provide for grain crop negotiations, leaving 'supersized farms' more empowered than ever before (Bunge 2017, 2018). Within this context, future research might consider the possible implications of these shifts in power for more marginalised actors in the system.

Perils of data-driven farming

While the potential benefits of precision agriculture seem clear, even if they are not able to be quantified as yet since the technologies are still in their infancy, there remain perils which, if not sufficiently mitigated, threaten to undermine the promise of data-driven, high-tech agrifood chains. **The most significant unintended consequence of ushering in the data age in farming is inadvertently creating a gold rush mentality that drives the biggest and strongest players to corner the market in data and then use their market power to extract extraordinary rents from the rest of the value chain.** Smallholder farmers stand to lose the most because firstly, they are generating the most data in agrifood chains; secondly, they likely have the least understanding of its true value or their rights in ownership of the data; and they are a fragmented group with limited economic and political clout.

One the of most significant trends, and indeed potentially, perils, in data-driven farming is the land grab to control the data produced by billions of connected and smart devices in the new ecosystem known as the 'Internet of Farming'. Large, tech-savvy players in the value chain have already understood that ownership and control of agronomic and equipment data has great value. The ability to know with high certainty which inputs perform the best under specific conditions and what yields were achieved and in what quantity has never been possible until recently, and this intelligence has tangible value.

Further, because standards and regulations around ownership and control of the data are opaque, the odds that farmers will be fairly compensated are low. This ambiguity is subject to benign neglect by those who are profiting the most, which are the large multinationals, data brokers, investment firms, and consultancies because no one wants to be forced to pay for something that has always been free. This information asymmetry will no doubt contribute to disruption in the markets for agricultural goods, promote supply and demand imbalances, and contribute to continued farming practices that do not support sustainability.

Data ownership and governance

One key issue in this respect is data ownership (JRC 2018). This creates problems of data protection, security, access, and imbalances in the bargaining positions of small farmers vis à vis service providers, as well as larger players along the value chain such as large agrifood corporations and distribution giants. At the EU level, a Code of Conduct on Agricultural Data Sharing by Contractual Arrangement was launched by a coalition of associations from the EU agrifood chain in April 2018 to facilitate data management in the agrifood chain, and attribute ownership to farmers. The Code provides that the right to determine who can access and use the data is attributed to the data originator, i.e. the individual or entity who created/collected the data either by technical means or by himself or who has commissioned data providers for this purpose. This initiative echoes similar self-regulatory schemes such as the American Farm Bureau's Privacy and Security Principles for Farm Data and New Zealand's Farm Data Code of Practice.[97] Sanderson et al. (2018) analyse these schemes and conclude that strong governance will be needed, including independence in evaluating and monitoring their effectiveness and impacts on players along the value chain. In particular, some of the problems identified are the extreme complexity of agrifood data contracts, lack of awareness amongst producers of what can be done with their data, as well as the terms of the data licences into which they are entering.

Self-regulatory schemes, however, are unlikely to be sufficient in protecting the data rights and ownership of farmers generally, and smallholder farmers specifically. Where the law is unclear or non-existent, larger more tech-sophisticated players are already moving in and claiming rights to data in jurisdictional no-man's lands. Worse still, in some cases they are wilfully blurring the legal lines between ownership and control in the name of rent seeking by using farmers' data without permission, betting on the fact that in the absence of clear laws, they will not be held accountable (Tatge 2016).[98] Governments, as the final arbiters on national competition policy, law, taxation, economic policy, and intellectual property and patent law, should not step back from making the hard choices on when and how to create policy and legislation around how data should be created, controlled, accessed, owned, and used.

In order for small farmers to benefit from value being generated from what amounts to a new asset class that is data, they need to become better informed about how data are generated, collected, used, most importantly, valued. This type of capacity building needs to include the basics of markets and assets classes, asset valuation, credit markets, credit scoring, and financial risk management. However, in order for this data to have real value that can be traded or used by a bank for collateral in exchange for access to financial products such as loans or working capital, governments and financial oversight bodies must first take a stand and issue guidelines, and ultimately legislation, on how data are treated in company accounts. In the US, data are currently being treated under the Generally Accepted Accounting Principles (GAAP) set forth by the Financial Accounting Standards Board (FASB) as an intangible asset on the balance sheets of companies. Intangible assets are not easily turned into cash and are not physical things. Examples include patents, trademarks, franchises, and copyrights. Intangible assets bring real economic value and the potential to drive revenue to the enterprise but yet cannot be offered as collateral, nor can the costs be capitalised on the balance sheet, which has the effect of making certain financial ratios appear more favourable as the cost of the asset is written off over time.

Data are essentially 'trapped' on the balance sheet of companies as an intangible asset that cannot be sold or borrowed against to generate value in the firm. And yet, the costs to maintaining and securing the data are very real, as are the losses incurred by those whose data are used without their knowledge or permission, as an input to revenue streams that accrue to an entity that had no lawful right to use that data. In the case of smallholder farmers, many have little understanding of how others are making use of, and profiting from, their data, therefore they do not realise the extent to which they are undermining their own rights and opportunities when they sign opaque agreements with companies that give them extraordinary latitude in how they use data generated by farmers.

The rise of AI: towards an ethical framework

The pervasive implementation of Artificial Intelligence throughout the agrifood chain is certainly going to create outstanding opportunities for the sector, but also features a number of potential downsides. In addition to the energy consumption of specific AI techniques and the lack of skills and connectivity in many countries, when applied in the B2C context AI poses challenges also in terms of possible bias, discrimination, lack of transparency and violation of end users' privacy and right to self-determination.

In particular, **the issue of bias and discrimination is inherent in the use of data-hungry AI techniques such as machine learning.** From the data collection phase, two main problems can emerge. First, the data itself may not be of good quality, or the sample from which data are collected not sufficiently representative of society. Typical examples are cases in which a specific ethnic group is underrepresented in the underlying training dataset, as is the case for facial recognition systems, which tend to display a much higher error rate when trying to recognise people with darker skin (Simonite 20019). In nutritional advice, the greater availability of data for specific countries and ethnic groups may lead AI systems to recommend diets that are not well-tailored to the local traditions or specific needs of the end user involved. At the same time, widespread use of personal data for the personalisation of nutritional advice also brings specific risks, such as the re-use of data for advertising, profiling or surveillance purposes: this risk reaches a peak whenever nutritional advice services require health data, such as allergies, current treatments, or previous surgical operations.

Even when bias does not creep into the early stages of AI development, it could still be incorporated in the **design of the algorithm to 'nudge' individuals towards specific decisions.** From the observation of the limited ability of humans to process complex information, as well as their dependence on 'proxies' when formulating decisions, the practice of nudging relies on empirical evidence of the stickiness of the default option, anchoring and framing effects (or 'endowment effects'), which create the possibility of influencing human decisions by 'choice architecture', i.e. presenting choices to individuals in a way that would make one option more attractive than the alternatives (Sunstein and Thaler 2009). Nudging has emerged as a frequent practice, with still-controversial results in terms of effectiveness, but also of legitimacy and adherence to ethical principles. In the age of AI and big data, **the plasticity of digital technology makes nudging exponentially easier and more far-reaching: thereby the term 'hyper-nudging' or the 'big nudge' is used by scholars.** Some scholars have observed that big data and AI may significantly expand the possibility of nudging, making it more effective: for example, being able to predict or directly observe the mood of individual consumers on different days of the week, as well as times of the day, can help in tailoring commercial messages in a way that maximises the desired outcome. The realisation of the potential risks of unethical use of AI has prompted several governments and corporations to adopt ethical principles. Most of these principles, however, are not accompanied by effective enforcement possibilities. The European Commission, with the help of a High-Level Expert Group on AI, is currently trying to bridge this gap. More generally, the relevance of steering AI towards sustainable development is still not fully recognised in the public debate. As an example, very few of the ethical frameworks for AI mention sustainable development. Jobin et al. (2019) analyse 84 existing ethical guidelines for AI, and find a reference to sustainability in only 14 of them.

CHAPTER 3
Main findings

This chapter has shown that digital technologies, while being potentially beneficial:

Can aggravate inequalities when it comes to connectivity, skills and capital;

Can have negative consequences for the environment and human health due to energy consumption and e-waste;

Can lead to job loss and further tilt the power balance from labour to capital;

Can reinforce capitalism's tendency towards market concentration;

Open new ethical questions when it comes to privacy, bias and hyper-nudging consumers.

Knowing about these challenges enables all stakeholders to take informed decisions, where this tool is the most useful and where it is not.

Only smart regulation can ensure that negative externalities are internalised and sustainable, and that economic and social value is produced.

NOTES TO CHAPTER 3

[87] On a positive note, developing countries have registered much faster growth in mobile broadband subscriptions. Penetration rates have risen from nearly zero in 2007 to 28.4 subscriptions per 100 inhabitants in 2018 in least developed countries, and have reached 61 subscriptions per 100 inhabitants in developing countries). The proportion of households in Africa with access to a computer has increased from 3.6% in 2005 to 9.2% in 2018 (ITU 2018; see also Smith 2018).

[89] A limited partner is an investor, usually an entity, that participates in an investment fund.

[90] World Economic Forum, "Europe's venture capitalists are closing the gap with Silicon Valley," accessed 08/10/2019 https://www.weforum.org/agenda/2017/11/europe-venture-capitalists-silicon-valley/

[91] See Elisa Tonda (2019), Presentation at the CEPS event on the Sustainability of Platforms, 11 June 2019, at https://www.ceps.eu/wp-content/uploads/2019/03/06112019-Elisa-Tonda_presentation.pdf

[91] These estimates are of course no more than informed 'guesstimates', since there is no central register with all active machines used by miners, their exact power consumption, etc.

[92] Elisa Tonda (2019), Presentation at the CEPS event on the Sustainability of Platforms, 11 June 2019, at https://www.ceps.eu/wp-content/uploads/2019/03/06112019-Elisa-Tonda_presentation.pdf

[93] See https://www.who.int/ceh/risks/ewaste/en/

[94] Acemoglu and Restrepo (2019) report that agricultural mechanization started in the second half of the 19th century reduced the labour share and employment in agriculture, but overall labour demand rose because a range of new tasks were introduced in both manufacturing and services. In particular, a range of more specialized blue-collar and white-collar jobs increased productivity, the demand for labour and the labour share in manufacturing and services.

[95] Rotz et al. (2019) report that automation is projected to rise to 28% overall by 2030, while the 'projected potential' for automation could reach 52% (Scott 2017). Farm manual labour and pesticide applicators are projected to be most highly automated by 2030 (97%). Farmers, ranchers, and agricultural managers, on the other hand, are least likely to be automated (4.7%).

[96] Rotz et al. (2019) report an interview with a retailer of robotic milking machines, who explained: "So let's say you have a hired man to milk 100 cows, well maybe you can milk your 100 cows now by yourself if you put in robots. So there is definitely some labour savings."

[97] Farm Data Accreditation Ltd, New Zealand Farm Data Code of Practice, ver 1.1, Cl 4. (American Farm Bureau Federation, n.a).

[98] A notable case involved Monsanto and John Deere in 2016. Monsanto bought a company called Precision Planting in 2012 and later sought to create a strategic relationship with John Deere that would allow them significant control over the collection and use of farmer data. Monsanto entered into an agreement to sell Precision Planting to John Deere, but the deal was blocked by the antitrust division at the US Department of Justice on the grounds that one company would have undue influence in the market for farm data, which could make it too expensive for farmers to access and use the data they generated in the first place (Plume 2017).

CHAPTER 4
Governing digitised agrifood for sustainability: towards a comprehensive policy mix

Chapter 4 Governing digitised agrifood for sustainability: towards a comprehensive policy mix

As shown in chapters 1 and 2, the promise of digitising agrifood is enormous. Digital technologies today appear necessary to make agrifood sustainable, and sustainable agrifood appears necessary to achieve sustainable development. At the same time, digitising agrifood requires first of all a rethink of the overall objectives of public policy; as well as a complex, systemic policy mix, rather than a single, 'one size fits all' solution. And while the elements in the policy mix may remain the same, the relative importance of individual elements may vary across countries, depending on geography, society and the economy.

From economic efficiency to sustainability: a paradigm shift in public policy

Much of modern economic policy has been inspired by the desire to achieve economic efficiency. In most cases, the key reference is to 'static efficiency', while in a growing number of cases the emphasis on innovation leads to a focus on 'dynamic efficiency'. While the former concept typically requires less concentrated market structures and price levels as close as possible to the underlying costs, the latter (especially in the Schumpeterian version) considers that more concentrated market structures could become acceptable, if they lead to more innovation and consumer welfare in the long run.

Regardless of the type of efficiency sought by the policymaker, mainstream economics has traditionally expressed faith in the market mechanism as a driver of efficient allocation of resources. This has led i.a. to limited intervention of judges in contracts, deep faith in cost-benefit analysis (known as 'Kaldor-Hicks' or 'Potential Pareto' efficiency) as a basis for policymaking, and a deep entrenchment of the 'invisible hand' approach in public policy. This approach is largely based on a 'bottom-up' conception of policymaking, in which absent market failures, the spontaneous forces of the market are expected to deliver desirable solutions; and policy benefits are only measured as the sum of the willingness to pay by individuals composing today's society, when prompted about a future state of the world (Renda 2011; 2019). The same approach is also related to the measurement of GDP as societal progress, and to shareholder capitalism as the most efficient form of corporate governance (Adler 2019; Kalff and Renda 2019).

Today, this approach appears unlikely to deliver the solutions that our planet and our society need. In a famous book about "prosperity without growth", Tim Jackson (2017) observed that "there is no simple formula that leads from the efficiency of the market to the meeting of ecological targets. Simplistic assumptions that capitalism's propensity for efficiency will allow us to stabilise the climate or protect against resource scarcity are nothing short of delusional". Likewise, the United Nations Environmental Programme (UNEP) reported that "while long-run relative decoupling of material extraction from GDP can be observed at a global level, this relative decoupling is not sufficient to prevent a persistent increasing trend in absolute resource extraction. Indeed, in contrast to the long-run relative decoupling trend over the 20th century, recent years' data suggest that resource extraction has begun to increase at a faster rate than GDP, suggestive of 'recoupling'." Nobel Laureate Joseph Stiglitz echoed these views in his recent "Rewriting the rules" books about the US and Europe, highlighting that inequality of income and, even more importantly, of opportunity requires urgent action, in the form of a new social contract.

Based on the current debate, there are several ways in which policymakers can incorporate economic, social and environmental sustainability in their policy mix. **The first is by taking action to require the internalisation of all negative externalities generated by the current agrifood chain as well as by the digital technology stack.** This means attributing responsibility for the over-use of pesticides, as well as incorporating embedded emissions in the price of food, as well as that of digital equipment. The likely consequences of this approach may include a massive increase in the price of meat, as well as higher prices for AI products featuring data- and energy-hungry techniques such as deep learning. This way, the market would fully account for the environmental costs generated by different value chains and products, and may re-orient the market towards sustainability. The same can be done for social sustainability, especially through the remuneration of end users and workers for the data and knowledge they contribute to the profitability of digital business models.

A second way is to **depart from the simple measurement of economic efficiency, set the SDGs as the final outcome to be achieved by public policy, and adjust all policies accordingly.** This implies, i.a. that better regulation tools are re-oriented from cost-benefit analysis towards multi-criteria analysis, in which criteria are aligned with the SDGs. On the private sector side, this approach may also require that the obligation to undertake non-financial reporting is extended to a broad set of companies. Increasing the transparency of the market on non-financial aspects (related to economic, social and environmental sustainability) may in turn facilitate the uptake of sustainable finance, as well as enhance consumer trust in the sustainability of the products and services they consume.

A third, and related, way to incorporate sustainability is to **work on the distributional impacts of the emerging technological re-intermediation.** As already mentioned, current technological developments, left unregulated, have proven to generate growing market concentration, and this can exacerbate a pre-existing situation of existing concentration in agrifood, particularly in the raw materials and seeds market, but also in distribution and logistics. This policy would entail, e.g. interventions such as remunerating farmers for their data, or attributing them the right to manage data produced by their fields; and preferentially adopting more distributed or decentralised governance arrangements in agrifood, through the mandatory interoperability and portability of data, under the control of farmers and end users.

Finally, the transition towards sustainability may require **a stronger reliance on mission-oriented innovation and industrial policy,** in which both public and private actors can join forces to achieve set goals, coordinating their efforts and avoiding 'crowding out' effects between public and private funds. If well managed and sufficiently agile, such coalitions and partnerships can become much more effective in triggering industrial transformation than market-only models such as venture capital. However, governance is of the essence, in particular when it comes to involving all stakeholders from the early stage in co-designing the future of the agrifood sector. Moreover, it would also be **essential that 'moonshots' are designed for the full value chain,** not only for either agriculture or food: as we have amply discussed throughout this report, the interrelations between the various parts of the value chain are so strong that only an integrated solution can deliver the substantial changes that are needed to restore sustainability.

Policymakers will certainly choose a different mix in different countries, but the elements outlined above seem to emerge as key for a meaningful reform that creates the preconditions for a sustainable transformation of agrifood with the help of digital technologies. In particular, the focus on outcomes is perhaps the most important: competitiveness in new technologies should be approached by governments as a means towards sustainability, not as a goal per se, as is too often the case due to global competition for the dominion of key domains such as AI or 5G connectivity (Renda 2019). The existence of a global platform for dialogue and policy coordination on the agrifood chain would further prevent that national efforts on digital technologies descend into a 'race to the bottom', or anyway become prey to the temptations of complete technological sovereignty and absence of global coordination.

The policy mix: a decalogue

Apart from the more general shift towards sustainability in the overall approach to policymaking and the policy cycle, more concrete measures must be adopted to make sure that the digitisation of agrifood happens both swiftly and sustainably. Below we list a number of the main interventions that would be needed along the value chain in order to fully realise the benefits of digitised agrifood, while at the same time minimising the risks and associated costs, and thus aiming at the economic, social and environmental sustainability of the value chain.

Connectivity: towards cost-effective solutions?

Connectivity is an essential precondition for any digitisation project, in all industries. However, the connectivity requirements for precision agriculture are most likely to differ from the ones emerging, for example, in automated vehicles or Industry 4.0. In agriculture, connectivity will need to ensure a wide coverage and low costs of deployment or maintenance, since most of the applications feature relatively low needs in terms of bandwidth and latency. **This makes technologies such as the legacy 2G network and LPWA technologies (LoRa, Sigfox) particularly suited for most current deployments. However, the long-term sustainability of these networks is not guaranteed** and given the lifespan of agricultural equipment, this uncertainty can lead manufacturers to delay technological choices. More sophisticated use cases (such as the use of video, full automation or augmented reality) will require either being able to function with intermittent connectivity, or waiting for the deployment of new generations of networks such as 5G. Additionally, to be able to deploy efficiently in rural areas, IoT solutions also need to be able to withstand the specificities of the environment (limited access to power, dust, rain, vibration, etc.). When not taken into account, these factors can significantly delay technology adoption.

For the time being, there seem to be good alternatives to 5G for actions such as detecting soil moisture, crop growth and livestock feed levels, and optimising watering or the application of crop fertilisers. This could be done through slave-hub architectures using LoRa networks, and then connecting the hub to 3G or 4G or even a fixed connection (via WiFi or even satellite). The greater the amounts of data exchanged, and the greater the degree of automation and the use of data-hungry applications such as video, the less attractive these models become. Already the use of agriculture drones that monitor crop health, scan areas, and take photographs would benefit from the capabilities of 5G (Dotecon and Axon 2018).

A foresight study conducted by the European Parliamentary Research Service (2016) confirmed that 5G coverage will become extremely relevant, if not critical, in agriculture, especially for use cases such as live mapping of soil moisture; variable rate fertilisation (including N-sensing); precision planting; data-centric farm management; connectivity to wind-farms; access to world markets. In some cases, 5G will be essential: for example, an industry analyst recently reported that currently, there are 30-60 second delays in communications between machines working on the same field, which complicates the coordination of activities; with 5G, communication could be cut down to less than one second.[99]

Table 3 – Use cases of 5G in agriculture

Use cases	Impact on industry	Critical requirements	Estimated value
Precision farming: Use of sensor data to measure crop yields, moisture levels and terrain topography	Ensure profitability and sustainability, protect environment	Connection density	> 100 /km^2
Smart Irrigation: Use of IoT to measure humidity, soil moisture, temperature etc. to calculate precise requirements for water	Higher irrigation efficiency	Connection density Battery life	> 100 /km^2 > 1 year
Agriculture drones: Use of UAVs to monitor crop health, scan areas, agriculture photography etc.	Enhanced protection, Efficient inspection and monitoring	Reliability Latency	> 99.999% < 5 ms
Soil and Crop monitoring: Use of sensors to monitor moisture and identify issues such as diseases or insects	Enable informed farming decisions, minimise erosion	Connection density Battery life	> 100 /km^2 > 1 year
Precision livestock farming: Real-time monitoring of productions, health, and welfare of livestock	Ensure optimal yield, enable informed farming decisions	Connection density Battery life	> 100 /km^2 > 1 year

Source: DotEcon and Axon based on publicly available information.

However, 5G deployment, let alone coverage, is in its infancy in most developed countries, and far beyond the horizon in developing and least developed countries. In particular, 5G will be prohibitively costly and technically difficult in rural areas in developing countries. As estimated by Oughton and Frias (2018), even if 90% of the population is expected to be covered by 2027, 5G coverage is unlikely to reach the final 10% due to exponentially increasing costs "making this proportion unlikely to be served by the market". The authors note that integrating spectrum including 700, 800, 2600 and 3500 MHz into existing sites could lower costs to achieve 10 Mbps in rural areas, but would still leave a major rural divide, as data rates would be much lower than in urban areas. Also, 5G may become problematic in terms of firm size: large providers such as John Deere equip every new machine that leaves their factory with a 4G LTE modem, Wi-Fi, and Bluetooth, but farmers keep their tractors on average for over 30 years (Lips 2017), which makes it very difficult for them to transition to smarter equipment in the short term. In addition, the type of 5G deployment that may be required for precision agriculture may still privilege coverage over bandwidth: in particular, a Study by Dotecon and Axon for the Body of European regulators of Electronic Communications (BEREC) predicted that less densely populated areas will be covered using the 5G standard aimed at providing mMTC capabilities, rather reaching the data rates available from eMBB; the same can be said about areas that require significant upgrades to the network (e.g. edge computing) to minimise latency. Table 1 below summarises the main use cases of 5G in agriculture as portrayed in that same study.

The connectivity imperative may thus, in the absence of public intervention, generate a new form of digital divide, between 5G 'haves' and 'have-nots'. This may happen between large and small farms (with larger farms being able to exploit economies of scale and superior financial resources, and thereby adopt 5G more quickly); between areas with 4G/5G connectivity, and areas that lack even basic broadband connections; and between developed and developing countries. Accordingly, while more developed countries may have to ensure that very-high-capacity mobile broadband coverage reaches rural areas and that smaller farms can have access to the technology, in developing countries the problems to be faced will most likely include also a significant upgrade of the infrastructure, even to guarantee good LoRa connectivity; and an assessment of the scalability of LoRa investments into 5G networks at a later stage. In addition, both for small farmers and less developed countries, the issue of technology affordability and accessibility will become essential, potentially triggering proposals for an international agreement on the licencing of key technologies at affordable conditions, as well as the provision of equipment 'as a service' with the help of international donors or government actors.

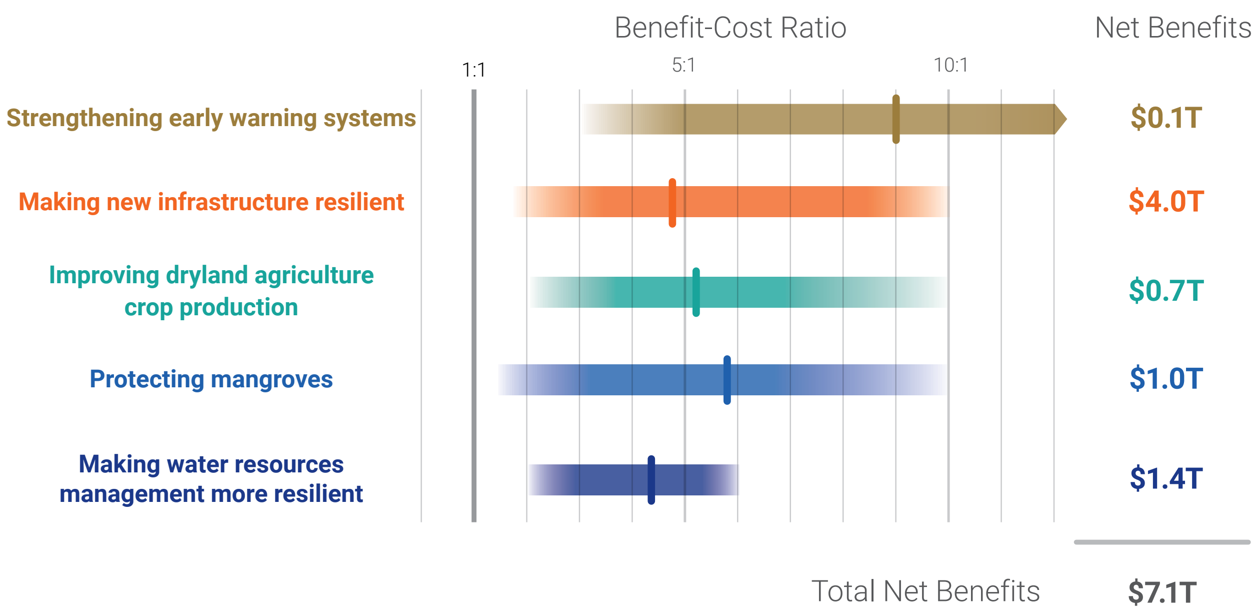
Tech deployment to maximise yield and reduce land use

Once connectivity is in place, the whole IoT stack has to be deployed: this, too, may happen at different speeds in different parts of the world. The problem is that while IoT is already being deployed in the United States and in some European countries, in other parts of the world this is far from being a prospect. This is even more problematic since, as shown in Chapter 2 above, it is in those other parts of the world that food losses and waste are more concentrated in the upstream parts of the value chain.

The deployment of IoT in the field brings significant positive externalities, but may also come at a very high private cost. As an example, think about the possible reduction in the use of fertilisers. As observed by a study for the European Parliamentary Research Service, the average nitrogen uptake rate in small grains is not greater than 50% in Europe, which means that 50% ends up in the air, the soil or the ground water; and at N-fertiliser costs of around €180 per hectare, this leads to considerable potential savings. In developing countries, the potential is even more remarkable, since less than 10% of all spray applications reportedly hit a sick plant, a weed or a parasite, and therefore 90% of spray is wasted and dispersed in the soil, water or air. **The potential savings per hectare amount to €170. The EPRS concludes that precision agriculture could achieve up to 50% of this savings potential by 2050.** Public policies could work to boost the uptake of new technologies, by rewarding farmers for the cost reductions that they generate when moving to new technologies. Start-ups like PEAT in Germany (producing Plantix) or Trace Genomics in California are already bringing to market image recognition applications that would substantially improve the ability of farmers to analyse the soil, prevent defective crops and take proactive measures to optimise the potential for healthy crop production. Another (ex) start-up, Blue River, claims to be able to eliminate 80% of the volume of chemicals normally sprayed on crops and can reduce herbicide expenditures by 90% thanks to its technology. Recently, it was acquired by John Deere in what seems to be a step towards further concentration of technology in this market.

Schimmelpfennig (2017) finds that information from precision agriculture "can promote stewardship and increase profits, but in some cases, it may raise operating costs". Balafoutis et al. (2017) confirm that technologies such as variable rate nutrient application, variable rate irrigation systems, controlled traffic farming and machine guidance have substantial emission reduction potential; and that other technologies such as variable rate pesticide application, variable rate planting/seeding and precision physical weeding show lower, but not irrelevant GHG emission mitigation. A study conducted by OnFarm, as reported by Gorli (2017), found that following the usage of IoT on the average farm, yield rose by 1.75%, energy costs dropped $7 to $13 per acre, and water use for irrigation fell by 8%. The US, where IoT is most widespread, produces 7,340 kgs of cereal per hectare of farmland, compared to the global average of 3,851 kgs of cereal per hectare. Having these figures in mind, it is easy to expect an uptake in IoT deployment especially in large farms: IoT device installations in the agriculture world are projected to increase from 30 million in 2015 to 75 million in 2020.

Figure 18 – Investing in five areas to improve climate resilience



Source: Global Commission on Adaptation (2019).

Implementing these technologies, however, requires investments in skills, connectivity and funding, which could come from public resources, given the extent of the positive externalities that this transition would generate. One possibility would be to leverage the resources available in global funds such as the Least Developed Countries Fund, on which agreement was reached in September 2019: the Fund will devote $160 million to help the poorest countries prepare for climate change. Research by the Global Adaptation Council found that investing $1.8 trillion globally in five areas from 2020 to 2030 could generate $7.1 trillion in total net benefits. The five areas considered are early warning systems, climate-resilient infrastructure, improved dryland agriculture, mangrove protection, and investments in making water resources more resilient.

The Global Commission on Adaptation observed that "a more resilient food future will rely on sharp increases in agricultural R&D, which has **demonstrated benefit-cost ratios between 2:1 and 17:1;** better alignment of government finance and incentives for farmers with long-term, sustainable, climate-smart production; and a step change in access to information, innovative technologies, and finance to enhance the resilience of 500 million small-scale farming households whose livelihoods are most critically impacted by climate change". This falls squarely in line with the results of our analysis, which focuses on small-scale farmers not only for environmental, but also for social sustainability reasons, and those of long-term economic sustainability.

Entrepreneurship, capacity building and technology transfer: reaching out to smallholders

Innovation does not flourish in a vacuum. Most experts would agree that the success or failure of innovation to take hold and scale to solve challenges depends on a network of interconnected actors – governments, civil society, the private sector, universities, individual entrepreneurs, and investors – to work in a mutually supportive and complementary manner to achieve an outcome. These networks form the basis of local ecosystems comprised local actors who are close to their communities (Konnola et al. 2017).[100]

It is widely acknowledged that agricultural extension programmes play a critical role in agricultural development and improving

Figure 19 – ICTs in agricultural extension services

Source: FAO-ITU. Adapted from E-Agriculture Strategy Guide: Piloted in Asia-Pacific Countries.

farmer livelihoods. Developing countries have benefited from agricultural extension services often funded by donor organisations. These programmes serve as the key conduit by which farmers access the technology and the knowledge they need to increase their yields, incomes, and implement sustainable farming practices. Many methods and approaches have been tried, including: top-down tech transfer, problem solving (one-to-one advice), education (formal and structured), and participatory 'bottom-up, farmer first' approaches, each with different outcomes, successes, and challenges. Perhaps the key lesson for donors and governments is that there is no 'blueprint' that can be successfully ported from one country to another: extension systems need to be modified and adapted to match the local context.

Two of the best-known multilateral donors working at the forefront of extension programmes targeted at smallholder farmers in developing countries are the Technical Centre for Agricultural and Rural Cooperation (CTA)[101] and the United Nations – FAO. Both have the aim of increasing the accessibility of agricultural innovations for all their member countries, but in particular to developing countries that do not have the resources or capacity to take advantage of new technology, methods, or farming practices. The FAO aims to address these gaps by enabling the transformation of agricultural innovation systems (AIS) of its member countries, meaning the organisations and enterprises that develop new products, processes and organisational structures to achieve food security, economic development, and sustainable natural resource management. CTA funds and implements numerous programmes with a particular focus on leveraging technology, each with a context-specific implementation. CTA's work on digitalisation, in particular, focuses on increasing the profitability and productivity of smallholder farmers by leveraging digital solutions and strengthening business innovations. It promotes precision agriculture solutions, weather information, soil sensors, drones for agriculture (where CTA is the key convener of the African UAV4Ag community) and other data-driven farming practices, as well as new services for farmers in the areas of finance and insurance.

The modern age of data-driven farming requires updated thinking around agricultural extension systems and practices. While many facets of these programmes – technology and best practices transfer, partnerships and knowledge sharing, training, market development – are still important, digital technology applied to agriculture and all its activities from farm to fork adds a new layer of complexity that necessitates updating these capacity-building practices to incorporate the implications of digital technology. First, farmers need the skills to be 'digital ready' in order to take advantage of technology-based solutions: using the internet, mobile phones and social media/networks, messaging apps, and an understanding of data and how it can be collected, shared, used, and accessed. Second, countries need to have the basic infrastructure that makes digital agriculture and related digital extension programmes possible, including: availability, connectivity, affordability, and ICT in education. Lastly, supportive policies and programmes (e-government) for digital strategies are needed, along with data governance policies and standards, in order to keep data open and accessible to all stakeholders, especially farmers. Solving these challenges will enhance the effectiveness of the assistance, making agrifood systems more sustainable globally by providing farmers with more tailored information and advice improving their output, yields, and helping them to move higher up the value chain. [15]

Donors are making significant moves towards 'climate-smart agriculture' approaches that integrate climate change into planning and development of sustainable agricultural systems.[102] In 2017, the World Bank, which stopped funding traditional 'travel & visit' extension services in the early 2000s, revamped its agriculture strategy to embrace digital technology more fully. It formed an internal group to focus on digital agriculture, with a particular focus on digitally-enabled advisory services. In 2018, the Bank launched its disruptive technology for agriculture strategy and formed an expanded central team to address this topic. Digitally-enabled extension services are increasingly being funded by donors as part of larger strategies to enable D4Ag entrepreneurial ecosystems to incubate start-ups, attract venture capital investment, provide links to markets and value chains, facilitate tech transfer, improve farmer productivity, and enhance resilience in agrifood systems. The centrepiece of the World Bank's new D4Ag strategy is the Ag Observatory, launched in 2018. It consists of a platform that harnesses public sector data and open-source datasets and applies machine learning models developed by data analysis company aWhere to create an agriculture intelligence platform that generates predictive models to help avert climate change-moderated food loss events before they occur.

The idea of using digital technology in extension services and capacity building is not new but is becoming more technologically advanced. The FAO operates Technologies and Practices for Small Agricultural Producers (TECA), an online platform that gathers effective agricultural technologies and practices to facilitate knowledge-sharing globally. The CTA runs several programmes dedicated to the digitisation of agricultural extension advisory services, specifically Data4Ag, the e-Granary mobile platform, MUIIS (Market-led, User-Owned Information Service), and Data4Ag, to name a few. These examples demonstrate the shift towards platformisation, leveraging big data and analytics, as a key trend in agricultural extension services in the 21st century. This increases productivity and sustainability by delivering credible and actionable information in real-time, helping farmers transition from time, labour, input and resource-intensive practices to more efficient and sustainable planning, production, and management systems.

Against this background, it is important to recall that research for, and by, the World Bank already showed a decade ago that the redistribution of land in the hands of large agricultural firms has had no meaningful impact on the reduction of poverty, and has led to no significant improvements in R&D productivity, whereas "small-scale farmers generally use land, labour, and capital more efficiently than do large-scale farmers who depend primarily on hired labour" (Binswanger-Mkhize et al. 2009). Similarly, the 2009 International Assessment of Agricultural Knowledge, Science and Technology for Development questioned the benefits of capital-intensive, industrial agriculture, urging a shift of international donor support toward agro-ecological practices that are less dependent on capital and external inputs.[103] Moreover, the empowerment of small-scale farmers is also important from a social perspective, in particular with respect to the creation of human capital, the eradication of poverty and the reduction of the gender gap, among others.

Data aggregation: a new tool for distributed, sustainable governance

According to OnFarm (a connected farm IoT platform provider), **the average farm will generate 4.1 million data points by 2050.** As we already explained in Chapter 2 above, using collected data to directly improve production practices could enable a 20% increase in income while reducing herbicide and fuel consumption by 10-20%. However, the key problem with data is that small-scale farmers are not yet well equipped to make the best use of them, absent dedicated advisory services and third-party support. As already observed, the diffusion of data-driven agriculture may thus end up exacerbating the dependency of small-scale farmers on large corporations, who increasingly specialise in IoT, AI and data-driven agriculture by exploiting their superior resources.

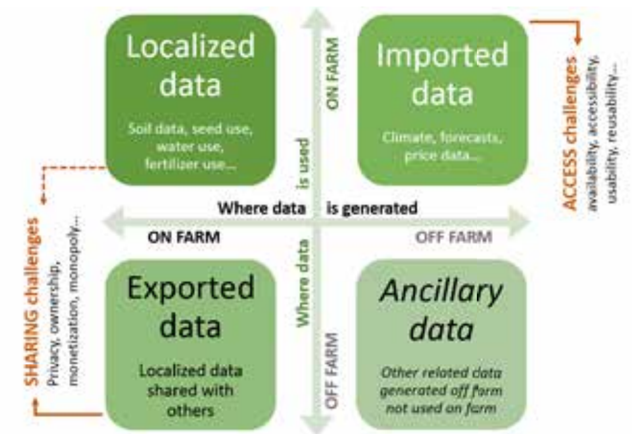
Accordingly, new solutions and dedicated services will be needed, possibly leading towards community-led data management, coupled with the provision of basic skills and the gradual hand-over of responsibility to the local community. **This, coupled with adequate investment in connectivity, could provide a solution for the about two-thirds of the developing world's 3 billion rural people that live in about 475 million small farm households, working on land plots smaller than 2 hectares.** Currently, as observed by the FAO, "agricultural research is becoming increasingly private, focusing on technologies which are knowledge intensive, being developed for larger commercial farms. This renders technology adoption by small farmers difficult. Smaller farms face considerable difficulties in accessing credit, as banks are often reluctant to lend to them due to poor collateral and lack of information". Possible actions that may tackle these problems of knowledge absorption and collective action include the following:

- **Community-based funding.** Thomas, Gunden and Legesse (2019), among others, analyse the role of community-based organisations (CBOs) in agriculture, and explore the logic for aggregating smallholders to achieve more sustainable farming models. The authors, however, do not explore the possible integration of digital technologies in the CBO model, which we believe would be extremely beneficial for the future of the agrifood chain. The EIP-AGRI also explored the potential to work at community level in supporting farms, with no specific emphasis on technology solutions. In our opinion, digital technologies provide an obvious case for community-based agricultural support, not only for cost-sharing purposes, but also for coordinated data management, as well as on account of the spillover effects of connectivity and IoT deployment for the full community.

- **Uberisation of assets.** One of the most compelling prospects to empower smaller farmers is the possibility to use equipment such as tractors and drones 'as a service', in what is often defined as 'uberisation' or 'servitisation' of assets. This point is related to the previous one, since community-based services can include cost-sharing and coordination arrangements to make effective use of shared resources such as drones. The latter are becoming cheaper, but may still cost at least $400, with a complete system for a small farm costing about $5,000. This may be too expensive, but if the one-off cost of acquisition is transformed into a service fee, the operational costs will become much more sustainable (an Octacopter drone only needs an estimated $1.20 worth of electricity from the grid to carry a 10 kg payload for 30 km). The servitisation of costly assets is then easily combined with aggregated data services. The use of drones is also a suitable way to shorten the supply chain, given the potential to rely on these devices for direct food delivery.[104]

- **Combining skills with smart agro-ecology solutions.** Agro-ecology has emerged as a way of redesigning food systems to achieve sustainability. It requires transdisciplinary, participatory, and transition-oriented research, and combines scientific research and community-based experimentation, emphasising technology and innovation that are knowledge-intensive, low cost, and easily adaptable by small and medium-scale producers. Skills training in agriculture should combine agro-ecology solutions with the use of data-driven, community-

Figure 20 – Four streams of farm data



Source: Maru et al. (2018).

based technologies (see above, previous points), in a way that combines the potential of technological innovation with the need for sustainable, locally-tailored and knowledge-based solutions.

- **Connecting insurance and donors with farmers.** The availability of continuous flows of interoperable, digitised data can help small farmers purchase insurance and establish trusted relationships with potential donors, thanks to enhanced possibilities to control land performance and a variety of indicators. In the scheme below, these are data generated on-farm for use off-farm by third parties, in support of the agrifood chain. As shown in the figure, sharing these data is at once challenging and critically needed.

- **Connecting smart farmer communities to the value chain.** Aggregating data and creating a community-based management of joint resources and information is also an effective way to connect local farmers to global supply chains, and to empower them with greater bargaining power (due to aggregation) in contractual relationships. Aggregation is considered as one of the most effective means of reducing risk and strengthening the livelihoods of small and marginal farmers. Benefits, beyond resource-sharing and cost reductions, include better access to knowledge, better access to government support schemes; and better contractual conditions especially in the absence of specific legislation on unfair trading practices along the supply chain.

As observed by Wolfert et al. (2017), since on-farm data will generally remain in the hands of individual companies, "investments are needed in a common pool infrastructure to transfer and integrate data and finally make applications out of it". Poppe et al. (2015) refer to this as Agricultural Business Collaboration and Data Exchange Facilities (ABCDEFs). It is essential that international funding helps the development of non-proprietary, or jointly managed ABCDEFs, rather than leaving the market to proprietary ones (such as former agrichemical giant Monsanto's FieldScripts). Examples include OpenATK or FIspace.[105] Moreover, these platforms should enable data sharing and re-use, while being respectful of privacy and security.

Key issues in this respect are ensuring trustworthy data collection, cleaning data, building interoperability between on-farm data, slicing data to ensure anonymisation, merging on-farm data with open, public data (e.g. on meteorology), retrieving individualised diagnosis and predictions, and thereby enabling co-opetition at the local level. These services can, in turn, enable the development of group insurance shared by farmers, and other forms of community empowerment.

The need to aggregate small-scale farmers into local organisations has emerged in particular in developing countries over the past years. For example, in 2015 the Government of India announced a $34 million investment to set up a "Producers Development and Upliftment Corpus (PRODUCE)" under the National Bank for Agricultural and Rural Development (NABARD). There and elsewhere, the role and impact of Farmer Producer Organisations (FPOs) has increased, very often with limited relation to the deployment of digital technologies. This is what we believe the next step of digitising agrifood should lead to.

Rebalancing bargaining power along the agrifood chain

Once connectivity, data and technology have been deployed, small-scale farmers must be connected to global supply chains. There, they will normally find much larger players, and often end up in a situation of economic dependency, or anyway weaker bargaining power. Here, governments may intervene to temper the superior bargaining power of a variety of players, including retailers, food processors, wholesalers, cooperatives, producers' organisations or individual, powerful producers. This requires the adoption of specific policy instruments, such as legislation on the agrifood supply chain to protect smaller players against large manufacturers and retailers; or rules on abuse of economic dependence (Renda et al. 2012; 2014).

Importantly, such rules are not going to be very effective in least developed countries, or more generally in all countries where the rule of law is weaker. The lack of a reliable judiciary reverberates on the effectiveness of adopting ad hoc legal rules that can adequately protect small-scale farmers. Moreover, the relationships between smaller farmers and larger players (e.g. distributors) are very often governed by private rules, rather than by public ones. For example, in the case of certification schemes such as GlobalGAP or the Marine Stewardship Council, private standards govern the relationship and risk allocation along the value chain much more than existing national laws (Cafaggi and Renda 2012).

Therefore, work has to be done in generating contractual templates and providing advisory services for both the relationship between farmers and distributors, and between farmers and data managers whenever the option of farmer-managed data is unavailable. In this respect, the use of blockchain technology and smart contracts might become a trust-enhancing tool in an otherwise imbalanced contractual relationship: a good example in this respect is Oxfam's BlocRice, a blockchain technology that connects rice farmers in the Cambodian village of Reaksmei, in the Preah Vihear province, with other people in the supply chain to ensure that poor farmers get a fair deal.[106] Importantly, most of these technologies require that farmers have access to a smartphone, which is not always the case (and should be accounted for when dealing with connectivity).[107]

Attribution of responsibility for negative externalities throughout the value chain

Another way to realign the digitised agrifood chain with sustainable development is to use traditional and new policy tools to hold industry players and end users accountable for the externalities they generate or legitimate (Buttel 2003). While the agrifood chain produces massive negative externalities in terms of waste, emissions, health impacts and loss of biodiversity, the digitised agrifood chain may represent a cure that is worse than the disease: as shown in Chapter 3, while reducing traditional externalities, digitised agrifood can lead to much greater energy consumption, e-waste, animal distress and harm due to the deployment of sensors, and more generally embedded emissions, which must be considered in the overall assessment of the potential of digital agrifood to achieve the SDGs.

Traditional ways to internalise externalities include the use of incentive schemes such as subsidies, taxation, or even the exclusion of certain technologies or production practices from public procurement. These policy approaches should be extended to reflect specific challenges of the digital age: for example, AI developers could be asked to declare the energy consumption costs related to the use of AI techniques such as deep learning, and the total environmental cost of using such techniques could then be included in the information available to end users. In the EU, and increasingly in other countries, ethical principles on AI include as a requirement the mitigation of both social and environmental impacts in the development and deployment process: this could in the future lead to legislation that enables more transparency in the social and environmental costs of using digital technologies in agrifood. A similar policy action would entail the attribution of responsibility to online intermediaries for the inclusion of non-financial indicators in their ranking algorithms.

Of course, the adoption of new technologies also creates positive externalities, since the benefits generated by digital agrifood are diffuse, and are not fully internalised in the form of additional revenues by those players that implement the technology. This requires attention by policymakers at all levels: for example, in finding ways to remunerate farmers and end users for the data they contribute to data management platforms; and end users for the use of their personal data to feed algorithms in personalised nutritional services; and also (in what is effectively the mirror image of policies for negative externalities) in rewarding with tax rebates or subsidies those players that decide to transition towards new and more sustainable technologies.

Incentives to shorten the supply chain through digital agrifood

It is widely acknowledged that shorter supply chains can be more sustainable, as well as better geared towards adequate empowerment of both small-scale farmers and end users. According to the UK's Soil Association, short supply chains are defined as a "production, processing and trading system", primarily based on organic and sustainable methods of agrifood production, where "the physical and economic activity is largely contained and controlled within the locality or region where it was produced, which provides health, economic, environmental and social benefits to the communities in those areas"(see Tanasă et al. 2016). The quantitative and qualitative assessment of Short Food Supply Chains (SFSCs), carried out by the researchers from the Joint Research Centre, emphasised numerous economic, social and environmental benefits (Kneafsey et al. 2013), including human capital (e.g. increased local employment opportunities, greater knowledge transfer); financial capital (support to small agricultural producers); physical capital (support to local stores and markets, local rural tourism); social capital (access to healthier food, increase of social interaction and spirit of belonging, etc.; and natural capital (more environment-friendly production systems, and possibility to minimise use of packaging).

Digital technologies can shorten the supply chain in many ways, and they have already started doing so. Obvious examples are the platformisation of food supply, which connects producers and end users more easily by reducing search costs and also delivery costs; but also blockchain deployment to improve food traceability, which in turn reduces the need for intermediaries. Generally speaking, platformisation is essential for achieving the full potential of short supply chains: however, it should be accompanied with adequate governance to avoid the concentration of both market power vis-à-vis end users, and bargaining power vis–à-vis farmers. Importantly, rules on unfair P2B (platform-to-business) and P2C (platform-to-consumer) practices are important to avoid shorter supply chains being accompanied by a dangerous 're-intermediation', rather than 'dis-intermediation', of the supply chain (Galli and Brunori 2013).

Public policies to enable reallocation of excesses

As already discussed throughout this report, the need to put in place policies to prevent and reduce food waste is increasingly strong, as the amount of food wasted or lost along the supply chain reaches a striking one third of the total. Policies can be divided in three major categories: prevention (reducing surplus at the source); recovery (reusing for human consumption); and recycling (feeding animals, creating energy or compost).

Mourad (2015) discusses possible approaches to food waste policy, comparing France and the US, arguing that the economic, social and environmental aspects have been approached more as competing rather than complementary stances. At the same time, she found that while 'strong prevention' would qualify as the strongest of possible approaches, in practice existing initiatives in the US and France only led to very marginal changes in the structure of the value chain. Strong prevention requires a departure from 'productivism', 'over-industrialisation', and 'homogenisation' of food production, along with the permanent availability of a wide range of foods through complex commodity chains. Strong prevention would also require, i.a., more seasonal variability, with greater proximity to the land or 'nature', and sharing more food through stronger social links, based on trust rather than formal agreements. Food waste reduction has not so far been directly included in the US Farm Bill or the European Common Agricultural Policy (see below), although the latter has taken steps towards less 'productivist' agriculture.

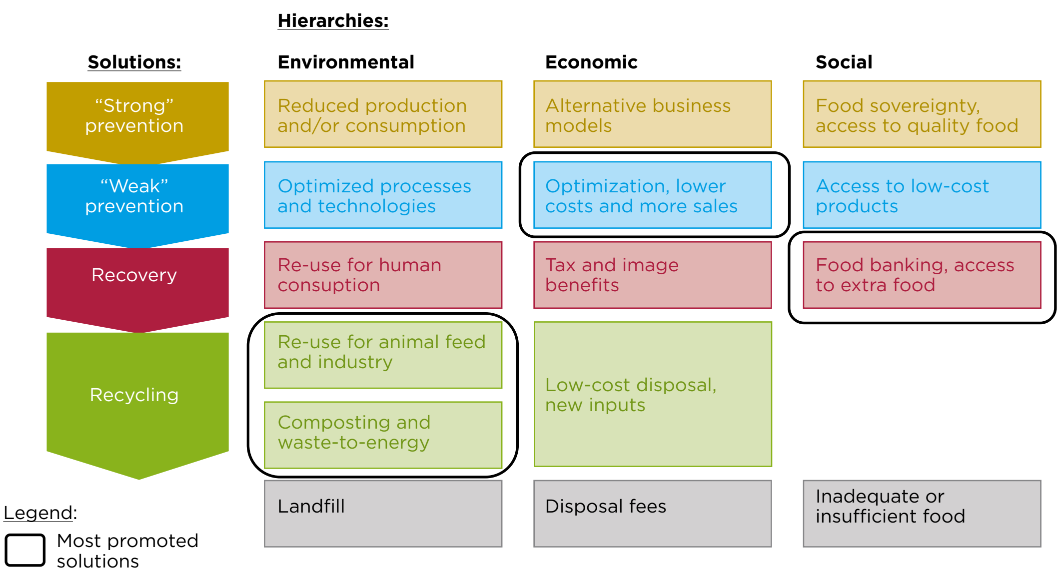
Against this background, the recent initiative by the French government to mandate the reallocation of food leftovers and excesses to charities seems to be exerting a tangible impact on food waste, and is forcing retailers to modify their practices in managing supplies and disposal of food, as well as to set up a system for the effective and efficient reallocation of food close to its expiry date. In the future, digital technologies such as blockchain and AI will most likely lead to more predictive, accurate supply and distribution of food; changes in modes of delivery and the shortening of the supply chains will shorten the time from order to delivery, thereby reducing the need for large orders and increasing the frequency of smaller orders. Most importantly, the platform and 'app' economy are already facilitating price discrimination for food close to expiry, segmenting the market, allowing for more participation of poorer consumers and thereby potentially tackling hunger and poverty.

While encouraging governments to adopt legislation similar to the French one, it remains clear that the full range of technologies discussed in this report will be best able to address the problem of food waste effectively by encompassing all three approaches to food waste, from (strong and weak) prevention to recovery and recycling. Public policy may want to support the adoption of these technologies, again on the basis of their prospective contribution to addressing negative social and environmental impacts.

An ethical and policy framework for AI and data management in B2C

In the most downstream part of the agrifood chain, consumer choice and awareness is one of the key drivers of future sustainability in the agrifood chain. Consumers that are connected, skilled and aware of the impact of the agrifood chain on the economy,

Figure 21 – Competing hierarchies of solutions to food waste/loss



Source: Mourad (2015).

society and the environment will be able to drive the demand towards more sustainable food. At the same time, deploying AI to encourage more sustainable and personalised consumption patterns can be a double-edged sword, as already explained in Chapter 3 above. Governments should ensure that personalised nutritional advice does not become a way to nudge end users towards specific brands or types of food, or even create addiction, thereby dis-empowering end users.

A way to achieve this result is to adopt an ad hoc policy framework for the use of AI in B2C relationships, where consumer choice is most affected by the interaction with AI systems. The most important aspects in this domain are data protection, clear rules on discrimination, respect for diversity, and the incorporation of sustainability criteria in the recommendation of products or services to be bought. We briefly explore them below.

- **Data protection.** AI systems (especially when based on machine learning) need personal data. A personalised nutrition system inevitably needs personal data, including sensitive health-related data, to fully perform its functions. It is essential that end users are put in a position to trust these systems, by requiring that data are not re-used for other purposes than that of providing advice, or sold to third parties for commercial reasons such as advertising. This is not straightforward for governments, also since advertising-based models are likely to be cheaper, or even free for end users.

- **Rules on discrimination.** AI-based personalised nutrition systems must discriminate to be useful to the end user. They should take into account several factors including preferences, age, health conditions, culture, ethnicity in order to provider optimal advice. This, in turn, also means that they will provide different advice to different users ('personalisation'): however, advice should not discriminate in a way that is commercially motivated, and clear rules have to be established to avoid that a specific online platform or application discriminates between equivalent products on the market by recommending specific brands or nudging end users towards specific retailers.

- **Respect for diversity.** Directing all individuals towards the same diet is not feasible, since the world differs in terms of preferences, traditions, intolerances, and of course, food availability. When training and developing AI systems, it is extremely important that the data used do not contain biases, or lack of representation of specific categories. For example, a given ethnic group may not have been adequately represented in the data used to train a given algorithm, and this may reverberate on the accuracy of the recommendations provided by the AI system. This applies both to cultural diversity (e.g. recommending types of food that are prohibited by specific cultures), and ethnic diversity (e.g. specific ethnicities feature particular intolerance for the specific products or ingredients, e.g. lactose).

- **Incorporating sustainability criteria in recommendation engines.** In the case of recommendation engines, it would be extremely important to include information on the sustainability of specific types of products, possibly even enticing users to engage in sustainable consumption practices through various forms of nudging (e.g. gamification, point based systems, etc.). If publicly endorsed, these systems can be used to trigger sustainable behaviour in various ways, provided that data protection is ensured, and untargeted social scoring is avoided.

Skills and awareness-raising for farmers and consumers

The diffusion of technological innovation depends on the ability of all actors along the value chain to implement, deploy and use the new solution. This is why none of the aforementioned technological solutions can really find its place on the market without the right skill set. This clearly calls into question the role of government in introducing education policies for all ages, and specifically training and upskilling paths for small-scale farmers, reskilling paths from other sectors into data-driven agriculture, and basic skills to consumers so that they can verify the sustainability of the products they consume, find new ways of finding the food of their choice in shorter supply chains, and interact with AI-enabled user interfaces for personalised nutritional advice, even coupled with general health, fitness and wellness advice.

Numerous studies have confirmed a positive relationship between education and productivity in the agricultural sector. But in the case of digitised agrifood, the skills needed are quickly evolving. In 2016, the EPRS identified three different skills sets as essential for young farmers that need to be trained in precision agriculture. Technological skills should aim at training farmers to work with robots and processed data, choose appropriate solutions according to the farming project, master the basic notions of computer science, advanced machinery (auto-steered equipment, drones) and complex apps (RTK, Satellite imagery). Environment skills include understanding legislation, gaining expertise in circular agriculture and knowledge of local ecosystems, and acquiring genetics expertise. Finally, managerial skills include business management, innovation management, entrepreneurship and marketing skills. Here, technology can again come to the rescue through the use of online courses and distance learning.

EU's role at home and abroad

The policy mix described above can usefully applied to the case of the European Union, where the debate is very lively, especially due to the ongoing reform of the Common Agricultural Policy, and also due to the recently announced "green new deal", which the new European Commission is expected to launch in the first half of 2020. Especially in the current context of global governance, the EU is the only large bloc that has sufficient ability, resources and credibility to lead the great transformation in the agrifood sector that is needed to achieve sustainable development. Below, we consider the main pillars of our policy mix, formulating specific recommendations for the European Union. The following section deals with the role of the EU at the global level, as an actor in sustainable development.

Digitising agrifood inside the EU

The European Commission has shown at times determination, at times elusiveness in its approach to SDGs. Although sustainable development is considered a fundamental and overarching objective of the EU, enshrined in Article 3 of the Treaty on European Union (TEU), and despite the existence of an EU strategy since 2001 and a set of Sustainable Development Indicators since 2005, the salience of this strategy at the highest political level had never been particularly strong before the launch of the 2030 Agenda: indeed, the EU was heavily criticised for lacking ownership and governance (Gregersen et al. 2016). The pragmatism shown by the European Commission President in de facto replacing the Europe 2020 agenda with the "ten priorities" (Renda 2015) appeared antithetical to the adoption of a more ambitious, far-reaching sustainability agenda. New legislation had to fall in one of the ten baskets, with no exceptions, and the relatively gloomy prospects of the economy in the first years of President Juncker's mandate jeopardised the adoption of courageous plans for the initially invoked "Triple A" in social policy. Internally, the Commission appeared divided in its Vice-Presidential structure, with the First Vice-President showing determination to pursue a sustainable development agenda, and others more oriented towards growth, or resilience. Similarly, emphasis on social and environmental goals has been weak in the European Semester cycle, as well as in important policy dossiers.

In this overall context, **the European Commission**

has shown, at least in theory, strong commitment towards the SDGs. In November 2016, a series of communications outlined the future agenda for 2030, centred on SDGs. The Commission presented the new agenda as a joint initiative with member states and "many different actors", aimed at fostering a "stronger, more sustainable, inclusive and prosperous Europe". Most importantly, in the Communication "Next steps for a sustainable European future", the Commission made clear its intention to mainstream sustainable development in European policies: this includes, most notably, the European Semester, the EU Budget, the better regulation agenda, and of course the external action strategy. **Such mainstreaming, however, has remained on paper: the Agenda 2030 has plateaued and gradually disappeared from the radar during the following two years.** This does not mean that the EU has remained inactive in pursuing sustainable development in Europe: only, the way in which progress was sought remained patchy and lacking an overall, consistent, coordinated, multi-level strategy as the "mainstreaming" idea would have implied.

Examples of demonstrable commitment towards the SDGs are numerous and include the creation of a multi-stakeholder platform on SDGs, which finalised its contribution to an upcoming Commission reflection paper in September 2018, highlighting the need for a more comprehensive and coordinated EU strategy. In specific policy domains, achievements have been notable. For example, the European Commission relaunched its ambitions in emissions reduction by proposing a net-zero emissions 2050 strategy at the end of November 2018, thus becoming the first major player to respond to the worrying findings of the most recent IPCC report, and outlining eight different scenarios to achieve the stated goal by 2050.[108] Recently, the Commission also published a review of member state commitments towards climate change, urging them to shift gear if the 2030 targets are to be achieved: currently, as an example, only eight member countries aim to phase out coal-powered electricity by 2030, which most likely will lead the EU to fail to deliver on its commitments under the Paris climate deal.

Looking at specific policies, **there has been no shortage of initiatives that, either explicitly or implicitly, could be subsumed under the umbrella of the SDGs.** For example, the new research and innovation policy subsumed under the **Horizon Europe** programme is consistently oriented towards SDGs. As stated by the Commission in its proposal, "Horizon Europe will strengthen the Union's scientific and technological bases in order to help tackle the major global challenges of our time and contribute to achieving the Sustainable Development Goals". But overall, what is missing is a coherent and ambitious policy approach towards the achievement of sustainable development in economic, social and environmental terms. Looking at the areas that fall under the scope of this report, the **reform of the Common Agricultural Policy** presented by the European Commission in November 2017 appears to be insufficient to realise the full potential of agriculture to contribute to the SDGs: the latter ended up being little more than a must-have preamble in an otherwise excessively timid reform. Lack of alignment and coherence is visible also in digital technologies: the Commission seems likely to miss the opportunity to **promote the development of Artificial Intelligence in relation to SDGs:** the current agenda and Coordinated Plan on AI adopted in December 2018 and April 2019 are focused on EU "competitiveness", rather than sustainable development. Similarly, in trade policy the ongoing negotiation of key trade agreements such as the one between the EU and Mercosur, the need for strong provisions on Trade and Sustainable Development was criticised as being subordinated to the need to achieve market openness, whatever the environmental and human rights consequences.

The recent **Reflection Paper on Agenda 2030 adopted by the European Commission** marks an important milestone towards defining a more ambitious strategy for the EU and sustainable development in the next decade. The Commission observes that EU agriculture has made real progress on the climate and environment front, reducing greenhouse gas emissions by 20% and nitrates levels in rivers by 17.7% since 1990. However, more needs to be done, both in agriculture and in the food system. The SDGs, the Commission claims, "offer the way forward": it is estimated that a global food and agriculture system in line with the SDGs could create new economic value of more than EUR 1.8 trillion by 2030 and over 200 million full-time jobs globally by 2050.[109] The report also observes that the EU is well positioned to become a "global sustainable food champion", and the proposed reform of the Common Agricultural Policy will be instrumental to this end by ensuring that member states' national plans reflect the sustainability principles embedded in the CAP objectives. Moreover, the Common Fisheries Policy has reportedly led to progress in improving sustainability, but awaits proper implementation, including the sustainable management of all fish stock and the development of sustainable aquaculture.

This patchwork of initiatives, still lacking full coordination, is reflected in the state of advancement of the EU towards SDGs. Recently, in a stocktaking exercise of progress achieved over the past five years, Eurostat found that progress was strongest for SDG 3 (Good health and well-being), SDG 4 (Quality education) and SDG 7 (Affordable and clean energy); slow or inexistent for other SDGs, and even negative on SDG 10 (Reduced inequalities), due to the continued rise of income inequalities within member states. Eurostat still uses a very limited number of indicators to track progress towards SDG 15 (Life on Land), but observed that "other stocktaking reports and evaluations conclude that the **status of ecosystems and biodiversity in the EU is insufficient, and that the negative impacts of EU consumption patterns on global biodiversity are considerable".**[110] Moreover, Eurostat found that the labour productivity of the EU's agricultural sector has improved and the area under organic farming is increasing; however, some adverse impacts of agricultural production are increasing, as evidenced by the severe declines in the common farmland bird and grassland butterfly populations. Furthermore, ammonia emissions from agriculture have been increasing. Finally, despite positive developments in the employment rate of graduates, **education outcomes for reading, maths and science are still below the EU target, and data on adult participation in learning are also disappointing.** This, as Europe's labour market prepares to face the challenge of digital transformation, is worrying and may constitute a limit to what digital technologies can do for sustainability.

Agrifood in the Green New Deal

The von der Leyen Commission seems likely to lead to a **renewed commitment towards sustainability, in particular from an environmental perspective, thanks to the launch of a "European Green Deal",** as defined by the new President-elect in her political guidelines. The guidelines also state clearly that "climate change, biodiversity, food security, deforestation and land degradation go together. We need to change the way we produce, consume and trade. Preserving and restoring our ecosystem needs to guide all of our work. We must set new standards for biodiversity cutting across trade, industry, agriculture and economic policy". Part of the Green Deal will also entail the presentation of a Biodiversity Strategy for 2030, and action to "preserve the vital work our farmers do to provide Europeans with nutritious, affordable and safe food", a goal that inevitably requires better living conditions and business prospects for European farmers. **The President-elect thus proposed a new "Farm to Fork Strategy" on sustainable food along the whole value chain.** And the Commissioner-designate for Agriculture, Janusz Wojciechowski, stated in his confirmation hearing that "there is a clear need to simplify the policy and widen the use of new technologies and practices across the farming community", adding that the availability of adequate infrastructures to deploy new technologies is key, and stating his intention to “ensure better connectivity of rural areas through the roll out of fast internet”. The Commissioner-designate also showed awareness of the key importance of supporting small-scale producers as a way to achieve sustainability.

Importantly, the new European Commission will work on a **coordinated a strategy for a healthier planet** by combining the actions of Executive Vice-President Frans Timmermans (Green New Deal), the portfolio of Agriculture Commissioner-designate Janusz Wojciechowski (who will be in charge, i.a. of completing and implementing the reform of the CAP), the portfolio of the Health Commissioner-designate Stella Kyriakides (who is leading the new ‘farm to fork’ strategy), and the dossier of the Environment Commissioner-designate Virginijus Sinkevicius. The commitments expressed by these three leaders during their hearings are

Figure 22 – The nine objectives of the CAP

Source: European Commission.

far-reaching, but still fall short of referring to the essential role of digital technologies. For example, Kyriakides publicly committed to lowering the EU’s dependence on pesticides,[111] whereas Sinkevicius stated that Europe needs to “subsidise ecological farming more and more”. These resounding statements must also be appraised in light of the efforts made by the Directorate-General for Research and Innovation, in particular with respect to the launch of a new mission on “soil health and food”, as well as the ongoing relaunch of the partnerships in the agricultural sector (see below); and the work of the Directorate-General for Communications Networks, Content and Technology, which led to the adoption, in April 2019, of a joint commitment between the European Commission and 25 member states for the “digitalisation of European agriculture and rural areas”. These are extremely encouraging new developments. However, they will only be new and encouraging if they are followed by a coherent, ambitious, transformative and coordinated strategy at the EU and member state level. We explore all these issues in more detail below.

Reforming the CAP

A key role in the reform of Europe’s approach to the agrifood sector will inevitably be played by the ongoing reform of the Common Agricultural Policy (CAP). On 1 June 2018, the European Commission presented legislative proposals on the CAP beyond 2020. These proposals aim to make the CAP more responsive to current and future challenges such as climate change or generational renewal, while continuing to support European farmers for a sustainable and competitive agricultural sector. The Commission proposed i.a. that funding for the CAP be moderately reduced – by around 5% – due to lower contributions in a future union of 27 members. The overall objectives of the reformed CAP overlap to some extent with the scope of this report. As shown in the figure, the CAP aims i.a. at rebalancing power in the food chain, triggering climate-related action, ensuring a fair income for farmers, preserving the landscape and biodiversity, and protecting food and health quality.

The European Commission, in selecting the nine objectives of the CAP, made extensive reference to digital technologies. For example, the potential of blockchain as a means to increase the transparency of the value chain is acknowledged in a policy brief dedicated to the improvement of imbalances in the value chain.[112] There, the Commission observes that

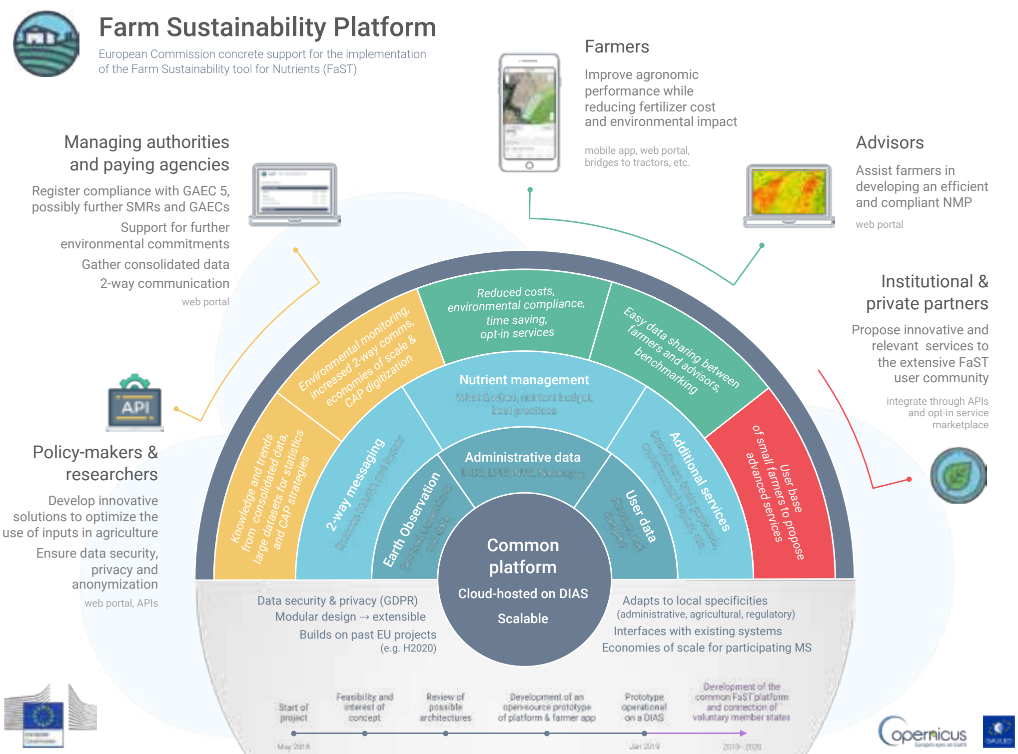
"Blockchain technology can provide cheaper access to information; can improve communication and information flow (accuracy and speed) between players in the chain", but warns that "there are several challenges that must be addressed for adoption on a wider scale in the supply chain. The technology is not yet fully mature and regulatory framework might need to be adapted, to tackle issues of capacity, validation time, scalability, confidentiality, security of the systems and ownership of data/chains so that they reduce imbalances in the chain". The Commission also refers to shorter supply chains, arguing that they "deliver important social benefits, relinking farmers to the consumers and contributing to a revival of rural communities".

In another brief, the European Commission recognises the potential of precision farming within the CAP, to improve soil management. The Commission identifies three gaps: a knowledge gap, related to farmers' lack of skills in managing and trading data; an application gap, which refers to the diffusion of technological innovation; and a perception gap, triggered by the high start-up costs and risk of insufficient return on investments, which limit incentives to invest in the new technologies.[113]

All in all, despite the acknowledgement of the opportunities provided by digital technologies, the proposed reform of the CAP still seems to be relatively vague in proposing new tools to boost technological adoption. The Commission appears to rely on parallel initiatives, such as the Farm Sustainability Tool for Nutrients (FaST, see box below), made mandatory for income support beneficiaries, and projects funded by Horizon 2020 and Horizon Europe, the EIP-AGRI network, and Rural Development funding.

The EPRS foresight study on precision agriculture looked in depth at possible options to promote new technologies in the CAP, and ended up contemplating the possibility of granting a "sustainability bonus"

Figure 23 – The European Commission's FaST platform



to farmers conditional on investment in precision agriculture technologies (which would be in line with our analysis in Chapter 4 above); and the creation of a dedicated third pillar within the CAP (2021-2027) dedicated to environment and sustainable technologies.[114]

The new rules adopted by the European Commission will allow the data from the EU's Copernicus Sentinel satellites and other Earth observation data (EGNOS) to be used as a primary evidence when checking farmers' fulfilment of requirements under the CAP for area-based payments (either direct payments to farmers or rural development support payments), as well as cross-compliance requirements, such as stubble burning. Other new forms of evidence will also be acceptable for the first time, as part of a broader shift towards a "monitoring approach" that will lead to a decrease in the number of on-farm checks. These additional types of evidences include geo-tagged photos, information captured by drones (e.g. aerial imagery), and other digital data owned by the farmer (suitable for use for reporting purposes), such as data provided by automatic guidance systems with very high accuracy (less than 10 cm) GNSS-based positioning or with RTK correction with 2 cm accuracy, which allows the creation of highly accurate field boundaries; data provided by modern harvesting equipment that creates yield maps, which are automatically uploaded to the cloud and can easily be shared with paying agencies; as-applied digital maps of seed, fertiliser or pesticides are other highly accurate sources to prove what crop has been grown and the field size. Several member states have already indicated their intention to start taking advantage immediately of the possibilities offered by digital technologies. It will benefit public administrations by reducing the costs of monitoring controls and checks, and also the farmers, by reducing the burden of the reporting process and avoiding subsequent on-farm checks. Several EU regions have already set out initiatives in this direction.

Towards a decentralised governance model

One of the main findings of our report is related to the choice of governance modes for sustainable agrifood. The need for more balance along the value chain reverberates on the desirability of more distributed, decentralised approaches to governance. However, the current EU approach to the CAP and to rural development support, while acknowledging the importance of rural communities, does not go far enough in supporting the creation of local organisations (such as FPOs) and the empowerment of these organisations with new skills and competences, including in particular data management and sharing, but also entrepreneurship and the managerial and legal competences needed to make the most out of the new digital technologies in an ever-changing market context.

In the programming period 2014-2020, the Rural Development Plans of member states were expected to focus on the promotion of local markets and short supply chains, producers groups and inter-branch organisations, quality schemes, the restructuring of farms with low degree of market participation and farms in need of agricultural activity diversification in order to meet the EU priorities for Rural Development (Article 5 of EU Regulation 1305/2013). In addition, member states were able to provide support to farmers through the so-called LEADER approach (*Liaison Entre Actions de Développement de l'Économie Rurale*), which entails i.a. the involvement of local representatives in decision-making through Local Action Groups. While the LEADER initiative was limited to the European Agricultural Fund for Rural Development (EAFRD) or the European Maritime and Fishery Fund (EMFF), Community-led Local Development was introduced in the Common Provision Regulation (CPR No 1303/2013) as a new tool that extends the LEADER method to the European Regional Development Fund (ERDF) and the European Social Fund (ESF).

However, the available counterfactual evaluations have shown very different results across areas, and the salience of the LEADER approach seems to have faded in the new proposed CAP.[115] Case studies have concluded that these policies can also hinder the development of local markets: for example, Karner (2010) finds that measures under RDPs and LEADER that impose "high minimum levels" for eligibility to grants may be an obstacle for investments by small farms and processors. They also recognised possible hindrances due to strict legal constraints (hygiene, certification, trading rules and direct selling legislations), inconsistent legal frameworks (as in Hungary or Poland), or the overall economic system favouring large-scale businesses and industrialised food production (as in the UK). Thus, institutional support potentially fostering decentralised food systems needs to be further tailored to small-scale entities (farmers and enterprises) and to reduce the administrative and financial burden (Santini & Paloma 2013).

Furthermore, **the integration of new digital technologies in the LEADER/CLLD approach seems still to be limited,** and the Commission should adopt guidance, ad hoc funding as well as non-financial support for the development of community-based solutions. Furthermore, a **stronger integration of those solutions with the Sustainable Development Goals** should be achieved in the coming year, as the Commission finalises its Agenda 2030 as well as the Green New Deal and the From Farm to Fork strategies.

Europe as a global actor: directions for trade and sustainability policy

Three years ago, in 2016, the European Commission adopted a new global strategy, deeply rooted in the SDGs both at home and globally. One year later, **the European Consensus on Development emphasised the role of "policy coherence for sustainable development" (PCSD)** as the approach to be adopted by the Commission in development and cooperation. Since then, the EU has adopted several initiatives to promote sustainability in both trade and development aid. Among them, the EU's new partnership with the countries of Africa, the Caribbean and the Pacific is expected to focus on fulfilling the SDGs; and so will the new Africa-Europe Alliance for Sustainable Investment and Jobs, launched in September 2018 with the perspective of creating up to 10 million jobs in Africa over the next five years. Most recently, EU trade policy has also marked a move towards stronger use of conditionalities linked to SDGs, for example in the recent EU-Mercosur Free Trade Agreement.

Our report claims that the transfer of knowledge and technology to developing countries will play an essential role in bringing the world back to a sustainable path; and that such transfers should be designed in a systemic and balanced way, to create the ecosystem needed for real development, empower all actors along the value chain and realise more diffuse benefits for the economies involved. The consequences of this shift are far-reaching, and include both general action items such as the achievement of greater consistency and impact in development aid and cooperation; and more technology-specific actions to be undertaken in order to ensure that the gap between developed and developing countries results in a further polarisation and dispersion of wealth and well-being across the globe.

A new governance: towards a conglomerate, multi-level system for sustainable development aid and cooperation

The European Commission should increasingly work together with member states to ensure that EU and national funds all move in a coherent direction to promote sustainable development in all countries in which funds and resources are deployed. Together with the EU, strong national delegations from countries like Germany and France (let alone the UK DFID) are active on the ground, with a very wide reach, and often the overlap creates a duplication of resources and inconsistencies in the pursued strategies. Since 2015, the EU and its member states have increasingly taken an interlinked approach to development cooperation, but a lot has to be done in order to increase coherence and coordination of efforts in this domain. A recent Commission Communication, containing a first "Joint Synthesis report", reports that Joint Programming between the EU and member states is now a reality in 21 countries, and under preparation in another 36.[116] However, alignment between these efforts and the SDGs, as well as a systematic assessment of the effectiveness of development aid, can still be significantly improved.

Second, **the EU should ensure that its instruments for development aid are coherent and oriented towards the SDGs.** For example, Aid for Trade (which represents a third of EU Official Development Assistance) should seek to reduce inequality and "leave no one behind", including by empowering small-scale farmers; and the External Investment Plan should consistently aim to support in a systemic way those parts of the population that most need it, with a view to reducing inequality, nurturing human capital, tackling the gender gap, strengthening institutions and the rule of law, and ultimately creating the preconditions for sustainable development. In particular, SDG Watch recently observed that the EIP agriculture investment window still seems to reach mostly "the better off groups of farmers, primarily men", who are often advantaged because of greater technological availability and better access to resources. Discussions are underway on the improvement of the EIP especially in the context of support to African agriculture, where the Plan has reportedly achieved rather disappointing results in its first round of operations through a guarantee scheme called European Fund for Sustainable Development.[117]

The two problems outlined above are now under discussion in the context of the creation of a new EU 'Bank for Sustainable Development'. However, there are still many possible scenarios for the creation of the new Bank, which should emerge as a cooperation between the European Investment Bank, the European Bank for Reconstruction and Development and member states' cooperation institutions. A recent report by a group of "wise men", appointed by the European Commission, observed that "the present fragmentation of the system, especially between the EIB and the EBRD, is detrimental to the fulfilment of the EU's priority goals and the achievement of the desired development impact. This argues for the consolidation and streamlining of development finance and climate activities outside the EU into a single entity, a European Climate and Sustainable Development Bank, in order to avoid overlaps, and strengthen the EU's presence, role and long-term capacity to deliver on EU development priorities". This report considers three options for consolidation: turning the EBRD into a the new Bank by transferring the extra-EU activities of the EIB to the EBRD; creating a new mixed-ownership bank with the EIB, the EBRD, member states and the European Commission as shareholders; or tasking the EIB with creating a subsidiary for its extra-EU activities and participating in it as a minority shareholder alongside member states, the European Commission, and national development banks (NDBs). In addition, the group urged the adoption of further steps, such as the creation of a strong policy centre in the EU, the use of the proposed Neighbourhood, Development and International Cooperation financial instrument as a catalyst for improvement; and some concrete short-term actions to be adopted until a political decision is taken on the institutional restructuring.

Taking action in this domain by revamping the governance of development aid is urgent, not only for the achievement of SDGs at the global level, but also to re-establish the EU's actorness as a trailblazer of sustainable development in a global context in which no other superpower can take on such a role. However, a great dose of political courage and commitment are needed given the inevitable obstacles of merging or restructuring consolidated, giant bodies such as the EIB and the EBRD, and imposing more coordination between large institutions at the national level, with different competences and traditions.

Launch new orchestration schemes to speed up digitising agriculture for sustainable development in key areas

While the EU completes its internal governance restructuring, it is of utmost importance that **more consistency and coordination is achieved in the overall landscape of cooperation for sustainable development.** From an EU perspective, it would be essential to leverage the resources and skills available in public and private organisations by setting up mission-oriented 'orchestration schemes', coupled with adequate governance and accountability to achieve specific milestones and targets. Orchestration schemes, in the definition given by Abbott and Snidal (2009), imply a governance mechanism in which public actors, such as international organisations and governments, convince intermediary actors, such as transnational city networks, to align their goals and targets, and subsequently leverage actions by third (target) actors towards a desired goal. Examples include the Global Environmental Facility and the GAVI Alliance have shown that, if well governed, such initiatives can couple the political commitment and resources offered by public institutions with the funds, the on-the-ground ability and the superior managerial skills often offered by private organisations.

In the field of agriculture, public-private or purely trans-national private initiatives are already present, but often lack sufficient stability and momentum to live up to their potential. The Initiative for Adaptation of African Agriculture to Climate Change, launched at the UNFCCC COP22 in Marrakech in 2016 aims to place the adaptation of African agriculture at the heart of climate change decision-making, and to foster implementation of solutions, particularly within the framework of the Global Climate Action Agenda. However, it has failed to build on its momentum (Dzebo 2019). The Global Alliance for Climate-Smart Agriculture led by the FAO is being hampered by a lack of dedicated staff. On the private side, the NGO-led Sustainable Agriculture Network established a relatively successful certification system spanning over 42 countries including 101 different crops and 1.2 million, mostly smallholder, farms on 3.5 million hectares, but remains a stand-alone initiative with no ability to mobilise the resources required for transformational change.

The EU, especially if endowed with a 'Bank for Sustainable Development', would be in a privileged position as an orchestrator of mission-oriented initiatives in combination with public institutions (e.g. FAO) as well as private organisations and foundations in EU and non-EU countries, and NGO-led initiatives. In particular, these orchestration schemes could help achieve the systemic, holistic approach to digitising agriculture that we outlined earlier in this section with our 'decalogue', by leveraging the significant human and financial resources available to the EIB, also in IT deployment and applications, and coupling them with the EBRD's ability to work in the field.

Embedding digital technology and agro-ecology in the future development and cooperation policy of the European Union

One key problem in the shaping of the future EU policy for aid to sustainable development is the lack of emphasis on the sustainable use of digital technologies and on distributed governance arrangements. As we have discussed throughout this report, digital technology is essential, although not sufficient, to achieve sustainability in the agrifood chain: absent a substantial commitment on the side of international donors, the digital transformation can only exacerbate inequality between and within countries.

Aid in this context should thus set goals and targets in all the following areas:

- **Helping developing countries leapfrog in connectivity.** This implies the deployment of Low Power Wide Area Networks on the fields, and the availability of satellite images, which the EU already reportedly makes available to countries facing extreme weather events, for free, thanks to its Copernicus system. The Global Agriculture Sectoral Information System project aims to develop climate services in support of decision-making in these contexts,[118] and should be deployed on the ground in developing countries in cooperation with local authorities and researchers. And 5G penetration in rural areas, when technology will allow, should not face significant delays compared to developed countries: however, this requires deep cooperation on spectrum policy, as well as with local telecom operators in the modernisation of the infrastructure, the construction of antennas, the installation of the sensors.

- **Offering an integrated bundle of technological solutions for the whole value chain.** In interacting with developing countries, emphasis should be put primarily on the production process, where most of the food waste occurs. The EU should offer new technologies at accessible and affordable cost to developing countries as part of development cooperation or trade agreements and develop a bundle of services and technological applications to customise such solutions to the specific conditions of the recipient region, co-creating solutions with local producers and communities. Such solutions should be oriented towards all SDGs, and accordingly prioritise distributed and decentralised governance, especially through community-based management. There, as we already discussed, technology shows its maximum potential for achieving the SDGs, including their economic, social and environmental dimensions. IoT, drones, equipment 'as a service', blockchain/smart contracts and AI applications should be developed together, in a way that allows a seamless interoperability and a user-friendly interface, with a view to making communities self-sufficient within a given timeframe. Support services could also be introduced to ensure that communities or associations of farmers are adequately accompanied in accessing global value chains and have access to insurance and financial services.

- **Use conditionalities and tech-enabled reporting.** Technology can help also in the monitoring of compliance with contractual agreements for development aid. For example, Reinsberg (2018) argues that blockchain technologies, through guaranteed enforcement of smart contracts, can strengthen the credibility of state commitments (e.g. collective burden-sharing rules among a group of donors or recipient-country compliance with policy conditionality in return for aid), meaning orchestration schemes would be less affected by trust-related problems and transaction costs; and that through leveraging prediction markets, blockchain technologies can also alleviate information problems related to the verification of real-world events along the entire aid delivery chain, and pave the way for greater access to insurance and financial markets, especially from a community-based perspective.

- **Human capital and skills.** Aid for sustainable development should also prioritise, alongside environmental aspects, the reduction of inequality and of the gender gap, as well as the increase of human capital. Thereby, aid should be aligned with 'shared value' principles and be made conditional on the local absorption of technology and entrepreneurial skills. Dedicated training programmes for community managers and farmers should be made available, in a way that creates the right environment for community-based, tech-enabled, agro-ecology-oriented business models.

Championing digital technology 'for good'

On the digital side, the EU will also be called to blaze the trail on the use of new technologies for good. This is not easy, given that the world is currently dominated by a digital arms race between the two largest economic and political superpowers, the US and China. As a result, many resources that could have been allocated to the development of IoT, AI and blockchain solutions 'for good' end up being earmarked in public and private budgets for military or pure consumer applications.

One clear example of the role that the EU can play in advocating the development of digital technologies for SDGs is in Artificial Intelligence, where the EU has stated its ambition to lead the way towards "Trustworthy AI". The international debate in this field is progressing slowly, along at least two possible tracks: one possibility is the creation of a coalition of like-minded countries such as Canada, France, Japan and the EU bloc could start agreeing on principles of responsible, ethically-aligned AI, possibly translating them into legislation that introduces risk assessment and dedicated oversight institutions at the national level; the alternative is a broader agreement, including also the United States, and possibly modelled on the OECD Principles on Artificial Intelligence, adopted in May 2019 by all OECD members and also by Argentina, Brazil, Colombia, Costa Rica, Peru and Romania. These principles were also echoed in June 2019 by the G20 human-centred AI Principles.

The likelihood of a 'Global Partnership on AI' based on these principles is probably greater than in the case of a coalition that at least initially excludes the United States: however, this would come with consequences, as the agreement would probably be less substantial. The OECD principles, like most other ethical AI principles, lack the operationalisation and enforceability that the EU framework is increasingly featuring. Most importantly, the EU's influence on the global debate on AI will also depend on whether EU institutions will manage to reach a sufficient level of policy coherence on the domestic front, as we advocated throughout this report. This is a domain in which Europe could really attempt to fill a gap, and try to lead the rest of the world. Failure to recognise and publicly promote the role of AI and its related technologies for a more sustainable future society would represent an enormous missed opportunity for Europe and the world.

CHAPTER 4
Main findings

Policymakers should take a systemic view when crafting policies for sustainable agrifood. Possible ways include:

Taking action to require the internalisation of all negative externalities generated by the current agrifood chain as well as by the digital technology stack.

Departing from the simple measurement of economic efficiency, set the SDGs as the final outcome to be achieved by public policy, and adjust all policies accordingly.

Working on the distributional impacts of the emerging technological re-intermediation.

A stronger reliance on mission-oriented innovation and industrial policy.

A holistic 'policy mix' is needed for future food system policies

1. Ensuring adequate connectivity
2. Deploying the full technology stack
3. Promoting entrepreneurship, building capacity and facilitating technology transfer
4. Generating and sharing data for distributed, sustainable governance
5. Rebalancing the bargaining power of farmers, distributors and data managers
6. Attributing responsibility for negative externalities throughout the value chain
7. Providing incentives to shorten the supply chain
8. Public policies to enable reallocation of excesses and reduction of food loss and waste
9. An ethical and policy framework for AI and data management in B2C
10. Raising the skills and awareness of farmers and consumers

The EU can play a leading role, but it must first do its homework

The CAP should be reformed to embrace sustainability through technology. The distribution of funding should not leave the bulk of resources in the hands of larger players.

The EU must adopt a decentralised governance model in all EU agrifood-related policies and investment. The integration of new digital technologies in the current approach still seems to be limited, and the Commission should adopt guidance, ad hoc funding as well as non-financial support for the development of community-based solutions.

Europe as a global actor: trade and sustainability policy priorities

The European Commission should work with member states to ensure that development aid moves in a coherent direction. The future EU 'Bank for Sustainable Development' should lead to an overhaul of the governance of development aid, transforming the EU into an orchestrator of mission-oriented initiatives that implement the systemic approach we advocate in this report.

EU development aid should be based on actions such as (i) helping developing countries leapfrog in connectivity; (ii) offering an integrated bundle of technological solutions for the whole value chain; (iii) using conditionalities and tech-enabled reporting to establish trust in the value chain and in international aid; and (iv) prioritising the reduction of inequality and the gender gap, and the increase of human capital.

The EU should be a trailblazer in the use of digital technologies 'for good', for example in the case of Artificial Intelligence.

NOTES TO CHAPTER 4

[99] See Nathalie Gagliordi, "How self-driving tractors, AI, and precision agriculture will save us from the impending food crisis", Tech Republic, 12 December 2018, at https://www.techrepublic.com/article/how-self-driving-tractors-ai-and-precision-agriculture-will-save-us-from-the-impending-food-crisis/

[100] It is worth pointing out the difference between a 'hub' and an 'ecosystem': hubs refer to location-based activities and ecosystems refer to an environment, organized around enabling policies, financial resources, and intellectual capital, which does not necessarily depend on specific location or a specific actor in that location. In agriculture, hubs play a critical role in innovation because agriculture by definition is hyper-local or regional. Solutions that work in one location may be completely inappropriate somewhere else. As such, it is necessary for governments to strengthen the enabling environment that supports hubs to address specific regional attributes and challenges related to sustainability at a particular point in the agrifood chain.

[101] CTA operates under the Cotonou Agreement between the countries of the Africa, Caribbean and Pacific (ACP) group and the European Union and is financed by the EU.

[102] The FAO defines CSA as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals" (FAO, 2013).

[103] See "Agriculture at a Crossroads", the Global IAASTD report, at http://www.fao.org/fileadmin/templates/est/Investment/Agriculture_at_a_Crossroads_Global_Report_IAASTD.pdf

[104] See the commentary by Sohail Hasnie and Sungsup Ra, "How the gig economy can transform farms in the developing world", at https://www.eco-business.com/opinion/how-the-gig-economy-can-transform-farms-in-the-developing-world/.

[105] See http://openatk.com/ and https://www.fispace.eu/.

[106] See the Borgen Project, "Blockchain Technology for Rice Farmers in Cambodia". At https://borgenproject.org/tag/smart-contracts-for-farming/

[107] See FAO's report on "eAgriculture in Action", edited by Gerard Sylvester, at http://www.fao.org/3/CA2906EN/ca2906en.pdf

[108] See the European Commission's In-Depth Analysis in Support of The Commission Communication COM(2018) 773, "A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. At https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[109] Food and Agriculture Organization of the UN (FAO), Green jobs. Available at: http://www.fao.org/ruralemployment/work-areas/green-jobs

[110] According to the European Environment Agency (2015), biodiversity is still being eroded, but some local improvements have been observed. See also European Commission (2015), The mid-term review of the EU Biodiversity Strategy to 2020, COM(2015) 478 final.

[111] She also stated that Europe needs "to encourage innovation in terms of using less toxic and low-risk alternatives ... We need to provide this so that farmers do not use chemicals that are harmful to human health, and we know that they are".

[112] See European Commission, CAP Explained, Brief No. 3, at https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-specific-objectives-brief-3-farmer-position-in-value-chains_en.pdf

[113] According to the 2017 Europe's Digital Progress Report, 44% of the EU population and 37% of the workforce had "insufficient" digital skills in 2016. There is a lack of infrastructure, many rural areas lag behind in broadband availability, while 76 % of the EU population has access to fast broadband (>30Mbps), only 40 % of homes in rural areas have such access.

[114] The sustainability bonus could be proposed as an alternative option to the current greening measures. In relation to the sustainability bonus, developing PA standards focusing on transparency, sustainability and interoperability through the Centre Européen de Normalisation (CEN), the International Organization for Standardization (ISO) and the European Telecommunications Standards Institute (ETSI).

[115] See the LD Net article, "CAP Strategic Plans: Where is LEADER?", at https://ldnet.eu/cap-strategic-plans-where-is-leader/.

[116] See Report from the European Commission, "Supporting the Sustainable Development Goals across the world: The 2019 Joint Synthesis Report of the European Union and its Member States {SWD(2019) 176 final}, at https://ec.europa.eu/europeaid/sites/devco/files/com-2019-232-repor-from-commission-sdgs-jsr_en.pdf

[117] See Vince Chadwick, "Agriculture task force takes aim at EU investment plan for Africa", Devex, 15 February 2019, at https://www.devex.com/news/agriculture-task-force-takes-aim-at-eu-investment-plan-for-africa-94214

[118] The SIS envisage 4 types of data products: (i) Provision of raw climate data in easily accessible and usable formats for downstream further analysis and forcing of agricultural impact models, both gridded and location specific; (ii) Provision and visualisation of agriculturally relevant climate indicators and statistics, if needed tailored using crop-specific parameters (e.g. thermal requirements); (iii) Provision of merged Earth observation-climate data indicators of crop productivity, harvest indices and crop water use; (iv) Provision of agricultural water resource indicators, such as those for soil moisture, surface- and groundwater availability, river discharge and reservoir status.

CHAPTER 5
Summary of our main findings

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This report has explored the potential benefits of implementing a variety of digital technologies along the agrifood chain. The digital technologies considered range from the Internet of Things to wireless connectivity, Artificial Intelligence, Distributed Ledger Technologies and various types of network architecture, including edge/cloud models. Our findings are far-reaching, but also show that absent careful policy intervention, the outstanding potential of digitising agrifood may not materialise, or may only be reaped by a small fraction of the market and society. As a matter of fact, digital technology has already proven to present both opportunities and challenges: we claim that a comprehensive policy mix for food systems can at once maximise the benefits, and minimise the risks.

Below, we briefly summarise our findings and recommendations.

Fixing agrifood is essential, but not sufficient, to save the planet

Recent authoritative reports have confirmed that the agrifood chain is a major contributor to climate change. The global agrifood chain is estimated to contribute between 21% and 37% of total net anthropogenic GHGs and uses the overwhelming majority of water resources on Earth. Most importantly, excessive and unsustainable use of land resources is leading to growing imbalances: agrifood is indeed pushing the planet beyond its sustainable boundaries. The greatest environmental degradation occurs on the upstream side related to farming activity, while food waste is more closely related to the downstream activities of consumers.

Moreover, food consumption is impacting the climate in many ways. A third of the food produced in the world each year is lost or wasted: this wasted food is responsible for roughly 8% of global emissions. Importantly, there are more than 820 million people that have insufficient food, but many more consume a diet that is so unhealthy that it contributes to severe health complications and premature death.

Thereby, it is essential to act at all levels of the agrifood chain, and develop a systemic view of food systems.

Digital technologies are essential, but not sufficient, to fix agrifood

Precision agriculture methods achieve efficiency and conservation through the smart use of AI, sensors and IoT, cameras, robotics, blockchain, and data in targeting the use of inputs in crop management, livestock management, and water and soil management. Small farmers stand to benefit more from the digitalisation and 'datafication' of agriculture than the mobile revolution benefited trade in the last two decades. Connecting small farmers to markets, information and services through blockchain platforms helps resolve trust and traceability challenges.

Our case studies shed more light on the potential of digital technology in the upstream parts of the value chain. Ignitia, for example, is an AI-powered weather pattern analysis and prediction platform, which leverages Earth observation data to improve accuracy and enable better land management. WeFarm, a digital P2P network and a farmer-centric app, allows for exchange of advice between poor farmers in the global south via SMS. GAIA, a web app, automatically identifies, locates and monitors micro-level, high- value crops at continent-scale, using high resolution satellite images.

Likewise, digital technology can massively help contain food waste, which typically happens in the downstream in developed economies (due to consumers' poor planning and over-purchasing); and in the upstream in less developed countries (mostly due to poor infrastructure and lack of cold storage). Our case studies include Albert Heijn, a global food retailer trialling an AI-powered, dynamic digital price tag solution; Too Good To Go, a mobile app matching unconsumed supply with unmet demand between restaurants and food retailers using alerts to subscribers; and Winnow Solutions: a computer vision tool helping commercial kitchens identify where waste food occurs to prevent overproduction.

As regards food consumption, AI-powered apps can create personalised services in nutrition by incorporating user data, computer vision, DNA testing, health records and data from wearables in the management of food sensitivities, body weight, and disease. While the benefits are potentially significant, so are the risks to privacy and user self-determination. We explore the case of Nutrino, a nutrition insights platform, and creator of Foodprint, analysing a person's physical response to foods; and Think Digital - Farm VR, an augmented and virtual reality technology designed to increase agricultural literacy amongst consumers.

Digital Technology: reaping the benefits, minimising the risks

In Chapter 3 of the report we warn policymakers that digital technology can feature a variety of risks, in terms of economic, social and environmental sustainability. Technology can, if not adequately coupled with a smart policy framework, aggravate inequalities when it comes to connectivity, skills and capital; produce negative consequences for the environment and human health due to energy consumption and e-waste; lead to job loss and further tilt the power balance from labour to capital; reinforce capitalism's tendency towards market concentration; and open new ethical questions when it comes to privacy, bias and hyper-nudging consumers.

Knowing about these challenges enables all stakeholders to take informed decisions, where this tool is the most useful and where it is not. We therefore develop a comprehensive policy mix aimed at ensuring that the implementation of digital technologies does not create new divides both between countries, and within countries.

A holistic 'policy mix' is needed: a new decalogue for future agrifood policies

Ensuring adequate connectivity. In agriculture, it is important to ensure a wide coverage and low costs of deployment or maintenance, since most of the applications feature relatively low needs in terms of bandwidth and low latency. This makes technologies such as the legacy 2G network and low power network technologies particularly suited for most current deployment. However, more sophisticated use cases will require either to be able to function with intermittent connectivity, or to wait for the deployment of new generations of networks such as 5G.

Deploying the full technology stack. Once connectivity is in place, the whole stack has to be deployed. Recent studies have shown the potential of these technologies, but implementing them requires skills, connectivity and funding, which could come from public resources, given the extent of the positive externalities that this transition would generate. One possibility is to leverage the resources available in global funds such as the Least Developed Countries Fund, on which agreement was reached in September 2019, which will devote $160 million to help poorest countries prepare for climate change. Recent research found that investing $1.8 trillion globally in five areas from 2020 to 2030 could generate $7.1 trillion in total net benefits. The Global Commission on Adaptation recently observed that a more resilient food future must rely on sharp increases in agricultural R&D, which has demonstrated benefit-cost ratios between 2:1 and 17:1.

Promoting entrepreneurship, building capacity and facilitating technology transfer. The modern age of data-driven farming requires updated thinking around agricultural extension systems and practices. While many facets of these programmes – technology and best practices transfer, partnerships and knowledge sharing, training, market development – are still important, digital technology applied to agriculture and all its activities from farm to fork adds a new layer of complexity. In particular besides skills and data, supportive policies and programmes (e-government) for digital strategies are needed, along with data governance policies and standards, in order to keep data open and accessible to all stakeholders, especially farmers.

Generating and sharing data for distributed, sustainable governance. According to OnFarm (a connected farm IoT platform provider), the average farm will generate 4.1 Million data points by 2050. Using collected data to directly improve production practices could enable a 20% increase in income while reducing herbicide and fuel consumption by 10-20%. However, the key problem with data is that small-scale farmers are not yet well-equipped to make the best use of them, absent dedicated advisory services and third-party support. As already observed, the diffusion of data-driven agriculture may end up exacerbating the dependency of small-scale farmers on large corporations such as John Deere or Monsanto, who increasingly specialise in IoT, AI and data-driven agriculture by exploiting their outstanding resources. Accordingly, new solutions and dedicated services will be needed, possibly leading towards community-led data management, coupled with the provision of basic skills and the gradual hand-over of responsibility to the local community.

Rebalancing the bargaining power of farmers, distributors and data managers. Once connectivity, data and technology have been deployed, small-scale farmers must be connected to global value chains. There, they will normally find much larger players, and often end up in a situation of economic dependency, or weaker bargaining power. Here, governments may intervene to avoid that the superior bargaining power of both large distributors and data managers translates into unfair commercial practices and lack of profitability on the side of the smaller farmers. This requires the adoption of specific policy instruments, such as legislation on unfair trading practices in the retail sector, or rules on abuse of economic dependence. Digital technologies can help through the use of smart contracts.

Attributing responsibility for negative externalities throughout the value chain. While the agrifood chain produces massive negative externalities in terms of waste, emissions, health impacts and loss of biodiversity, the digitised agrifood chain may represent a cure that is worse than the disease, leading to greater energy consumption, e-waste and animal distress. Traditional ways to internalise externalities include the use of incentive schemes such as subsidies, taxation, or even the exclusion of certain technologies or production practices from public procurement. These policy approaches should be extended to reflect specific challenges of the digital age: for example, AI developers could be asked to declare the energy consumption costs related to the use of AI techniques such as deep learning, and the total environmental cost of using such techniques could then be included in the information available to end users.

Providing incentives to shorten the supply chain. Shorter supply chains can be more sustainable, as well as more geared towards adequate empowerment of both small-scale farmers and end users. Digital technologies can shorten the supply chain in many ways, and they already started doing it. Obvious examples are the platformisation of food supply, which connects more easily producers and end users by reducing search and delivery costs; but also blockchain deployment to improve food traceability, which in turn reduces the need for intermediaries

Public policies to enable reallocation of excesses. Policies can be divided in three large categories: prevention (reducing surplus at the source); recovery (reusing for human consumption); and recycling (feeding animals, creating energy or compost). Digital technologies such as blockchain and AI will lead to more predictive, accurate supply and distribution of food. Most importantly, the platform and "app" economy are already facilitating price discrimination for food close to expiry, segmenting the market, allowing for more participation of poorer consumers and thereby potentially tackling hunger and poverty.

An ethical and policy framework for AI and data management in B2C. Three aspects are most important in this domain. First, it is essential to require that personal data are not re-used for other purposes than that of providing advice or sold to third parties for commercial reasons such as advertising. Second, while personalised nutrition systems must discriminate to be useful to the end , they should not discriminate in a way that is commercially motivated, and clear rules have to be established to avoid that a specific online platform or application discriminates across equivalent products on the market, by recommending specific brands or nudging end users towards specific retailers. Finally, in the case of recommendation engines, it would be extremely important to include information on the sustainability of specific types of products, possibly even enticing users to engage in sustainable consumption practices through various forms of nudging (e.g. gamification, point-based systems, etc.).

Raising the skills and awareness of farmers and consumers. Numerous studies have confirmed a positive relationship between education and productivity in the agricultural sector. But in the case of digitised agrifood, the skills needed are quickly evolving.Technological skills should aim at training farmers to work with robots, work with processed data, choose appropriate solutions according to the farming project, gain an understanding of computer science, advanced machinery and complex apps. Environment skills include understanding legislation, gain expertise in circular agriculture; and gain knowledge of local ecosystems. In all of these domains, technology can come again to the rescue through the use of online courses and distance learning.

The EU can play a leading role, but it must first do its homework

The policy mix described above can usefully applied to the case of the European Union, where the debate is very lively especially due to the ongoing reform of the CAP, and also due to the recently announced "green new deal", which the new European Commission is expected to launch in the first half of 2020. **The EU is the only large bloc that has sufficient ability, resources and credibility to lead the great transformation in the agrifood sector that is needed to achieve sustainable development.** The European Commission has shown, at least in theory, strong commitment towards the SDGs, and promised to mainstream them in policies such as the European Semester, the EU Budget, the better regulation agenda, and the external action strategy. The von der Leyen Commission seems likely to lead to a **renewed commitment towards sustainability, in particular from an environmental perspective, thanks to the launch of a "European Green Deal",** as defined by the new President-elect in her political guidelines. Importantly, the new European Commission will work on a **coordinated a strategy for a healthier planet** by combining the actions of several commissioners. The commitments expressed so far are far-reaching, but still fall short of referring to the essential role of digital technologies. Meanwhile, in April 2019 a joint declaration between the European Commission and 25 member states was signed for the "digitalisation of European agriculture and rural areas", which may bring encouraging new developments for digitising agrifood.

Reforming the CAP to embrace sustainability

A key role in the reform of Europe's approach to the agrifood sector will inevitably be played by the ongoing reform of the CAP. The European Commission, in selecting the nine objectives of the CAP, made extensive reference to digital technologies. The proposed reform however seems to be still relatively vague in proposing new tools to boost technological adoption. Possible options to promote new technologies in the CAP include **granting a "sustainability bonus" to farmers** conditional on investment in precision agriculture technologies; and **creating a dedicated third pillar dedicated to environment and sustainable technologies.** Most importantly, the distribution of funding in the CAP should not leave the bulk of funding in the hands of larger players, as is currently the case. **Small-scale farmers are the ones that deserve more support** in order to lead the agrifood chain towards a more sustainable path.

Adopt a decentralised governance model in all EU agrifood-related policies and investment

The need for more balance along the value chain reverberates on the desirability of more distributed, decentralised approaches to governance. The current EU approach to the CAP and to rural development support does not go far enough in supporting the **creation of local organisations and the empowerment of these organisations with new skills and competences,** including in particular data management and sharing, but also entrepreneurship and the managerial and legal competences needed to make the most out of the new digital technologies in an ever-changing market context.

Furthermore, **the integration of new digital technologies in the current approach seems still to be limited,** and the Commission should adopt guidance, ad hoc funding as well as non-financial support for the development of community-based solutions. Furthermore, a **stronger integration of those solutions with the Sustainable Development Goals** should be achieved in the coming year, as the Commission finalises its Agenda 2030 as well as the Green New Deal and the From Farm to Fork strategies.

Europe as a global actor: directions for trade and sustainability policy

Three years ago, in 2016, the European Commission adopted a new global strategy, deeply rooted in the SDGs both at home and globally. One year later, **the European Consensus on Development emphasised the role of "policy coherence for sustainable development" (PCSD)** as the approach to be adopted by the Commission in development and cooperation. Today, this new orientation needs further promotion and political commitment.

A new governance: towards a conglomerate, multi-level system for sustainable development aid and cooperation

The European Commission should increasingly work together with member states to ensure that EU and national funds all move in a coherent direction to promote sustainable development in all countries in which funds and resources are deployed. Together with the EU, strong national delegations from member states are active on the ground, with a very wide reach, and often the overlap creates a duplication of resources and inconsistencies in the pursued strategies. Despite the adoption of a recent first "Joint Synthesis report", alignment between these efforts and the SDGs, as well as a systematic assessment of the effectiveness of development aid, can still be significantly improved.

Second, **the EU should ensure that its instruments for development aid are coherent and oriented towards the SDGs. For example, Aid for Trade** (which represents a third of EU Official Development Assistance) should seek to reduce inequality and "leave no one behind", including by empowering small-scale farmers; and the External Investment Plan should consistently aim to support in a systemic way those parts of the population that most need it, with a view to reducing inequality, nurture human capital, tackle the gender gap, strengthen institutions and the rule of law, and ultimately create the preconditions for sustainable development.

The creation of a new EU 'Bank for Sustainable Development' should be accompanied by an overhaul of the governance of development aid. This is urgent, not only for the achievement of SDGs at the global level, but also to re-establish EU's role as a trailblazer of sustainable development in a global context in which no other superpower can take on such role. However, a great dose of political courage and commitment are needed given the inevitable obstacles of merging or restructuring consolidated, giant bodies such as the EIB and the EBRD, and imposing more coordination between large institutions at the national level, with different competences and traditions.

Launch new orchestration schemes to speed up digitising agriculture for sustainable development in key areas

The EU, especially if endowed with a bank for Sustainable Development, would be **in a privileged position as an orchestrator of mission-oriented initiatives in combination with public institutions (e.g. FAO) as well as private organisations and foundations** in the EU and non-EU countries, and NGO-led initiatives. These orchestration schemes could help achieve the systemic, holistic approach we advocate in this report.

Embedding digital technology and agro-ecology in the future development and cooperation policy of the European Union

Digital technology is essential, although not sufficient, to achieve sustainability in the agrifood chain: and absent a substantial commitment on the side of international donors, the digital transformation can only exacerbate inequality between and within countries. Aid in this context should thus set goals and targets in all the following areas:

- Helping developing countries leapfrog in connectivity;
- Offering an integrated bundle of technological solutions for the whole value chain;
- Using conditionalities and tech-enabled reporting

to establish trust in the value chain and in international aid;

- Prioritise the reduction of inequality and of the gender gap, as well as the increase of human capital.

Championing digital technology 'for good'

The EU will be called to blaze the trail on the use of new technologies for good. One clear example is in Artificial intelligence, where the EU has stated its ambition to lead the way towards "Trustworthy AI". This is a domain in which Europe could really attempt to fill a gap, and try to lead the rest of the world. Failure to recognise and publicly promote the role of AI and its related technologies for a more sustainable future society would represent an enormous missed opportunity for Europe and the world.

REFERENCES

REFERENCES

- Abbott, K. W. and D. Snidal, (2009), "Strengthening international regulation through transmittal new governance: Overcoming the orchestration deficit", Vanderbilt Journal of Transnational Law, Vol. 42:501.

- Abbott, K. W., P. Genschel, D. Snidal and B. Zangl (eds.) (2015), International organizations as orchestrators, Cambridge: Cambridge University Press.

- Acemoglu, D. and D. Autor (2011), 'Skills, Tasks and Technologies: Implications for Employment and Earnings', in Handbook of Labor Economics, vol. 4, 1043–171, Elsevier.

- Acemoglu, Daron and Pascual Restrepo (2019), "Automation and New Tasks: How Technology Displaces and Reinstates Labor", Journal of Economic Perspectives, vol 33(2) (https://www.nber.org/papers/w25684).

- Adler, M. D. (2019), Measuring Social Welfare: An Introduction, Oxford University Press.

- Ajena, F. (2018), "Agriculture 3.0 or (Smart) Agroecology?", Green European Journal, (https://www.greeneuropeanjournal.eu/agriculture-3-0-or-smart-agroecology/).

- Alliance for IoT Innovation (2019), "IoT and digital technologies for monitoring of the new CAP", AIOTI WG06 – Smart Farming and Food Security, May, (https://aioti.eu/wp-content/uploads/2019/05/AIOTI-CAP-controls-and-ICT-technologies-May-2019.pdf).

- Alreshidi, E. (2019), "Smart Sustainable Agriculture (SSA) Solution Underpinned by Internet of Things (IoT) and Artificial Intelligence (AI)", International Journal of Advanced Computer Science and Applications, Vol. 10, No. 5 (https://arxiv.org/ftp/arxiv/papers/1906/1906.03106.pdf).

- American Farm Bureau Federation, "Privacy and Security Principles for Farm Data", accessed 11/11/19 (https://www.fb.org/issues/technology/data-privacy/privacy-and-security-principles-for-farm-data/).

- Arntz, M., T. Gregory and U. Zierahn (2016), "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis", OECD Social, Employment and Migration Working Paper 189, Paris: OECD Publishing.

- Ashford, N. and A. Renda (2016), "Aligning policies for low-carbon systemic innovation in Europe", Report for the European Climate Foundation's Institute for Industrial Innovation and Competitiveness (i24c), November.

- Atik, C. (2019), "Data Ownership and Data Portability in the Digital Agriculture Sector: A Proposal to Address A Novel Challenge", presentation (https://fsr.eui.eu/wp-content/uploads/Can-Atik-Presentation-EUI-Updated-Version.pdf).

- Balafoutis, A., B. Beck, S. Fountas, J. Vangeyte, T. van der Wal, I. Soto, M. Gómez-Barbero, A. Barnes, and V. Eory (2017), "Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation", Farm Productivity and Economics. Sustainability, 9. 1339. 10.3390/su9081339.

- Balsari, P., S. Böttinger, E. Cavallo, G. Gavioli, K. Hawken, Y. Kishida, P. Pickel, A. Savary, J. Schueller and M. Yang (2018), "Report of the Study Group 3, Ethics of the future agricultural mechanization development Group members/contributors", Club of Bologna.

- Barilla Center for Food and Nutrition and Economist Intelligence Unit - EIU (2018), Fixing Food 2018: Best practices towards the Sustainable Development Goals.

- Barilla Center for Food and Nutrition and Macrogeo (2017), Food and Migration. Undestanding the Geopolitical Nexus in the Euro-Mediterranean, BCFN 2017.

- Binswanger-Mkhize, P., C. Bourguignon and R. van den Brink (eds.) (2009), Agricultural Land Redistribution: Toward greater Consensus, The International Bank for Reconstruction and Development, The World Bank, Washington DC (http://documents.worldbank.org/curated/en/943811468153560954/pdf/488960PUB0REPLACEMENT0FILE09780821376270.pdf).

- Bonanno, A. and L. Busch (2015), Handbook of the International Political Economy of Agriculture and Food, Elgar.

- Brondizio, Eduardo S., Josef Settele, Sandra Díaz and Hien T. Ngo (eds) (2019), Global assessment report on biodiversity and ecosystem services, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, May, IPBES secretariat, Bonn, Germany (https://www.ipbes.net/global-assessment-report-biodiversity-ecosystem-services).

- Buttel F. H. (2003), Internalizing the societal costs of agricultural production, Plant physiology, 133(4), 1656–1665. doi:10.1104/pp.103.030312.

- Cafaggi, F. and A. Renda (2014), Measuring the Effectiveness of Transnational Private Regulation, (http://ssrn.com/abstract=2508684) or (http://dx.doi.org/10.2139/ssrn.2508684).

- Campbell, B. M., D. J. Beare, E. M. Bennett, J. M. Hall-Spencer, J. S. I. Ingram, F. Jaramillo, R. Ortiz, N. Ramankutty, J. A. Sayer, and D. Shindell (2017), "Agriculture production as a major driver of the Earth system exceeding planetary boundaries", Ecology and Society 22(4):8 (https://doi.org/10.5751/ES-09595-220408).

- Castaño Mirón, Javier, Maria Blanco and Pilar Martínez (2019), "Reviewing Counterfactual Analyses to Assess Impacts of EU Rural Development Programmes: What Lessons Can Be Learned from the 2007–2013 Ex-Post Evaluations?", Sustainability, 11, 1105, 10.3390/su11041105.

- Castro, Rosa J., and A. Renda (2019), Regulatory Oversight and Coordination: Selected National Experiences, Report for the OECD, forthcoming 2019.

- Center for Global Development (2013), "Time for FAO to Shift to a Higher Gear: A Report of the CGD Working Group on Food Security", Working Group on Food Security, Washington DC (https://www.cgdev.org/sites/default/files/FAO-text-Final.pdf).

- Chan, S. & Amling (2019), "Does orchestration in the Global Climate Action Agenda effectively prioritize and mobilize transnational climate adaptation action?", International Environmental Agreements: Politics, Law and Economics, October, Volume 19, Issue 4–5, pp 429–446 (https://doi.org/10.1007/s10784-019-09444-9).

- Chan, S., I. Boran, H. van Asselt, G. Iacobuta, N. Niles, K. Rietig et al. (2019), "Promises and risks of nonstate action in climate and sustainability governance", Wiley Interdisciplinary Reviews: Climate Change, 10(3), 572.

- Coase, R. H. (1937), "The Nature of the Firm", Economica, New Series, Vol. 4, No. 16 November, pp. 386-405.

- Craglia, M. (ed.) (2018), Artificial Intelligence: a European Perspective, European Commission, Joint Research Centre, doi:10.2760/11251.

- DotEcon Ltd and Axon Partners Group (2018), Study on Implications of 5G Deployment on Future Business Models, Body of European Regulators for European Communicators, No BEREC/2017/02/NP3, March (https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/8008-study-on-implications-of-5g-deployment-on-future-business-models).

- Dzebo, A. (2019), "Effective governance of transnational adaptation initiatives. International Environmental Agreements: Politics", Law and Economics (https://doi.org/10.1007/s10784-019-09445-8).

- EAT Foundation (2019), "Healthy Diets from Sustainable Food Systems: Food Planet Health", Summary Report of the EAT-Lancet Commission, Norway (https://eatforum.org/content/uploads/2019/01/EAT-Lancet_Commission_Summary_Report.pdf).

- Ehsan, Ahvar, Anne-Cécile Orgerie and Adrien Lebre (2019), "Estimating Energy Consumption of Cloud, Fog and Edge Computing Infrastructures", IEEE Transactions on Sustainable Computing, IEEE, pp.1-12 (ff10.1109/TSUSC.2019.2905900ff. ffhal-02083080f).

- EIP-AGRI Service Point (2015), "Participatory approaches for agricultural innovation", European Commission (https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_brochure_participatory_approaches_2015_en_web.pdf).

- Euractiv (2019), "The Environment in the CAP", Special Report, 11-19 July (https://en.euractiv.eu/wp-content/uploads/sites/2/special-report/EA-SPECIAL-REPORT-DGAGRI-EN-24072019.pdf).

- European Commission (2019), "High level expert group on Artificial intelligence", Draft Ethics Guidelines on Trustworthy AI (https://ec.europa.eu/digital-single-market/en/news/draft-ethics-guidelines-trustworthy-ai).

- European Commission (2019), "Reflection Paper Towards a Sustainable Europe by 2030", 30.1.2019 COM(2019) 22 final.

- European Economic and Social Committee (2019), "Study on exposing EU policy gaps to address the Sustainable Development Goals", Study by SDSN (https://www.eesc.europa.eu/sites/default/files/files/qe-02-19-009-en-n.pdf).

- European Parliament Research Service (2016), "Precision agriculture and the future of farming in Europe Scientific Foresight Study" (http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf).

- Eurostat (2015), "Farm structure survey 2013: While area used for agriculture remained stable, over 1 out of 4 farms disappeared between 2003 and 2013 in the EU, Almost a third of holding managers aged 65 or over", Eurostat Press Office (https://ec.europa.eu/eurostat/documents/2995521/7089766/5-26112015-AP-EN.pdf/e18e5577-c2a4-4c70-a8c7-fd758ea7b726).

- Food and Agriculture Organisation of the United Nations (2017), "Water for Sustainable Food and Agriculture", A report produced for the G20 Presidency of Germany (http://www.fao.org/3/a-i7959e.pdf).

- Food and Agriculture Organisation of the United Nations (2018), Transforming Food and Agriculture to Achieve the SDGs: 20 interconnected actions to guide decision-makers (http://www.fao.org/3/I9900EN/i9900en.pdf).

- Food and Agriculture Organisation of the United Nations (2019), Information and Communication Technology (ICT) in Agriculture, A Report to the G20 Agricultural Deputies (http://www.fao.org/3/a-i7961e.pdf).

- Frost and Sullivan (2019), "Growing Industry Applications of LPWAN Technologies", White Paper (https://rfdesignuk.com/uploads/9/4/6/0/94609530/murata_lpwan_study.pdf).
- Gagliordi, N. (2018), "How self-driving tractors, AI, and precision agriculture will save us from the impending food crisis", TechRepublic (https://www.techrepublic.com/article/how-self-driving-tractors-ai-and-precision-agriculture-will-save-us-from-the-impending-food-crisis/).
- Galli, F. and G. Brunori (eds) (2013), "Short Food Supply Chains as drivers of sustainable development. Evidence Document", Document developed in the framework of the FP7 project FOODLINKS (GA No. 265287). Laboratorio di studi rurali Sismondi, ISBN 978-88-90896-01-9.
- Ge, Lan, Christopher Brewster, Jacco Spek, Anton Smeenk and Jan Top (2017), Blockchain for Agriculture and Food; Findings from the pilot study, Wageningen, Wageningen Economic Research, Report 2017-112. 34 pp.; 4 fig.; 2 tab.; 18 ref.
- Global Commission on Adaptation, "Adapt Now: The Urgency of Action", Executive Summary (https://gca.org/global-commission-on-adaptation/report).
- Global Environment Facility (2019), "Governments commit to shared climate action through Least Developed Countries Fund" (https://www.thegef.org/news/governments-commit-shared-climate-action-through-least-developed-countries-fund).
- Gorli, R. (2017), "Future of Smart Farming with Internet of Things", Journal of Agriculture and Water Works Engineering, Vol. 1, Issue 1.
- Gregersen, C., J. Mackie, C. Torres (2016), "Implementation of the 2030 Agenda in the European Union: Constructing an EU approach to Policy Coherence for Sustainable Development", Discussion Paper 197, Maastricht: ECDPM.
- Hasnie, S. (2018), "How the gig economy can transform farms in the developing world", Eco-Business (https://www.eco-business.com/opinion/how-the-gig-economy-can-transform-farms-in-the-developing-world/).
- Herranz, L., Weiqing Min and Shuqiang Jiang (2018), "Food recognition and recipe analysis: integrating visual content, context and external knowledge", Cornell University arXiv:1801.07239v1 (https://arxiv.org/pdf/1801.07239.pdf).
- IFAD (2017), Remote sensing for index insurance Findings and lessons learned for smallholder agriculture (https://docs.wfp.org/api/documents/WFP-0000023503/download/).
- IHS Markit (2018), "The Internet of Things. A movement, not a Market", presentation (https://cdn.ihs.com/www/pdf/IoT_ebook.pdf).
- Inter-governmental Panel on Climate Change (2019), "Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems", August (https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf).
- Jackson, T. (2017), Prosperity without Growth, New York: Routledge.
- Kalff, D. and A. Renda (2019), Hidden Treasures. Mapping Europe's Sources of Competitiveness Advantage in Doing Business, CEPS Paperback, CEPS, Brussels.
- Kampelmann, S., W. Achten, T. Bauler, D. Petalios, S. Doeblin (2014), Review Report on Decentralised and Ecological Seeds and Farming in the EU (http://www.arc2020.eu/wp-content/uploads/2014/02/Ecological-Agriculture-Report-final-1.pdf).
- Karner, S. (2010), "Local Food Systems in Europe. Case studies from five countries and what they imply for policy and practice", IFZ Graz, (http://www.genewatch.org/uploads/f03c6d66a9b354535738483c1c3d49e4/FAAN_Booklet_PRINT.pdf).
- Klasson, M., C. Zhang, H. Kjellström (2019), "A Hierarchical Grocery Store Image Dataset with Visual and Semantic Labels", Cornell University arXiv (https://arxiv.org/abs/1901.00711).
- Klingebiel, S. and S. Paulo (2015), "Orchestration: An Instrument for Implementing the Sustainable Development Goals", German Development Institute Briefing Paper 14/2015, August.
- Kneafsey, M. and L. Venn, U. Schmutz, B. Bálint, L. Trenchard, T. Eyden-Wood, E. Bos, G. Foster and M. Blackett (2013), Short Food Supply Chains and Local Food Systems in the EU. A State of Play of their Socio-Economic Characteristics, Joint Research Centre Scientific and Policy Reports (https://publications.jrc.ec.europa.eu/repository/bitstream/JRC80420/final%20ipts%20jrc%2080420%20(online).pdf).
- Konnola, T., J. Leceta, A. Renda and F. Simonelli (2016), Unleashing Innovation and Entrepreneurship in Europe: People, Places and Policies, Report of a CEPS Task Force, CEPS, Brussels.
- Liakos, K. G., P. Busato, D. Moshou, S. Pearson and D. Bochtis (2018), Machine Learning in Agriculture: A Review, Sensors 2018, 18, 2674.
- Lianos, I. and D. Katalevsky (2018), "Merger Activity in the Factors of Production Segments of the Food Value Chain: A Critical Assessment of the Bayer/Monsanto merger", Centre for Law, Economics and Society (CLES), University College London (UCL), Policy Paper Series: 1/2017.
- Lips, M. (2017), "Length of Operational Life and Its Impact on Life-Cycle Costs of a Tractor in Switzerland", Agriculture 7. 68 (https://doi.org/10.3390/agriculture7080068).
- Malak-Rawlikowska, A. et al. (2019), "Augmented Reality in the Integrative Internet of Things (AR-IoT): Measuring the Economic, Environmental, and Social Sustainability of Short Food Supply Chains", Sustainability, Volume 11(15), p. 4004 (https://www.mdpi.com/2071-1050/11/15/4004#cite).
- Manikas, I. G. Malindretos, S. Moschuris (2019), "A Community-Based Agro-Food Hub Model for Sustainable Farming", Sustainability. 11. 1017. 10.3390/su11041017.

- Maru, A., D. Berne, J. de Beer, P. Ballantyne, V. Pesce, S. Kalyesubula, N. Fourie, Ch. Addison, A. Collett and J. Chaves (2018), "Digital and Data-Driven Agriculture: Harnessing the Power of Data for Smallholders", contribution paper towards the Collective Action on Farmers' Data Rights (https://hdl.handle.net/10568/92477).

- Mazzucato, M. (2018), The Value of Everything: Making and Taking in the Global Economy, Penguin.

- McKinsey Global Institute (2017), A future that works: Automation, employment and productivity.

- Mourad, Marie (2016), "Recycling, recovering and preventing "food waste": Competing solutions for food systems sustainability in the United States and France", Journal of Cleaner Production (126. 10.1016/j.jclepro.2016.03.084).

- Mousseau, F. (2019), "The highest bidder takes it all: The World Bank's new scheme to privatise land in the Global South", Bretton Woods Project, April (https://www.brettonwoodsproject.org/2019/04/the-highest-bidder-takes-it-all-the-world-banks-new-scheme-to-privatise-land-in-the-global-south/).

- Nakamoto, S. (2008), "Bitcoin: A peer-to-peer electronic cash system", (https://bitcoin.org/bitcoin.pdf).

- Nirenjena, S., B.D. Lubin, M. Monisha (2018), "Advancement in Monitoring the Food Supply Chain Management Using IoT", International Journal of Pure and Applied Mathematics, Vol. 119 No. 14 2018, 1193-1197 (https://acadpubl.eu/hub/2018-119-14/articles/2/154.pdf).

- Oughton, E. J. and Z. Frias (2018), "The cost, coverage and rollout implications of 5G infrastructure in Britain", Telecommunications Policy, Elsevier, Vol. 42(8), pp. 636-652.

- Pastor, A., P. Kabat, A. Palazzo, H. Biemans, F. Ludwig, Y. Wada, M. Obersteiner, P. Havlík and N. Shirakawa (2019), "The global nexus of food–trade–water sustaining environmental flows by 2050", Nature, 10.1038/s41893-019-0287-1.

- Phupattanasilp, P. and S. Tong (2019), "Augmented Reality in the Integrative Internet of Things (AR-IoT): Application for Precision Farming", Sustainability, Volume 11, p. 2658. (https://www.researchgate.net/publication/332993074_Augmented_Reality_in_the_Integrative_Internet_of_Things_AR-IoT_Application_for_Precision_Farming).

- Plume, K. (2017), "Monsanto scraps deal to sell Precision Planting to Deere", Reuters, accessed 11/11/19 (https://www.reuters.com/article/us-monsanto-m-a-deere/monsanto-scraps-deal-to-sell-precision-planting-to-deere-idUSKBN17X2FZ).

- Poppe, K., S. Wolfert, C. Verdouw and A. Renwick (2015), "A European Perspective on the Economics of Big Data", Farm Policy Journal, Vol. 12 No. 1, Autumn Quarter.

- Purdy, M. and P. Dougherty (2017), "Why Artificial Intelligence is the Future of Growth", Accenture/Frontier Economics Report (https://www.accenture.com/t20170927T080049Z__w__/usen/_acnmedia/PDF-33/Accenture-Why-AI-is-the-Future-of-Growth.PDFla=en).

- PWC (2017), "Sizing the Prize. What's the real value of AI for your business and how can you capitalise?", PWC Analysis (https://www.pwc.com/gx/en/issues/analytics/assets/pwc-ai-analysis-sizing-the-prize-report.pdf).

- PWC (2018), The Macroeconomic Impact of Artificial Intelligence, February (https://www.pwc.co.uk/economic-services/assets/macroeconomic-impact-of-ai-technical-report-feb-18.pdf).

- Rapsomanikis, G. (2015), "The economic lives of smallholder farmers: An analysis based on household data from nine countries", Food and Agriculture Organization of the United Nations, Rome (http://www.fao.org/3/a-i5251e.pdf).

- Rawe T, M. Antonelli, A. Chatrchyan, T. Clayton, J. Fanzo, J. Gonsalves, A. Matthews, D. Nierenberg and M. Zurek (2019), "Transforming food systems under climate change: Local to global policy as a catalyst for change", CCAFS Working Paper no. 271, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, the Netherlands (www.ccafs.cgiar.org).

- Reinsberg, B. (2019), "Blockchain technology and the governance of foreign aid", Journal of Institutional Economics, 15(3), pp. 413-429. (doi:10.1017/S1744137418000462).

- Renda, A. (2011), "Law and Economics in the RIA world", Intersentia Series, European Law and Economics, July.

- Renda, A. (2016), Regulation and R&I policies. Comparing approaches in Europe and the US, Special Report for the European Commission, Directorate-General for Research and Innovation, doi 10.2777/675733.

- Renda, A. (2017), "How can Sustainable Development Goals be 'mainstreamed' in the EU's Better Regulation Agenda?", CEPS Policy Insights No 2017/12, March.

- Renda, A. (2018), "Cost-benefit analysis – Limits and Opportunities", in Garben, S. and I. Govaere (eds) (2018), The EU Better Regulation Agenda: Critical Reflections on the Past, Present and Future, Hart Publishing.

- Renda, A. (2018), "The Trolley Problem and Self-Driving Cars: A Crime-Scene Investigation into the Ethics of Algorithms", CEPS Policy Insight, No. 2, CEPS, January and College of Europe Working Paper, Economics Department.

- Renda, A. (2019), "Europe's struggle to set global AI standards", in Dubber, M., F. Pasquale and S. Das, Oxford Handbook of Ethics of Artificial Intelligence, forthcoming.

- Renda, A. (2019), "Moral machines: the EU agenda for human-compatible AI", in Barfield, W. (ed), Cambridge Handbook on Artificial Intelligence, forthcoming.

- Renda, A. (2019), "Regulation and International Regulatory Cooperation: Selected Challenges posed by the Digital Transformation", OECD Report, OECD.

- Renda, A. (2019), "The Age of Foodtech: Optimizing the Agri-Food Chain with Digital Technologies", in Valentini, R., J. Sievenpiper, M. Antonelli and K. Dembska (eds.), Achieving SDGs through Sustainable Food Systems, Springer publishing.

- Renda, A. (2019), "Up, down, and sideways: the endless quest for EU's optimal multi-level governance", in Brousseau, E., J. M. Glachant and J. Sgard (eds.), Oxford Handbook of International Economic Governance and Market Regulation, Oxford University Press.

- Renda, A. (2019), Artificial Intelligence: Ethics, Governance and Policy Challenges, CEPS Task Force Report, CEPS, Brussels, February.

- Rockström, J., W. Steffen, K. Noone, Å. Persson et.al. (2009), "A safe operating space for humanity", Nature, 461: 472-475 DOI 10.1038/461472a.

- Rockström, J., W. Steffen, K. Noone, Å. Persson et.al. (2009), "Planetary boundaries: exploring the safe operating space for humanity", Ecology and Society 14(2): 32.

- Rolnick, David, Priya L. Donti, Lynn H. Kaack, Kelly Kochanski, Alexandre Lacoste, Kris Sankaran, Andrew Slavin Ross, Nikola Milojevic-Dupont, Natasha Jaques, Anna Waldman-Brown, Alexandra Luccioni, Tegan Maharaj, Evan D. Sherwin, S. Karthik Mukkavilli, Konrad P. Kording, Carla Gomes, Andrew Y. Ng, Demis Hassabis, John C. Platt, Felix Creutzig, Jennifer Chayes, Yoshua Bengio (2019), Tackling Climate Change with Machine Learning, Cornell University arXiv:1906.05433, November.

- Rotz, S., E. Gravely, I. Mosby, E. Duncan, E. Finnis, M. Horgan, J. LeBlanc, R. Martin, H. Neufeld, L. Pant, V. Shalla and E. Fraser (2019), "Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities", Journal of Rural Studies, 10.1016/j.jrurstud.2019.01.023.

- Ryan, M. (2019), "Ethics of Using AI and Big Data in Agriculture: The Case of a Large Agriculture Multinational", ORBIT Journal, 2 (2) (https://doi.org/10.29297/orbit.v2i2.109).

- Sanderson, J., L. Wiseman, S. Poncini (2018), "What's Behind the Ag-Data Logo? An Examination of Voluntary Agricultural Data Codes of Practice", International Journal of Rural Law and Policy (https://doi.org/10.5130/ijrlp.1.2018.6043).

- Sarig Y., L. Clarke, I. De Alencar Nääs, R. Hegg, A. Munack and G. Singh (2001), "Code of ethics for the agricultural machinery - manufacturing sector", Club of Bologna.

- Schimmelpfennig, D. (2018), "Crop Production Costs, Profits, and Ecosystem Stewardship with Precision Agriculture", Journal of Agricultural and Applied Economics, 50(1), 81-103 (doi:10.1017/aae.2017.23).

- Servillo, L. and M. Bruijn (2018), "From LEADER to CLLD From LEADER to CLLD: The Adoption of the New Fund Opportunities and of Their Local Development Options", European Structural and Investment Funds Journal, Volume 6 (2018), Issue 3, pp. 223 – 233.

- Shacklett, M. (2018), "IoT Gains a Foothold in Food Supply Chains" (https://www.foodlogistics.com/technology/article/20993391/iot-gains-a-foothold-in-food-supply-chains).

- Shi, X.; An, X.; Zhao, Q.; Liu, H.; Xia, L.; Sun, X; Guo, Y. (2019), "State-of-the-Art Internet of Things in Protected Agriculture", Sensors 19(8), 1833 (https://www.mdpi.com/1424-8220/19/8/1833/htm).

- Simon, L. (2018), "Spanish producers go digital to shorten food supply chains", Euractiv, (https://www.euractiv.com/section/agriculture-food/news/spanish-producers-go-digital-to-shorten-food-supply-chains/).

- Simonite, T. (2019), "The Best Algorithms Struggle to Recognize Black Faces Equally", Wired, accessed 11/11/19 (https://www.wired.com/story/best-algorithms-struggle-recognize-black-faces-equally/).

- Smith, A. (2018), "Mobile Connectivity Index 2018: Analysing the state of mobile internet connectivity across the world", GSMA, accessed 11/11/2019. (https://www.gsma.com/mobilefordevelopment/programme/connected-society/mobile-connectivity-index-2018-analysing-the-state-of-mobile-internet-connectivity-across-the-world/).

- Steffen, W., K. Richardson, J. Rockström, S.E. Cornell et.al. (2015), "Planetary boundaries: Guiding human development on a changing planet", Science 347: 736, 1259855.

- Sterner, T., E.B. Barbier, I. Bateman et al. (2019), "Policy design for the Anthropocene", Nature Sustainability 2, 14–21 doi:10.1038/s41893-018-0194-x.

- Strubell, E., A. Ganesh and A. MacCallum (2019), "Energy and Policy Considerations for Deep Learning in NLP", Cornell University arXiv 3645-3650. 10.18653/v1/P19-1355.

- Sunstein, C.R. and R.H. Thaler (2009), Nudge. Improving Decisions about Health, Wealth, and Happiness, Penguin Books.

- Sustainable Development Solutions Network and Bertelsmann (2019), Sustainable Development Report 2019.

- Tanasă, L., V. Dinu, B. Codrin; S. Ioan, S. Doboș (2016), "Short food supply chains as a meachanism for sustainable development", in Agrarian Economy and Rural Development - Realities and Perspectives for Romania, 7th Edition of the International Symposium, The Research Institute for Agricultural Economy and Rural Development (ICEADR), Bucharest, pp. 316-324.

- Tatge, J. (2016), "The land grab for farm data", TechCrunch, (https://techcrunch.com/2016/07/06/the-land-grab-for-farm-data/).

- Thomas, T., C. Gunden and B. Legesse (2019), "Accounting for the Impact of Sustainable Agriculture: The Role of Community Based Organization and Local Governance Structures in Promoting Sustainable Agriculture", IntechOpen, DOI: 10.5772/intechopen.84385.

- Todorovic, V., M. Maslaric, S. Bojic, M. Jokic, D. Mircetic and S. Nikolicic (2018), "Solutions for More Sustainable Distribution in the Short Food Supply Chains", Sustainability, 10, 3481.

- University of Oxford (2018), "New estimates of the environmental cost of food" (http://www.ox.ac.uk/news/2018-06-01-new-estimates-environmental-cost-food).

- Usubiaga-Liaño, A., G. Mace and P. Ekins (2019), "Limits to agricultural land for retaining acceptable levels of local biodiversity", Nature Sustainability, 2. pp. 491-498. 10.1038/s41893-019-0300-8.
- Verdouw, C. N., S. Wolfert and B. Tekinerdogan (2016), "Internet of Things in Agriculture" (https://www.researchgate.net/publication/312164156_Internet_of_Things_in_agriculture).
- Verma, M., R. Hontecillas, N. Tubau-Juni, V. Abedi and J. Bassaganya-Riera (2018), "Challenges in Personalized Nutrition and Health", Frontiers in Nutrition, 5: 117.
- Wang, X. (2017), "Business Model of Sharing Economy in Agriculture" AgriGoods Herald, September (http://paper.nzdb.com.cn).
- WEF (2018), "Harnessing Artificial Intelligence for the Earth" (http://www3.weforum.org/docs/Harnessing_Artificial_Intelligence_for_the_Earth_report_2018.pdf).
- Wezel, A., S. Bellon, T. Doré, C. Francis, D. Vallod and C. David (2009), "Agroecology as a Science, a Movement and a Practice. A review", Agronomy for Sustainable Development, 29: 503–515.
- Willett W., Johan Rockström, Brent Loken, Marco Springmann, Tim Lang, Sonja Vermeulen, et al. (2019), "Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems", EAT-Lancet Commission, CJL Lancet, February 2; 393(10170):447-492.
- Williamson, O. E. (1985), The Economic Institutions of Capitalism (New York: The Free Press).
- Williamson, O. E. (1999), "Public and Private Bureaucracies: A Transaction Cost Economics Perspective", Journal of Law, Economics, & Organization, Vol. 15, No. 1, JLEO Bureaucracy Conference, April, pp. 306-342.
- Williamson, O.E. (1979), "Transaction-Cost Economics: The Governance of Contractual Relations", The Journal of Law & Economics, Vol. 22, No. 2, October, pp. 233-261.
- Wiseman, L., J. Sanderson, A. Zhang and E. Jakku (2019), "Farmers and their data: An examination of farmers' reluctance to share their data through the lens of the laws impacting smart farming", Wageningen Journal of Life Sciences, in Press, Corrected Proof, May.
- Wolfert, S., L. Ge, C. Verdouw, M.J. Bogaardt (2017), "Big data in smart farming - a review", Agricultural Systems, 153, pp. 69-80.
- World Bank (2016), "Digital Government 2020: Prospects for Russia", (http://pubdocs.worldbank.org/en/840921460040867072/Digital-Government-Russia-2020-ENG.pdf).
- Wright, H., S. Vermeulen, G. Laganda, M. Olupot, E. Ampaire and M.L. Jat (2014), "Farmers, food and climate change: ensuring community-based adaptation is mainstreamed into agricultural programmes", Climate and Development, 6:4, 318-328, DOI: 10.1080/17565529.2014.965654.
- Yang, H.; S. Kumara, S. Bukkapatnam, F. Tsung (2019), "The Internet of Things for Smart Manufacturing: A Review", IIE Transactions (https://www.researchgate.net/publication/330408457).
- Yiannas, F. (2018), "A New Era of Food transparency Powered by Blockchain", Innovations, Vol. 12, number ½, MIT Press (https://www.mitpressjournals.org/doi/pdf/10.1162/inov_a_00266).
- Zhang, L., I. Dabipi, W. Brown Jr. (2018), "Internet of Things Applications for Agriculture", The Institute of Electrical and Electronics Engineers Inc., John Wiley & Sons, Inc. (http://iranarze.ir/wp-content/uploads/2018/10/E9758-IranArze.pdf).

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