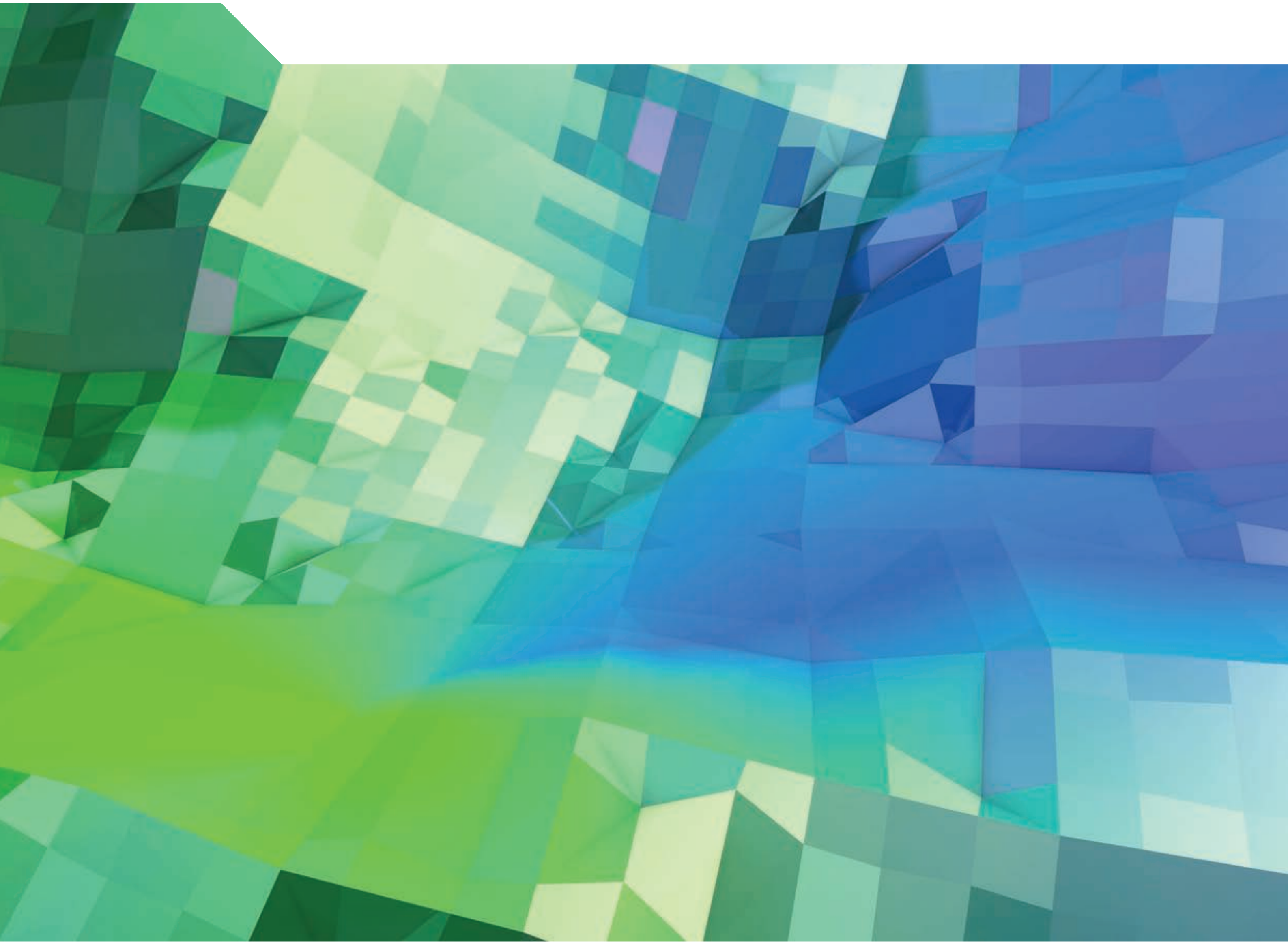
Digital Opportunities for Better Agricultural Policies



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Digital Opportunities for Better Agricultural Policies

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BETTER POLICIES FOR BETTER LIVES

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Foreword

This report considers how digital technologies can be used to support agricultural policies within different stages of the policy cycle, with a particular focus on policies to improve agricultural sustainability.

Analysis in this report draws on the relevant literature, expert interviews, the ten in-depth illustrative case studies (Part IV) and the results of a detailed questionnaire sent to OECD members on the use of digital technologies by agencies responsible for designing, implementing and monitoring agri-environmental policies (Annexes A and B).

Chapter 1 provides an overview of the report's findings and policy recommendations.

Part I (Chapter 2) describes recent advances in digital technologies which are the focus of this report, and discusses the drivers of digitalisation in the agriculture sector.

Part II (Chapters 3 and 4) provides an overview of the opportunities of new technologies for better decision-making, policy design and monitoring. It provides a conceptual framework for analysing how digital technologies create opportunities for better agricultural policies. Using the example of agri-environmental policies as a subset of agricultural policies more generally, Chapter 3 then discusses the potential for digital technologies to improve policies within all components of the "policy cycle", and how technologies can enable new policy approaches which were previously unfeasible. Chapter 4 discusses the challenges to successful uptake of technologies by policy-makers and programme administrators and provides practical guidance in addressing them.

With a view to ensuring that the use of digital technologies to support policies is well-integrated with the use of these technologies in the broader agriculture and food context, Part III (Chapter 5) provides a high-level overview of the benefits of digital technologies for agriculture and considers the governance and regulatory environment needed to enable the use of data and digital technologies, for policy-making but also for other purposes, while addressing risks. Chapter 5 briefly discusses several issues related to digitalisation of the agriculture sector which are relevant beyond the sphere of using digital tools to improve policy. The OECD is pursuing further work on some of these matters, in particular, on regulatory aspects relating to data governance in agriculture.

Part IV brings together ten case studies developed as background for the rest of the report. Their purpose is illustrative rather than comparative. The case studies focus on different types of digital technologies, and how they are used or managed by public authorities, sometimes in co-operation with the research and private sectors. Together they highlight the diversity of use of technologies for policymaking and implementation, as well as illustrating potential roles for governments in the development of a data infrastructure. The case studies were taken from six countries and regions: Australia (2), the European Union (1) Estonia (1), the Netherlands (2), New-Zealand (1), and the United-States (3). The country and region coverage was not intended to be comprehensive across all OECD countries; the overall selection was based on judgement by the OECD Secretariat and guided by the objective to include a diverse range of relevant examples. The intent is not to provide a systemic review of public bodies' initiatives in relation to the use of digital technologies for the design and implementation of agri-environmental policies; this more systematic view was obtained via the use of a Questionnaire designed for this (Annex A). For comparative results, please consult the questionnaire analysis.

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Executive Summary

In 2016, OECD Agriculture Ministers issued a Declaration on Better Policies to Achieve a Productive, Sustainable and Resilient Global Food System, which placed "a high priority on developing policies to underpin competitive, sustainable, productive and resilient farm and food businesses" (OECD, 2016[1]). Recent and ongoing developments in digital technologies can help deliver such "better policies". *Advances in data collection technologies*, particularly *in situ* and remote sensors, have markedly increased the spatial and temporal data resolution of agricultural data, and reduced the cost of gathering such information. *Adoption of precision agriculture machinery* in the agriculture sector provides a new source of data that is relevant for policy. *Advances in data processing, "artificial intelligence" and computing power* allow vast amounts of data from many and varied sources to be analysed and deliver new insight relevant for policy makers and administrators, as well as for producers and other actors in agriculture and food. *Advances in encryption and data protection technologies, together with advances in institutions for data sharing*, offer the opportunity to broaden access and reduce the transaction costs of accessing agricultural micro data while preserving confidentiality where necessary. These developments provide opportunities to improve policies by helping to overcome information gaps and asymmetries, lowering policy-related transaction costs and enabling people with different preferences and incentives to work better together.

Evidence from an OECD questionnaire highlights that policy administrators are already using digital technologies and data to improve the way they deliver agri-environmental policies. Use of some technologies and related data is developing faster than others, albeit often on an *ad hoc* basis even within government organisations. Currently, the digital technologies and data sources most commonly used by policy administrators are data from remote-sensing, GIS-based analytical tools, and digital communications tools. Almost all organisations responding to the questionnaire considered that digital technologies could provide benefits in terms of improving communications with other government organisations and with farmers, facilitating new programmes and services, and decreasing organisational costs. Further, only a minority of organisations considered that understanding the benefits, or communicating these benefits to stakeholders, were a challenge hampering the use of digital technologies or "Big Data" for policy purposes.

Yet, further opportunities are evident. Administrators can make use of digital technologies to improve current policies or enable new ones, for example policies that are more results-based or less compliance-driven. In particular, the paper identifies three key opportunities. First, governments have the opportunity to design and implement more "data-driven" policies and to evaluate policy performance more robustly. Second, governments can use digital technologies to re-think monitoring and compliance, reducing compliance burden for producers and public costs of administering monitoring and compliance programmes. Digital technologies can also enable new approaches which reward (financially or reputationally) going "beyond compliance", rather than relying on heavy penalties to incentivise compliance. Finally, governments can make use of algorithms to improve administrative functions, reducing costs, freeing up staff time and reducing the likelihood of human error. Algorithms can also enable governments and researchers to undertake more complex and detailed analyses, to help produce new knowledge, faster.

However, available evidence shows that institutional and regulatory constraints can hamper the use of digital technologies by policy administrators in some cases. Perceived practical challenges include a lack of financial resources, and the substantial change to current workflows, policies or programmes that would be required to make more use of digital technologies and 'Big Data'. Privacy or confidentiality regulations can also be a constraint in some cases. A lack of standardisation and differing regulatory regimes obstructs efforts to achieve representativeness or comparability in policy-relevant indicators.

Beyond existing constraints, there are a number of new issues that need to be addressed. Governments need to address the challenge of how to integrate data of varying quality, temporal and spatial scales, and sensitivity to produce useful knowledge. Governments can do more to encourage good data management practices and ensure sensor technologies are validated and calibrated for use in policy or regulatory contexts. Devolution of decision-making to computers within the policy cycle also raises several important questions about transparency, oversight and responsibility. An important issue is the need to be explicit about the limitations of data, models and algorithms, which is becoming ever more prominent as governments and industry increase their reliance upon them. Finally, adoption of new digital tools to deliver better policies risks creation of new information asymmetries or a "digital divide" between those who can access or use digital tools and those who cannot. Potential pitfalls await if these questions are not addressed satisfactorily.

More broadly, the capacity to make use of digital technologies in agriculture depends on more than access to basic connectivity infrastructure (broadband, telecommunication services, etc.). It also depends on development of a range of data collection and analysis services and on the regulatory environment (which encompasses interoperability rules, data quality standards, norms or regulations on data ownership and data privacy, skills, shared modelling frameworks, digital platforms, cloud-based storage and processing, etc.). These elements collectively shape the creation of effective systems of digitalisation in agriculture, and together provide an enabling *data infrastructure*.

Governments can play an active role in building data infrastructures for agriculture. In doing so, it is important that all uses of digital technologies, including for better agricultural and agri-environmental policies, are part of a coherent approach to digitalisation of the sector as a whole.

More specifically, governments can first make *existing data relevant to agriculture more available to other actors* to enable the development of new services supporting decision-making both by governments and farmers. Governments can also take an "online first" approach to delivery of government services and interactions with producers. This can reduce administrative costs for both governments and producers, and enable new kinds of services. Second, governments might have a role in *supporting connectivity and the development of a data collection infrastructure* (sensors network, remote sensing, etc.), including by directly investing in data collection technologies where there is a public good or public interest rationale to do so.

Chapter 1.

Overview of findings and recommendations

This overview draws together the findings from this report and provides recommendations for policy makers and agri-environmental programme administrators, both about how they can make use of digital technologies to improve policies, and how policies can appropriately support uptake of digital technologies in agriculture. Further, some recommendations are relevant for governments more broadly, as they touch on issues such as innovation and competition.

1.1. How can governments best use digital technologies to improve agri-environmental policies?

Digital technologies can help achieve policy goals by reducing the problems caused by information gaps, information asymmetries, and incentive misalignments, all of which can contribute to increased transaction costs and limit the feasible set of policy options. Opportunities to address these problems by using digital tools exist along the "policy cycle". The conceptual framework in this report can be used to identify where potential exists to make (increased) use of digital technologies to improve agri-environmental policies throughout the cycle.

Adoption of digital technologies by agri-environmental policy makers offers substantial opportunities to reassess and redesign existing policies. Recent technological developments have dramatically improved the cost-effectiveness of both in situ and remote sensors and changed the calculus of which policy type within the broad spectrum of policy options are the most effective and efficient. Increased spatial and temporal data resolution is allowing governments to act on their commitments to adopt "data-driven policy", in particular by enabling:

- policy makers to better understand environmental impacts of agriculture and formulate policy objectives which more holistically capture these impacts;
- design of highly differentiated and targeted policies;
- new data-driven monitoring and compliance systems; and
- improved ability to measure risk and manage uncertainty.

Further, new technological solutions to preserve privacy while increasing access to data can allow governments to become more open and to increase the availability of data for policy-relevant research, policy-making, implementation, monitoring and compliance, and evaluation. A combination of digital technologies can be used to underpin more inclusive policies promoting sustainable, productive agriculture.

However, digital technologies are not a panacea; they are a means to an end, and can create new challenges. The potential for these challenges to occur should be considered both up front, so that policy design can take them into account and mitigate them where possible, and during policy implementation, so that challenges can be addressed as they arise and digital tools can be refined. Key recommendations under thematic headings are below.

1.1.1. Making use of digital technologies in policy design and implementation

Digital tools can enable new information-rich policy approaches (see, for example, Case Study 1). Governments have the opportunity to reassess and potentially revise existing standards and regulations to ensure latest technologies can be included. Specific recommendations are:

- Governments should review environmental standards relevant for agriculture which refer to average concentrations or emissions over a particular period of time, to allow for point-in-time data and continuous monitoring as a supplement to or replacement for average parameters. Policies which address farming practices, often based on some form of technology standards, may be able to be reformed to use performance standards.

- Governments can potentially revise existing administrative service standards (e.g. commitments to process programme applications within a certain timeframe) in light of the ability to adopt time-saving and cost-reducing technologies (e.g. greater automation of administrative procedures, use of online platforms and e-services for payments)

High resolution earth observation data, as well as and improved data on a wide range of agricultural and environmental variables, paves the way for more nuanced, targeted agri-environmental policies, even over large spatial scales. However, knowledge gaps remain (and likely always will to some degree), and a combination of tools may be necessary. There is also still an ongoing need to improve scientific understanding of complex physical processes. In addition, economic considerations (e.g. costs and benefits of investments to improve understanding) also need to be taken into account. Specific recommendations for using digital technologies to implement more targeted policies are:

- Policy decisions still should be made based on a holistic consideration of benefits and costs, not simply on the basis that a policy option has, with digital technologies, now become technically feasible.
- Governments considering implementing spatially-targeted and result-based programmes should consider using digital tools, recognising that there is a role for both digital data collection (sensor technologies) to measure results directly and for digital analytical tools (particularly agri-environmental models).
- Pilots for testing targeted and results-based programmes should explicitly aim to evaluate the cost-effectiveness of using digital tools (including the data that digital tools generate).

Adoption of new digital tools for policy risks creation of a “digital divide” between those who can access or use the tool and those who cannot. Also, the production of new knowledge available to certain parties (e.g. service providers) but not to others (e.g. service users) can inadvertently create new information asymmetries. Adoption and design of policy tools should recognise these risks and mitigate them by taking the position that digital policy tools and related data should in principle be as open as possible, with restrictions on access being clearly justified.[1] To maximise both the ability of users to use such digital tools correctly, and for digital tools to link together, the design of digital tools should include development of user guides, training and interoperability features.

Use of digital technologies for policy purposes is often approached on an *ad hoc* basis; for example, decisions about digital technologies are often made at the level of individual policies or programmes rather than at an organisational or whole-of-government level. Government agencies should evaluate opportunities systematically, even if actual use of given technologies remains only for specific purposes. The case for creating new digital tools also needs to consider whether existing tools can be improved, and also how digital tools work together with other tools. A coherent approach can help ensure that initiatives generate additional benefits by using a mix of old and new technologies and provide for multi-dimensional integration of digital tools (e.g. interoperability between digital tools, integration of digital tools with other tools) to ensure efficiency and effectiveness.

1.1.2. Using digital technologies can improve monitoring and compliance for agri-environmental and agricultural policies and programmes

Remote sensing and related technologies offer the potential to drastically reduce the cost of monitoring efforts to improve agricultural sustainability. Digital technologies can also be used to move toward more collaborative approaches which encourage proactive participation of farmers in the overall monitoring procedure.

In fact, the relative ease of monitoring certain kinds of actions or environmental impacts using digital technologies may motivate a shift towards them in policy design on these actions or impacts. However, such changes should be carefully considered: policies should generally not limit farmers' actions to only those which can be easily monitored by digital technologies, as this may constitute a *de facto* technology standard which limits farmers' options for becoming more sustainable. Rather, policies should continue to be evaluated based on their total costs (and benefits), not only transaction costs of monitoring.

In voluntary policy contexts (such as voluntary agri-environmental programmes), administrators may face a conflict between short-term goals (ensuring compliance with current programme requirements) and long-term goals (encouraging re-enrolment). Governments should explore options to circumvent this dilemma, which could include:

- more flexible, digitally-enabled compliance approaches which focus on monitoring and helping farmers learn how to comply, rather than an audit-and-sanction approach;
- making changes to policy design in order to foster improved compliance in future, which could include design elements such as:
  - a greater focus on long-term results;
  - making use of technology to design schemes which only pay once compliance is demonstrated (e.g. via geo-tagged beneficiary-provided photographs, remote sensing);
  - use of market-based instruments where famers are paid for ecosystem services and compliance is managed via market contracts;
  - designing flexible requirements which "follow nature" (e.g. mowing dates), which fosters alignment between short- and long-term objectives by not unnecessarily restricting farmers' choices.

Data publication, reporting or transparency requirements can be an effective policy tool for incentivising compliance even if the result is that the data is never actually reported to or used by the government except in cases of non-compliance. Data transparency requirements can be an important component of self-auditing, self-reported-compliance, and collective compliance mechanisms.

1.2. Governments should champion efforts to improve access to agricultural data

Micro-level agricultural data (for example, farm level or field level data) is needed for evaluating the effectiveness and efficiency of agricultural and agri-environmental policies, as well as for developing new, tailored services for agricultural producers. Governments have a key role to play to improve access to agricultural data, including the ability to link datasets, while preserving confidentiality where needed. Specific recommendations are:

- Government statistical agencies, administrative agencies (e.g. paying agencies for voluntary programmes) and regulatory agencies (e.g. environmental regulators) should increase their interaction and explore ways to pool data. They should also work together with data providers and data users to establish a clear framework governing data access.

- Governments should investigate how administrative data can be re-used to support: 1) agricultural and agri-environmental policy implementation; 2) policy-relevant research; and 3) services to farmers. Governments should formulate clear policies for access and use of administrative data which take into account both the benefits and risks.
- Improving access to agricultural micro data held by governments requires a coherent, tiered data dissemination strategy. The recommended approach is as follows:
  - Take a risk-based approach to allowing access to agricultural data held by government: that is, consider and clearly articulate reasons why specific data or classes of data cannot be openly provided, including identifying the magnitude of potential harm and the likelihood of risks eventuating. This could be accompanied with commitments to periodically review pre-existing legislative requirements to protect confidentiality of agricultural data.[2]
  - Invest in data services such as providing linked datasets to increase the usefulness of government data collection. One important aspect of this is to link farm financial datasets with physical data such as soils, precipitation, and other climate variables. Governments should also consider how provision of government-held data interacts with datasets from other sources.
  - Increase use of secure remote access mechanisms allowing trusted researchers to access agricultural micro data.
  - Explore greater use of new technologies (such as "confidential computing" and other advances in encryption) that avoid the traditional confidentiality-accessibility dilemma.
- Data-collection agencies should explore how the burden of existing data collection by government organisations can be lessened while maintaining or strengthening data collection through the use of digital technologies, including considering how digital tools could be used to gather data via alternative pathways; they should also put in place data management frameworks which include methodologies for the evaluation of data quality for data from alternative sources and planning. Finally, government might have a role in ensuring the longevity and robustness of these data sources.
- Governments should explore ways to incentivise provision of private sector data for public use and for agricultural research. This should include consideration of providing incentives for farmers to allow their data to be shared for policy purposes; options include monetary incentives (i.e. payments for data provision) and non-monetary incentives such as provision of regulatory safe-harbours for data providers or provision of services which use data that has been provided (e.g. benchmarking services).

Issues related to the treatment of data are critical not just in the context of the use of government-held agricultural data to improve agri-environmental policy, but form part of the broader debate about how digitalisation can be used to create value in the food system. For this reason, the study also takes a broader look at the issue of data and data governance in agriculture. While a full consideration of all of the regulatory aspects conditioning the use of digital technologies in the agriculture sector is beyond the scope of this report, some key findings and recommended "first steps" are identified towards ensuring that the regulatory environment, notably in relation to data and data governance, provides protection where needed, while not stifling innovation.

1.3. Data infrastructures and data governance for agriculture: Potential roles for government

The capacity to create value in the food system using digital technologies depends on: 1) access to basic connectivity infrastructure (broadband, telecommunication services); 2) a range of data collection, storage and analysis services (sensors, modelling, digital platforms, cloud-based storage and processing, software systems for managing and processing data to yield actionable insights); and 3) the regulatory environment (the soft infrastructure representing the institutional environment defining interoperability rules, data quality standards, norms or regulations on data ownership and data privacy).

The options for governments partly depend on the state of these existing infrastructures. Within the same environment, governments might adopt different roles, from a central planner to an enabler, an investor or a regulator. Governments can potentially support the development of a data infrastructure in agriculture in the following ways:

- As a *regulator*, the government can create an environment enabling private sector investments and competition, for example by setting interoperability standards. More broadly, governments may need to consider issues in relation to the collection, use and sharing of data and other related regulations, as well as issues in relation to trust, whether in the use of data or in the technology.
- As an *investor*, the government can support connectivity and the development of a physical data collection infrastructure (sensor network, remote sensing, direct development of the data infrastructure and creation of markets for usage rights) and the development of innovative services.

1.3.1. Governments can play an active role in future development of digital tools for policy and for agriculture more broadly

Governments can actively support development of digital tools for agriculture and for better policies in a number of concrete ways. These include:

- Governments can undertake regular horizon-scanning exercises to ensure they remain up-to-date with new digital tools.
- Governments, in their role as users of technology, can make their user requirements clear to technology developers, and consider use of co-innovation models to ensure that technology developments both meet users' needs and that users are challenged to re-assess their needs in light of technological developments.
- Governments, in their roles as (co-)providers and leaders of technology development, can invest in relationships with academia and technology developers working in emerging technology areas, particularly in the field of sensor development, and work together to ensure technologies are validated and calibrated for use in policy or regulatory contexts. Governments should also engage with researchers who work with agricultural data to conduct policy-relevant research, to maximise the use of such data for policy.

- Use of technology for policy purposes may incentivise adoption of technology on-farm. This can be beneficial; however, there is the potential for net increase in regulatory burden on farmers if government policies push farmers to adopt technologies by requiring them to satisfy mandatory regulatory requirements, when there is no net benefit to farmers. As in general, policy makers should carefully evaluate whether any expected net increase in regulatory burden is justified. Governments should endeavour to ensure technology adoption does not become a force for exclusion rather than inclusion.

Notes

[1] *Open data* refers to the possibility of citizens to access data, however it does not mean that data is necessarily visible by all. Privacy and trade secrets still prevail and cryptographic keys are used to control access to such data. These are particularly popular in the public sector, with open government data, and with the scientific community as a solution to promote enhanced access to and use of data.

[2] Note that this recommendation does not presume that an open data approach will be appropriate in all cases. Rather, it is recommended that governments consider the possibility of opening datasets as a useful conceptual starting point so that the case for confidentiality requirements can be appropriately (re-)evaluatced and transparently made.

Part I. What’s new? Digital technologies and agriculture

Chapter 2.

Digital innovations and the growing importance of agricultural data

This chapter describes recent advances in digital technologies and analyses the drivers of digitalisation in the agriculture sector.

The agriculture sector has a long history of innovating and adopting new technologies to increase productivity, manage risk and improve environmental, social and economic sustainability. The use of digital technologies and related innovation—by farmers and also by policy makers and administrators—is another step in this history, which offers new opportunities but also brings new challenges. The OECD's Recommendation of the Council on Digital Government Strategies defines "digital technologies" as:

> *ICTs [information communication technologies], including the Internet, mobile technologies and devices, as well as data analytics used to improve the generation, collection, exchange, aggregation, combination, analysis, access, searchability and presentation of digital content, including for the development of services and apps. (OECD, 2014[1])*

The definition encompasses existing information communication technologies (ICTs), many of which have been used in agriculture since their inception – for example, Landsat satellite data has been used to generate soil and land-use land cover maps, for global agricultural production monitoring and for GPS since 1972 (Leslie, Serbina and Miller, 2017[2]). In many cases, recent advances have substantially broadened the breadth, scale and immediacy of what these technologies are able to deliver. Advances in *in situ* and remote sensing technologies have greatly increased the spatial and temporal resolution of physical measurements, and allowed for low-cost, automated measurement of many aspects of agricultural production that were previously only able to be measured in a limited way – for example at discrete points in time by a human observer conducting a field visit. Advances in massive data acquisition, storage, communication, and processing technologies have enabled the rapid transfer of vast quantities of data which would not have been possible even a decade ago, and have greatly magnified the ability to process large datasets and to automate analytical processes with machine learning.

These technological developments have occurred in the context of evolution of local and global challenges facing the food system, including the increasing need to produce more food with fewer resources, leading to changes in policy objectives. Sustainability is not a new objective of agricultural policies; however, it is an objective which has been difficult to effectively integrate into the agriculture policy mix (OECD, 2017[3]; OECD, 2013[4]).

Agricultural policies co-evolve alongside technological progress; each both drives and is shaped by the other. Earlier waves of technological progress in agriculture introduced mechanisation, higher yielding and more resilient seed varieties, and the first foray into precision agriculture with the adoption of satellite-based GPS for farm machinery guidance. These earlier waves did in some cases make extensive use of data, for example in developing conventional breeding and genetic engineering. Building on these past advances, the current wave of technological progress centres on the creation, use, combination, analysis and sharing of agricultural and other data in digital format to improve the sustainability and productivity of agriculture and food systems.[1] This chapter briefly summarises the key technological innovations in this most recent wave, as well as the key drivers for digital technology adoption in the agriculture sector.

2.1. Overview of recent and ongoing digital innovations for agriculture and food

A range of new technologies promise to improve efficiency and significantly impact business models in the agriculture sector. These technologies can be grouped according to their function in relation to data, broadly defined to include any piece of information available in machine language (Table 2.1). Key categories are data collection, data analysis, data storage, data management and data transfer and sharing. The category of data transfer and sharing includes technologies which use data transfer or sharing to facilitate other kinds of transactions, such as transfer of ownership or value, communication (between humans or digital devices) and digitally-delivered services.

Many of these technologies can be used directly by policy makers and administrators (section 2.2). Others (e.g. software for automating agricultural machinery) are unlikely to be directly used by policymakers and administrators, but are nevertheless relevant for improving policy-making because they are capable of producing, sharing, managing (e.g. securely storing) or analysing policy-relevant data. Moreover, policies can be designed with these technologies in mind: while this work does not focus directly on policies aimed at fostering adoption in the agriculture and food sectors[2], agricultural and agri-environmental policies may nevertheless alter incentives for farmers and other actors to adopt certain technologies.

Some of the technologies listed in Table 2.1 have existed in some form for many years, but recent advances have greatly improved the ability to obtain, analyse, manage or transfer data that is relevant for agricultural policies, including by reducing the cost and increasing the speed of data collection, analysis and dissemination.

The sub-sections below provide an overview of key recent technological and institutional innovations, and identify some of the factors driving digitalisation in the agriculture and food sectors. Specific ways in which these trends can benefit policy-making, or the agriculture sector more broadly, are identified in subsequent chapters.

Table 2.1. Digital technologies for agriculture and food

Technology purpose	Category	Sub-category
Data collection technologies [a]	Remote sensing	Satellite-mounted data acquisition / monitoring systems
		UAV / drone-mounted data acquisition / monitoring systems
		Manned aircraft data acquisition / monitoring systems
	In situ sensing	Water quantity meters
		Water quality sensors [a], air quality sensors [a]
		In situ meteorological sensors [a]
		In situ soil monitors [a]
		In situ biodiversity, invasive species or pest monitors
		Crop monitors
		Livestock monitors
		Data from precision agricultural machinery
	Crowdsourcing data collection	'Serious games' for gathering agri-environmental data [b]
		Citizen science [c]
	Online surveys / censuses	Data collection portals (e.g. online census)
	Financial / market data collection	Retail scanner data
		Business software for recording financial or market information (e.g. database entry systems)
Data analysis technologies	GIS-based and sensor-based analytical tools	Digital Elevation Modelling
		Land Use-Land Cover mapping
		Watershed modelling
		Soil mapping
		Landscape modelling
		Software (programs, apps) for translating sensor and other farm data into actionable information
		Software for automating agricultural machinery which uses sensor or other farm data as input [d]
		Software for measuring and grading agricultural outputs (e.g. carcass grading software)
	Crowdsourcing data analysis	Crowdsourcing applications for data sorting / labelling
	Deep learning / AI	Data cleaning algorithms
		Big data analysis algorithms
		Machine learning
		Predictive analytics

Technology purpose	Category	Sub-category
Data storage technologies	Secure and Accessible Data Storage	Cloud storage
		Confidential Computing [e]
		Virtual data centres
Data management technologies	Data management technologies	Distributed ledger technologies (e.g. Blockchain)
		Interoperability programs and apps
Data transfer and sharing: Digital communications; trading, payment and service delivery platforms	Digital communication technologies	Digital data visualization technologies
		Social Media
		Web-based video conferencing
		Machine-assisted communication (e.g. chatbots, natural language generation algorithms)
	Online platforms - property rights, payments, services and markets	Online property rights and permits registries
		Online trading platforms
		Platform-based crowdfunding for agriculture and agri-ecosystem services
		Online payment platforms (for public programs)
		Service delivery platforms

Notes: a. Advances in sensor technology are comprised not only of advances in digital technologies, and in particular advances in the creation of wireless sensor networks, but also innovations in physics or chemistry. For example, advances in nanotechnology have been critical to the development of the most advanced physical sensors existing today. This project focusses on the digital components of sensor technologies and related services.

b. *Serious games* are publicly-available apps which seek to employ citizen effort for data collection or data processing. These apps have "a serious purpose but [include] elements of gamification (i.e., the addition of game elements to existing applications) to help motivate the volunteers (Bayas et al., 2016[5]). In the agricultural context, serious games have to date been used primarily for land use and land cover monitoring and classification.

c. *Citizen science technologies* are technologies which facilitate "public engagement and participation in science and innovation" (Daejeon Declaration, 2015[6])

d. In relation to technologies which automate agricultural machinery, such as automated milking systems, planters and harvesters, and irrigation systems, this project focusses on the sensor and software components and related services of these technologies.

e. See Box 2.2.

2.1.1. Global and local: Recent advances in remote sensing and edge-of-field monitoring

Much recent progress has been made in the use of satellite-based remote sensing to produce higher resolution (both spatial and temporal) and more accurate data products for agriculture. According to Atzberger (2013[7]) "[r]emote sensing data can greatly contribute to the [agricultural] monitoring task by providing timely, synoptic, cost efficient and repetitive information about the status of the Earth's surface". It can provide comprehensive information on crop acreage, biomass and yield, monitoring of stressors (e.g. drought) as well as precise information on farm management actions such as crop rotations, and structures such as farm buildings, fencing, conservation buffers etc.

Gholizadeh, Melesse and Reddi (2016[8]) provide a detailed survey (circa 2016) of the evolution of space-borne and airborne sensors which provide data for water quality assessment. Their analysis shows a steadily increasing spatial resolution (including the launch of multiple satellites over the period 2007-2014 which provide sub-metre resolution), as well as a steady decrease in the time between revisits from more than two weeks for most satellites in the period before 2000, to around 1-2 days more recently. Gómez, White and Wulder (2016[9]) similarly explain that, until recently, land cover maps generally were based on relatively coarse resolution data (>1km), but that now there has been a significant increase in capture of medium resolution (10m-100m) data by earth observation satellites. Pettorelli, Safi and Turner (2014[10]) refer to data provided by the EU Sentinel satellites as a "game changer" for global efforts to monitor biodiversity (on both agricultural and other lands). Bégué et al. (2018[11]), reviewing the potential for remote sensing to provide data on cropping practices, similarly note that the Sentinel satellites are expected to overcome previous limitations and constraints and improve the ability to detect small and fragmented land use types (e.g. irrigated areas) and to obtain regional and global data on soil tillage practices. Such advancements pave the way for increased use of satellite-based data products to provide field-level, landscape-level and even global data to improve agricultural policies in a variety of ways. Box 2.1 provides further detail on the EU's Copernicus programme.

Box 2.1. The use of remote sensing by the European Union Joint Research Centre and the Monitoring Agriculture Resources (MARS) programme

The Sentinel satellites of Europe's environmental Copernicus programme are used, among other things, to study changes in farming on a weekly basis, with a 10 metre resolution, and with a free and open data policy. The European Union Joint Research Centre (JRC) has been using satellite data for identification of information on crop areas and yields since 1988. Satellite data allow the observation of changes in land use: which crops are being grown, how well they are developing, etc. This data can be used to predict seasonal yield, and to support thinking about how to cope with low harvests in various places in the world. This includes crop yield forecasting, enabling early warnings of crop shortages and failure and to support aid for food insecure countries.

Increased accuracy of satellite data allows more effective and efficient management and monitoring of the Common Agricultural Policy (CAP). The increased capacity of satellites allows improved remote monitoring of agriculture, with measurement of field areas, identification of crop types, geo-location of landscape features and assessment of environmental impacts.

Various agencies throughout Europe (including in Spain, Lithuania, Greece, the United Kingdom, Serbia, Belgium, the Czech Republic, Slovenia, Romania and the Netherlands) are testing the potential of such data to simplify processes and streamline monitoring. Monitoring previously covering only 5% of producers can now be extended to 100%, potentially changing the policy design and implementation of the CAP (see Sen4CAP project for the modernisation and simplification of the CAP in the post-2020 timeframe). For a further discussion of use of remote sensing for CAP administration, (See Box 3.7 in section 3.2.5.

Source: JRC, Copernicus and Sen4CAP projects.

Advances in unmanned aerial vehicles (UAVs, drones) and remote sensor design have also dramatically reduced the cost and improved the efficacy of airborne remote sensing. This has opened up a new field: the use of UAVs for conservation[3] (also referred to as "drone conservation") (Koh and Wich, 2012[12]). Airborne remote sensing is also becoming increasingly important as a source of data for high resolution mapping (e.g. land cover and land use, elevation, soils, watersheds, etc.), particularly for remote areas and for areas with high cloud cover which impede some kinds of satellite-based sensors. UAVs also offer the opportunity to capture better species-specific data relevant for biodiversity policies, by automating wildlife counts and greatly improving the accuracy and level of detail of biodiversity indicators (Hodgson et al., 2018[13]; Arts, van der Wal and Adams, 2015[14]). On-farm uses of UAVs as part of precision agriculture systems are also multiplying: for example, early evidence suggests that farmers are able to use drones to significantly decrease the cost of monitoring crop growth, increase data resolution and identify areas presenting potential problems (e.g. identification of low yield areas, earlier and quicker identification of pests or disease) (Jarman, Vesey and Febvre, 2016[15]; Hunt and Daughtry, 2018[16]).

Rapid technological advances have also occurred in edge-of-field monitoring (EOFM). For application in water quality, Daniels et al. (2018, p. 5[17]) note that within a relatively short time period, EOFM "has evolved as a research concept and tool to a routine practice to document runoff water quality on real, working farms". Harmel et al. (2018[18]) provide a brief history of EOFM, noting that widespread use of electronic sampling devices began in the 1990s. Automated electronic sampling also emerged, and became more common in the 2000s. Current research is focussing on reducing the cost of sampling systems, making further practical improvements, and devising methods for measuring uncertainty. Daniels et al. (2018[17]) note that cost is still an obstacle preventing widespread adoption of EOFM by farmers and that there may be a role for government to provide financial assistance for EOFM; for example, the authors note that, recognising the value of EOFM for monitoring of the performance of on-farm conservation activities, USDA NRCS now offers cost share assistance for several EOFM activities.

2.1.2. Automating and accelerating analysis: The new capacity to harvest, combine and analyse data in agriculture and food

The use of digital data in agriculture was first introduced as a source of productivity growth through precision farming.[4] At first, precision agriculture mostly involved the use of guidance systems, yield monitoring, variable rate application,[5] long-distance transmission of computerised information (telematics) and data management (OECD, 2016[19]). A plethora of unrelated systems were developed to gather data about on-farm activities and performance such as yield variation and the characteristics of production assets.

Yet, while a large amount of data was being acquired and used for various specific purposes, much of it was not able to be combined with other data and was not readily re-usable beyond the initial intended purpose. Moreover, much agricultural data accessible by other actors such as governments, researchers and the public has been only in aggregated form; use of data at the level of the individual animal, field or farm has therefore been costly and limited.

One of the key reasons data has not been used to its full potential to date is that farmers often lacked the tools and skills to fully exploit data and use them for decision-making. The inability to link data across systems, each focussed on a specific task, prevented both insights into the relationship between certain management practices and within the farm system, at least in the absence of costly manual data synthesis. A single data point does not make much sense without a context, benchmarks, trends, or causal references. While this data can be individually informative, the insights obtained can be considerably multiplied if data of different types and from different sources[6] can be combined.

Several technological innovations have recently significantly increased the capacity to collect, aggregate, process and analyse agricultural data: massive data acquisition, storage, communication, and processing technologies. These innovations allow the digitisation and datafication of agriculture:

- *Digitisation*: the conversion of analogue data and processes into a machine readable format (OECD, 2019[20]). Many types of agricultural data were previously held in paper-based filing systems. Digitisation thus does not create new data, but rather by converting existing data into digital format allows data to be used and transferred in new ways.
- *Datafication*: is the transformation of action into quantified digital data, allowing for real-time tracking and predictive analysis. Datafication takes

> previously unrecorded processes and activities and produces data that can be monitored, tracked, analysed and optimised (Naimi and Westreich, 2014[21]).

ICTs, including the Internet and the development of connected sensors which transform the analogue world into machine readable data, are increasingly leveraging large volumes of digital data. Datafication and digitisation have together not only rapidly expanded the volume of agricultural data recorded in digital format, but have also expanded data coverage to many aspects of farm production and associated variables of interest, including for public policies (e.g. discharge of waste, nutrients from farms) for which data was not previously available.

These large streams of data, and the capacity to combine them, are referred to as "big data" (OECD, 2015[22]).[7] The access and processing of these large volumes, enabled by increased computing power, in turn enabling helps to infer relationships, establish dependencies, and perform predictions of outcomes and behaviours (OECD, 2015[23]), informing real-time decision-making.

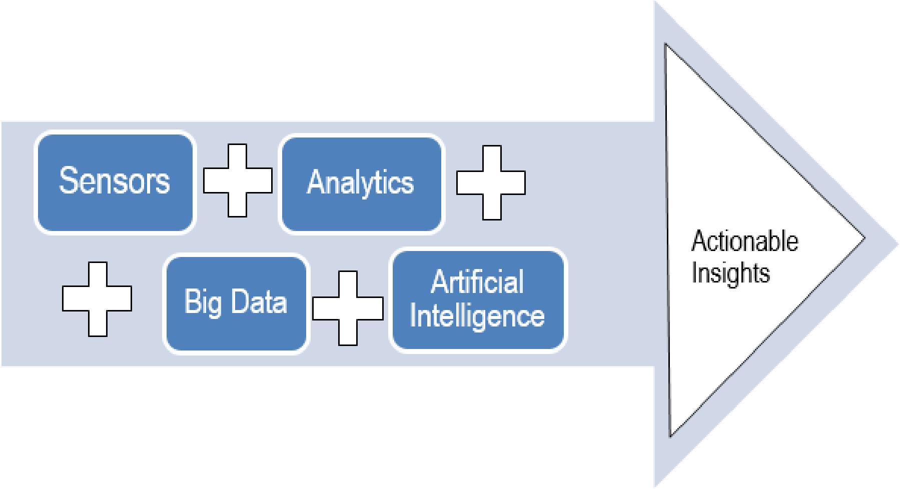
Indeed, having more data is not enough. But combined with progress in communication and processing capacity, this data is progressively used to create knowledge and provide advice about production processes, and even to automate some activities on farm. This is referred to as *actionable insights*[8] at the farm level (Figure 2.1): farmers can benefit from the knowledge created over time on their own farm but also by others, either peers or research and development institutions. Nevertheless, turning data into useful information generally requires models and algorithms, as well as knowledge about factors such as data quality and error tolerance for each data source. These provide the basis for new forms of knowledge, and new services and tools, with the potential to deliver significant change in agricultural practices as well as agriculture and food value chains (Wolfert et al., 2017[24]). This combination of precision farming with digitalisation has led to labels such as “farming 4.0” or “smart digital farming”.

The combination of data is further facilitated by cloud computing, which allows computing resources to be accessed in a flexible on-demand way with low management effort (OECD, 2014[25]). Cloud computing offers the capacity for the data to be stored and aggregated in locations other than where it is created or used, which supports big data analytics (OECD, 2016[26]).

Finally, all these innovations have underpinned advances in Artificial Intelligence (AI), defined as the ability of machines and systems to acquire and apply knowledge and to carry out intelligent behaviour (OECD, 2016[26]). AI helps computers interact, reason, and learn like human beings to enable them to perform a broad variety of tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, translation between languages, and demonstrating an ability to move and manipulate objects accordingly. Intelligent systems use a combination of big data analytics, cloud computing, machine-to-machine communication and the Internet of Things (IoT) to operate and learn (OECD, 2017[27]).

The availability of these new tools enable the creation of new information, and in particular, “actionable insights” not only for farmers but also regulators and policy makers who are increasingly demanding data to support policy-making is increasing, as governments move deliver “data driven” policies and services (OECD, 2014[1]), and see Case Study 8 for an example in Estonia).

Figure 2.1. Technological revolution for the production of actionable insights in agriculture



Note: This figure makes use of the term Artificial Intelligence (AI), introduced in 1956 and defined as a broad concept of machines being able to carry out tasks in a way that is considered "smart". Recent advances in AI have been done through machine learning. Machine Learning is a current application of AI, according to which machines should get access to data to be able to learn for themselves. See Note 8 for a definition of "actionable insights".

Reflecting the dynamic nature of many factors relevant to land management decisions, there is strong demand for up-to-date information. One particularly beneficial aspect of new data analysis tools is that they are often designed to be dynamic and updatable. These features lessen the need for constant investment in new hardware or software, and better match users' needs. Therefore, tools that can allow for rapid update of information better match demand for information, and as such are likely to be used more, both now and in the future (source: Part IV, Case Study 1).

2.1.3. Advances in encryption, data protection and data sharing technologies, and institutions for data sharing

Advances in technologies for data access, management and sharing are changing the technical feasibility, costs and risks associated with access to and use of agricultural data. Key developments are:

- *Confidential computing and multi-party computation*: "Confidential Computing" allows access to a proscribed set of analytics functions that are performed over encrypted data that is not disclosed to the data scientist or analyst. This enables a new, low friction, method of doing exploratory linkage and analysis of datasets (source: Case Study 6).
- *Synthetic data release*: A recent advance in privacy technology is known as *Differential Privacy.* This is a quantifiable measure of the privacy of certain data analytics techniques that involve random perturbation of either the data being analysed or the analysis itself. Researchers are currently working on a variety of differentially private mechanisms to allow the release of synthetic unit record datasets that contain statistically similar data to the original data, but can guarantee that the released data cannot be re-identified. These methods can allow the release of government datasets with fewer restrictions than are currently needed to ensure confidentiality. These techniques involve adding

noise to the data, and so have some impact on the utility of the data for analytics (source: Case Study 6).

- *Advances in data visualisation software:* recent years have seen the release of many different kinds of software which assist users to more easily customise visualisation of data. Many actors in the agriculture sector (including public agencies) are making use of such software to improve the usability of existing datasets and facilitate access by making access more "user friendly". Examples include:
    - software such as Tableau, Qlikviw, and Datawrapper which allow users to easily customise data requests and view data via dashboards, customisable charts, etc., generally via web-based platforms;[9]
    - Geographic Information System (GIS) software such as ArcGIS, QGIS, MapInfo ®, GRASS GIS.[10]

Institutions for accessing, managing and sharing agricultural data are evolving alongside the technological innovation described above. Institutional innovations are important pathways for ensuring that opportunities offered by technological innovation can be realised in practice. Key developments in recent years are:

- Open data principles[11]
- FAIR data principles (Case Study 6)
- New arrangements for improving access to agricultural data held by public organisations (Box 2.2 and Case Study 6)
- Interoperability and metadata standards (Case Study 1 and Part III)
- New partnerships for co-innovation and collaboration in research and governance (Case Studies 1 and 9)
- New models of collective governance for agriculture and for data (Case Study 2)
- Digital property rights and data access rights.[16]

Given that policies are themselves institutions, and moreover ones which can in turn shape other institutions (for example by creating or protecting property rights, incentivising collaboration, setting a regulatory framework for data access), many of the examples given in this report, particularly via the case studies, are examples of how institutional innovation is enabling governments to make better use of digital technologies, or enabling others to do so. Further discussion of such institutional innovations are provided throughout this report.

Box 2.2. Advances in arrangements for access to agricultural data held by public organisations (Case Study 6)

Technological solutions have been developed over many years to enable more data to be available for use, such as anonymisation and data obfuscation techniques. There are also a large number of newer approaches to confidentialisation to facilitate data sharing for research while protecting privacy or meeting confidentiality requirements. All of these have been used in successful, large scale implementations in Australia and internationally (O'Keefe and Rubin, 2015[28]; Reiter and Kohnen, 2005[29]):

- *De-identified open data access* – the analyst downloads the data directly (e.g. datasets accessible via the GODAN initiative[1])
- *User agreements for offsite use* (licensing), in which users are required to register with a custodian agency, and sign a user agreement, before receiving data to be analysed offsite.
- *Remote analysis systems*, in which the analyst submits statistical queries through an interface, analyses are carried out on the original data in a secure environment and the user then receives the (confidentialised) results of the analyses.
- *Virtual Data Centres* (VDCs), which are similar to remote analysis systems, except that the user has full access to the data, and are similar to on-site data centres, except that access is over a secure link on the internet from the researcher's institution (e.g. the USDA-ERS data enclave platform provided by NORC;[2] Australian Bureau of Statistics DataLab[3]). VDCs may also make use of *containerisation*, where the analyst can access the data in a limited way, on a secure platform through a containerised application (e.g. the SURE platform used by the Sax Institute[4]).

Secure, on-site data centres, in which researchers access confidential data in secure, on-site research data centres (e.g. the Secure Access Data Center, France[5]).

Each arrangement makes data available at a specified level of detail, where sensitive detail can be reduced by methods including removal of identifying information; confidentialisation of the data by one of a range of methods, including aggregation, suppression or the addition of random "noise"; or replacement of sensitive variables or data with synthetic ("made-up") data.

Notes

1. The Global Open Data for Agriculture and Nutrition (GODAN) initiative promotes the "the proactive sharing of open data to make information about agriculture and nutrition available, accessible and usable". GODAN promotes data sharing both within and across national borders. See https://www.godan.info/, accessed August 2018.

2. "The [United States] Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS), in coordination with the Food and Nutrition Service (FNS) utilise the [university of Chicago's NORC] Data Enclave to provide authorised researchers secure remote access to data collected as part of the Agriculture Resource Management Survey (ARMS), the primary source of information to the US Department of Agriculture and the public on a broad range of issues about US agricultural resource use, costs, and farm sector financial conditions." See http://www.norc.org/Research/Projects/Pages/usda-ers-data-enclave.aspx, accessed August 2018.

3. "The DataLab is the data analysis solution for high-end users who want to undertake interactive (real time) complex analysis of microdata. Within the DataLab, users can view and analyse unit record information using up to date analytical software with no code restrictions, while the files remain in the secure ABS environment. All analytical outputs are checked by the ABS before being provided to the researcher." http://abs.gov.au/websitedbs/D3310114.nsf/home/CURF:+About+the+ABS+Data+Laboratory+%28ABSDL%29, accessed August 2018.

4. SURE is "Australia's only remote-access data research laboratory for analysing routinely collected [health-related] data, allowing researchers to log in remotely and securely analyse data from sources such as hospitals, general practice and cancer registries." See https://www.saxinstitute.org.au/our-work/sure/design-and-functionality/, accessed August 2018.

5. See https://www.casd.eu/en/, accessed September 2018. This is the channel for accessing agricultural micro-level data in France, including FADN data, but also surveys of farm practices. The CASD has been in place since 2012 and contains various types of sensitive data (e.g. health, taxation, business surveys, and administrative data such as agri-environmental measures).

Source: Case Study 6, Part IV.

2.1.4. The drivers of digitalisation of the agriculture and food sectors

The increased capacity to capture, manage and draw insights from data has the potential to disrupt the organisation of the food system, from influencing the supply and use of inputs in agriculture as well as the way agricultural products are supplied and valued downstream in the value chain. Digital data and technologies can enable better management of farms, agricultural productivity and resource use (on-farm drivers). Digitalisation of agriculture and farms is occurring across a broad spectrum, from low-tech solutions using mobile devices and platforms to provide management decisions services, to high-tech "digital farms" making use of integrated systems involving in-field sensors and internet of things (IoT); big data analytics for decision making; and drones, robotics and artificial intelligence (AI) for the automation of processes. The need for investments at the farm level varies enormously depending on the type of services required, which in turn depend on the type of production system and farm: for example, large extensive livestock producers do not have the same constraints and needs as hydroponics fruit and vegetable producers, or subsistence farmers. Regardless, all can benefit from new services. Whether investments in technologies are made on-farm or by service providers, the main reasons why farmers make use of digital technologies is that these technologies reduce costs or answer a new need in a changing environment

This increased capacity benefits both the agriculture sector itself and also upstream and downstream sectors. Agricultural big data can support real time farm management, a range of added-value services, and automation capabilities which in turn further support the improvement of agricultural processes (Sonka and Cheng, 2015[30]).

On-farm drivers for digitalisation of agriculture

The agricultural digital transformation potentially supports:

- Improved agricultural productivity and sustainability.
- Better risk management, including to adapt to or mitigate the impacts of climate change.
- Improved access to markets and business management.
- Improved management of administrative processes.

These processes need not require large on-farm investments: a mobile phone and a camera can be enough to provide services such as remote identification of pests. Many initiatives also currently rely on remote sensing, in particular satellite data. Satellite data are increasingly precise and the price of the information they create is decreasing. They also have the advantage of global coverage, homogeneous data and repeated observations creating historical data. Satellite data are already integrated in many systems, meaning that entry costs are low.

However, satellite data has its limits, in particular for provision of local services reaching farmers in an intelligible way. For service provision, satellite data will often have to be combined with other data or sensor systems. In particular as the level of precision is still not refined enough at the farm level. It is also necessary to pre-analyse satellite data to allow their use for analytics services and to reach and be useful to farmers (Case Study 8). An example of a satellite based system is the EU's Copernicus programme (Box 2.1).

Digital innovations can also indirectly affect farms' sustainable productivity. For instance, big data analytics increase the capacity of scientists to engineer plants resistant to drought or to certain pests, reducing their need for water or the use of chemical inputs, and increasing resilience of farmer's production to such exogenous events.[12] Such indirect pathways are acknowledged but not discussed further in this report.

Off-farm drivers for digitalisation of agriculture

There are also off-farm drivers such as increased demand for information on agri-food products from consumers, and the need to adopt technology on-farm in order to participate or remain competitive in increasingly digitised global value chains. Demand for farm-related data all along the value chain is increasing, both from the public and private sectors. Several downstream factors pushing agricultural producers toward increased digitalisation can be identified.

The first set of factors relate to value chain management and trade requirements. Digital technologies can support the creation and management of a “data cycle”[13] from farm to fork, where information is passed on by all actors in the supply chain, allowing for full traceability. Access to farm data can also improve efficiency in the management of trade regulations, particularly when trade systems are administered through the adoption of paperless trade and electronic documents (OECD/WTO, 2017). In particular, automatic recording of farm data (e.g. agriculture practices, provenance etc.) online can provide important information for customs processes and speed up clearance at the border. Overall, this can increase market access for agriculture producers and reduce trade costs.

The second set of factors relate to consumer demand and government implementation of agriculture policies. Newly created information or increased access to information can create new sources of value related to reputation and responding to consumer preferences. Food safety is one of the most important quality attributes for consumers and the effect of an outbreak on the reputation of a food processor or retailer can be lasting (Jouanjean, 2012[31]). The food industry is exploring use of digital technologies, in particular distributed ledger technologies (blockchain), to maintain secure digital records and improve traceability. The objective is to revamp data management processes across a complex network that includes farmers, brokers, distributors, processors, retailers, regulators, and consumers, to facilitate investigations into food-borne illnesses. Investigations can take weeks and can have dramatic consequences; digital technologies such as blockchain could reduce that time to seconds. There are also opportunities related to the use of other quality attributes beyond food safety for the creation of niche markets (see Jouanjean (2019[32])).

2.1.5. Adoption may be hampered by lack of skills; but what and whose skills?

It is often mentioned that farmers and advisors may not have the skills to use digital technologies or the full understanding of their potential uses (OECD, 2018[33]). It is undeniable that there is a difference in accessibility between generations, with a gap between the younger generations raised in the new digital era and older generations. However, the question of adoption is not necessarily a question of *farmers’* skills to use digital technologies themselves, or of technical understanding of how technologies work. Many digital tools for agriculture are platforms or applications which rather require an understanding of social media and awareness and trust about all the possibilities offered by such platforms. Such platforms are being used in developing countries by populations with low levels of formal school education.

The issue of what level of understanding is required is also relevant for high-tech digital tools. Digital technologies are an aid to decision-making and may even allow for automation of decisions on farm. This may entail farmers delegating parts of the knowledge and decision making on-farm to the technology, which is to say to those who programmed and created the technology. While farmers need not understand all the technical elements of technologies, they need enough understanding to be able to manage them effectively on their farms. For example, when using precision agriculture machinery, while farmers’ understanding may not necessarily extend to being able to perform maintenance themselves (e.g. on precision agriculture machinery), farmers need to be able to understand the technologies' functions and how to make use of digital elements such as yield maps, fertiliser or pesticide application regimes produced by precision agriculture machinery. They may also need to know how to use automation programmes (e.g. irrigation schedulers, robotic planters, harvesters). Understanding is also important for acceptance of recommendations: otherwise technologies may appear to be a "black box" and farmers may not act on recommendations due to a lack of confidence or trust.

Notes

[1] It is acknowledged that the current wave of technological progress also has some very important non-data-centric technological advances (e.g. advances in gene editing technologies). While such advances may rely on data and make use of digital tools, they are not the focus of the report.

[2] For example, innovation policies for agriculture and digital hard infrastructure policies aimed at bolstering the development of digital technologies in the agriculture sector (e.g. broadband).

[3] Koh and Wich (2012[12]) principally discuss the use of drones for conservation of endangered species, which is relevant to a variety of landscapes, including agricultural landscapes. For conservation more generally in agricultural lands, UAVs can be used not only for monitoring threatened species (and biodiversity more generally), but also for diverse activities such as monitoring erosion, water bodies in agricultural catchments, spread of invasive species.

[4] Precision farming uses geographical information systems (GIS) data, soil information, as well as information on weather and environmental conditions at the field level to optimise the management of the production process (this involves the choice of crop, when and how to apply inputs on the crop e.g. pesticides, fertilisers, water management, seeding rates and when to till or harvest the crop).

[5] Variable Rate Application (VRA) (also "Variable Rate Technology") refers to the application of a material, such that the rate of application is based on the precise location, or qualities of the area that the material is being applied to. VRA can be Map Based or Sensor Based.

[6] There are many categories of agricultural data, including: "agronomic data, financial data, compliance data, metrological data, environmental data, machine data, staff data, personal data, and operational data (employee data, usage data related to inputs such as fertiliser, and other mapping, sensor and related data created or needed to operate including raw data, field data and experimental data)." (Directorate-General for Parliamentary Research Services (European Parliament), 2018, pp. 14-15[36])

[7] While many definitions of "big data" exist, the term generally refers to (1) the large dimension of datasets; and (2) the need to use large scale computing power and non-standard software and methods to extract value from the data in a reasonable amount of time. Big Data is often characterised with respect to the "4 Vs" of volume, velocity (of data collection and dissemination), variety and value. See, for example, OECD (2016[37]).

[8] According to Technopedia: "Actionable insight is a term in data analytics and big data for information that can be acted upon or information that gives enough insight into the future that the actions that should be taken become clear for decision makers."

[9] See Tableau https://www.tableau.com/; Qlik https://www.qlik.com/us; Datawrapper https://www.datawrapper.de/; accessed March 2019.

[10] See as ArcGIS https://www.arcgis.com/index.html, QGIS https://qgis.org/en/site/; MapInfo® https://www.pitneybowes.com/ca/en/location-intelligence/geographic-information-systems/mapinfo-pro.html; GRASS GIS https://grass.osgeo.org/, accessed March 2019.

[11] Open data principles and digital property rights and data access rights will be discussed in a forthcoming OECD report on *Regulatory aspects of data governance for the digital transformation of agriculture*.

[12] See, for example, Mcfadden et al. (2019[38]), which describes recent development, adoption and management of drought-tolerant corn hybrids in the United States. Most of the current drought-tolerant corn hybrids available in the United States were developed using molecular breeding, which makes heavy use of big data and computer modelling.

[13] The concept of a "data pipeline" is often used in the context of value chains and cross-border trade logistics, as a way to make sure that information about products moves along with it throughout the value chain (see e.g. Solanki and Brewster (2013[34]); UNECE (2011[39]); Jensen, Vatrapu and Bjørn-Andersen (2018[35])).

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Part II. Making better policies with digital technologies

Chapter 3.

Realising digital opportunities for better agri-environmental policies

This chapter considers how the advances in digital technologies and related institutions can support delivery of better policies for agriculture. Much of the discussion and examples are drawn from the field of agri-environmental policy specifically. This allows an in-depth analysis of how digital technologies can be useful throughout the policy cycle. The approach also serves to highlight that some issues which agri-environmental policy makers need to consider when making use of digital technologies for policy are actually part of broader discussions about digitalisation in the economy. Chapter 5 considers some of these broader issues in more depth.

3.1. Digital opportunities for agricultural and agri-environmental policies: A conceptual framework

Use of digital technologies for agri-environmental policies is analysed based on the conceptual framework described in Figure 3.1. This framework begins with identifying fundamental issues which can constrain the use and development of digital technologies for policy. It then identifies the various components of the policy-making cycle and posits that digital technologies can have a role in all of these components. Finally, it identifies several types of challenges or issues that government organisations may need to overcome to fully realise the benefits offered by digital technologies.

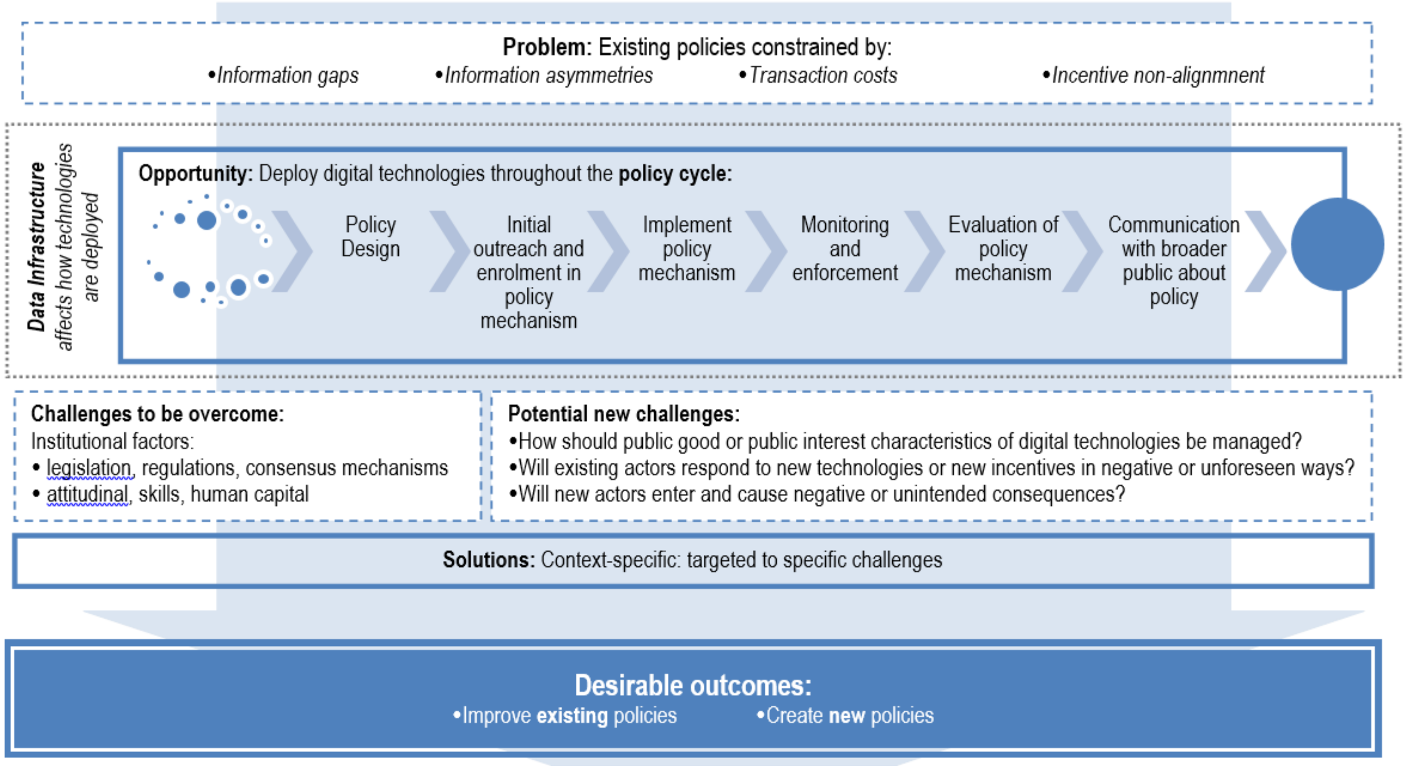
Digital technologies can help address fundamental problems[1] that constrain existing agri-environmental policies, caused by *information gaps (incomplete information),*[2] *asymmetric information,*[3] *transaction costs,*[4] and *non-alignment of incentives*[5] of different actors. These problems manifest in several ways: firstly, and perhaps most importantly, they can *constrain the set of feasible policy alternatives*, potentially limiting the scope of the policy or the policy mechanisms available to choose from. Secondly, within the set of feasible alternatives, they can *diminish the effectiveness or efficiency* of policy implementation.[6] This paper identifies how digital technologies can help address these fundamental problems.

As shown in Figure 3.1, opportunities to mitigate or overcome these problems via the use of digital technologies exist in all components of the ***policy cycle***. The policy cycle shown in the figure is a stylised representation of the broad components undertaken to design, successfully implement, and evaluate an agri-environmental policy. In the figure, the components are set out linearly; it is acknowledged that the particular components and ordering of components for a particular policy will depend on context – the emphasis here is on considering the usefulness of digital technologies for each component. The components, drawn from the literature on agri-environmental policy design (e.g. OECD (2008[1]) and OECD (2010[2]), are: *Policy Design*; *Initial outreach and enrolment* for the policy mechanism; *Implementing policy mechanism*; *Monitoring and enforcement* (if relevant); *Policy evaluation*; and *Communication with broader public about policy.*[7]

The data infrastructure referred to in Figure 3.1 represents the physical, digital and institutional structures enabling and governing the collection, transfer, storage, analysis of agricultural data to produce knowledge and advice, and enabling a feedback loop to farmers as well as policy makers. This underpinning infrastructure conditions how digital technologies are deployed throughout the policy cycle and influences the way policies can be designed and implemented. The data infrastructure is discussed further in Chapter 5.

Next, the conceptual framework identifies sources of challenges to successfully using digital technologies to solve the problems identified above. The first set of challenges relates to institutional constraints and path dependencies. These can be in the form of rigidities of legislation, regulation and legislative processes or consensus mechanisms which cannot easily be adapted for new technologies. They can also refer to resistance or lack of human capital within the public sector to adopt the new technology (including attitudinal factors or lack of skills), or on the part of other actors (for example, farmers may be reluctant to share data with administrators). The second set of challenges are dynamic challenges which are either caused by new technology itself or by actors' responses to the adoption of technologies intended to improve agri-environmental policies.

Figure 3.1. Conceptual framework for analysing digital opportunities for agricultural and agri-environmental policies



Source: Authors, adapted from OECD (2008[1]) and OECD (2010[2]).

Applying this conceptual framework, this chapter examines how digital technologies can help address the problems caused by *information gaps*, *information asymmetries, transaction costs* and *incentive non-alignment.* This chapter draws evidence relating to agri-environmental policies rather than agricultural policies in general, for two reasons. First, agri-environmental policies are particularly sensitive to the aforementioned issues. Second, his narrower focus makes the analysis more tractable and comparable across organisations and countries, and allows for deeper consideration of sustainability aspects. Nevertheless, many insights drawn are relevant more broadly.

Section 3.2 first provides an overview of use of digital technologies by organisations responsible for administering existing agri-environmental policies, using evidence obtained from an OECD questionnaire (Box 3.1). It then explicitly considers technology use to improve different components of the policy cycle. Section 3.3 considers how digital technologies can enable *new* policy approaches, which were previously unfeasible due to factors such as high cost or technical infeasibility.

Box 3.1. Adoption of digital technologies by agri-environmental policy makers and administrators: OECD questionnaire

Information on the actual use of digital technologies by public sector agencies is generally difficult to obtain, and there are very few sources which allow for comparisons across countries. While the OECD collects data on "Digital Government" and open data for its members and the United Nations (2016, p. xvii[3]) collects data on "E-Government" in support of sustainable development, these datasets relate to countries' government or public sector as a whole; no data is available at the agency level or specifically for the agriculture sector, and as such it is difficult to determine the level of adoption of digital technologies by government organisations (e.g. department or ministry or other government agency) responsible for agri-environmental policies.

To bridge this gap, the OECD conducted a questionnaire targeted specifically at these organisations. The questionnaire focusses on:

- which types of data are currently used and how they are gathered;
- the extent to which agri-environmental policymakers and programme managers make use of particular digital technologies in carrying out their functions as they relate to the agricultural sector, including for policy design, policy implementation, monitoring and compliance, policy evaluation, and communication (i.e. throughout the "policy cycle");
- the extent to which use of digital technologies differs across agri-environmental policy areas (water quality, water quantity, air quality, biodiversity, soils, climate change adaptation (on-farm), climate change mitigation (on-farm));
- strategies or management policies organisations are putting in place to maximise the beneficial use of digital technologies;
- organisations' experiences with digital technologies and future plans.

The Questionnaire received 46 responses covering 67 institutions (some responses consolidated data from several institutions) from 16 OECD member countries, plus the European Commission' Directorate-General for Agriculture. These responses provided data on 108 policies and programmes, as well as respondents' experiences with and views on use of digital technologies by their organisation. This dataset provides a wealth of information on how digital technologies are currently being used by reporting organisations.

Note: See Annex B for further information on the design and process for the questionnaire.

Employing digital technologies to address problems (whether to improve existing policies or enable new ones) may not necessarily be simple. Sections 3.2, 3.3 and 3.4 consider different types of challenges or barriers to the successful use of digital technologies: institutional constraints (see the left-side box in Figure 3.1) and new challenges *caused* by use of digital technologies (including issues arising from the public good characteristics of data and knowledge – see the right-side box in Figure 3.1).

Throughout these sections, insights drawn from ten case studies provide illustrations of the way technologies are being deployed in specific policy contexts, the type of challenges faced and the solutions found to overcome them, and "lessons learned" for others considering undertaking similar initiatives. The full set of case studies is available in Part IV.

3.2. Digital technologies throughout the policy cycle: Insights from agri-environmental policies

3.2.1. Use of agricultural data and digital technologies for agri-environmental policies: OECD questionnaire

The OECD Questionnaire gathered data on the use of digital technologies by organisations implementing agri-environmental policies and programmes, using the technology categories listed in Table 2.1.

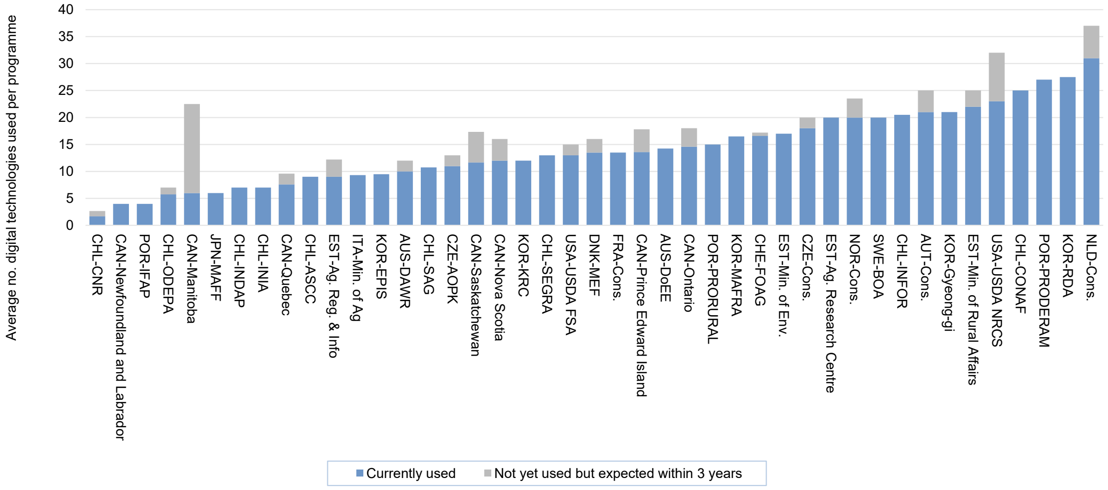
Respondents were asked to provide data for up to five agri-environmental policies or programmes, selected on the basis of respondent-assessed importance of the policy or programme for maintaining or improving the sustainability of agriculture in the respondent's country. Data was provided for 108 policies or programmes in total.

The average number of technologies currently used for policies and programmes or expected to be used within the next three years varies considerably between responding countries (Figure 3.2). The Netherlands (consolidated response of Ministry of Agriculture, Nature and Food Quality and Netherlands Enterprise Agency) was the most frequent user of technology for agri-environmental programmes, reporting significant use of digital technologies in all components of the policy cycle; Korea–Rural Development Agency and Portugal–PRODERAM[8] were the next most frequent users.

Use of digital technologies varied considerably not only across individual respondents, but also within countries. Use did not differ systematically according to the level of government of respondents (i.e. national versus regional, province, or watershed-level). However several national respondents did not answer this section, noting that all implementation was administered by other (usually sub-national) organisations.[9]

The most common policy areas[10] making use of digital technologies were *water quality* and *biodiversity* (each of these policy areas were selected for 76 out of 108 policies and programmes, noting multiple policy areas can be selected), while the most common policy mechanisms were *extension services and information provision* and *agri-environmental* *payments or subsidies*. Multiple policy areas and policy mechanisms were selected for the majority of policies and programmes reported on.

Figure 3.2. Use of digital technologies in agri-environmental policies and programmes



Notes: Figure reports number of technologies used in agri-environmental policies or programmes reported on. Where more than one policy or programme was reported on, an average is reported. Cons. = Consolidated response from more than one organisation. See Annex B for key to respondent acronyms.
Source: OECD Questionnaire.

When asked directly whether use of digital technologies differed across agri-environmental programmes or policy areas, 58% of respondents agreed or strongly agreed that technology use does differ, compared to 28% disagreeing or strongly disagreeing. 53% of respondents also agreed or strongly agreed that decisions about technology use were made at the level of the individual policy or programme (25% disagreed or strongly disagreed).

However, technology use did appear to vary with policy mechanism used: policies using environmental taxes as (at least one of) the policy mechanism(s) use on average almost twice the number of digital technologies as policies using trading schemes (environmental markets), although there were a low number of observations in for of these policy mechanisms. When grouped into mechanism categories, some differences across different technology types emerge. For example, GIS-based analytical tools, digital communication tools and online surveys or censuses are currently more intensively used (i.e. more often and in more components of the policy cycle) for administering economic instruments (environmental property rights, environmental taxes, agri-environmental payments or environmental markets) than for regulatory instruments (activity prohibitions or environmental standards). The converse is true for citizen science and crowdsourcing, which may reflect that use of these technologies is currently low overall, but that there are examples where regulators have invited community participation in monitoring programmes.

Overall, it appears that use of digital technologies for policy purposes is often approached on an *ad hoc* basis, in that decisions about digital technologies are often made at the level of individual policies or programmes. Government organisations should evaluate opportunities systematically, even if actual use of specific technologies remains only for specific purposes. The case for creating new digital tools also needs to consider whether existing tools can be improved, and also how digital tools work together with other tools (Box 3.2). A coherent approach can:

- help ensure that initiatives generate "additional" benefits by using a mix of old and new technologies.
- provide for multi-dimensional integration of digital tools (e.g. interoperability between digital tools, integration of digital tools with other tools) to ensure efficiency and effectiveness.

Box 3.2. Case Study lesson: Ensure initiatives generate "additional" benefits by using a mix of old and new technologies

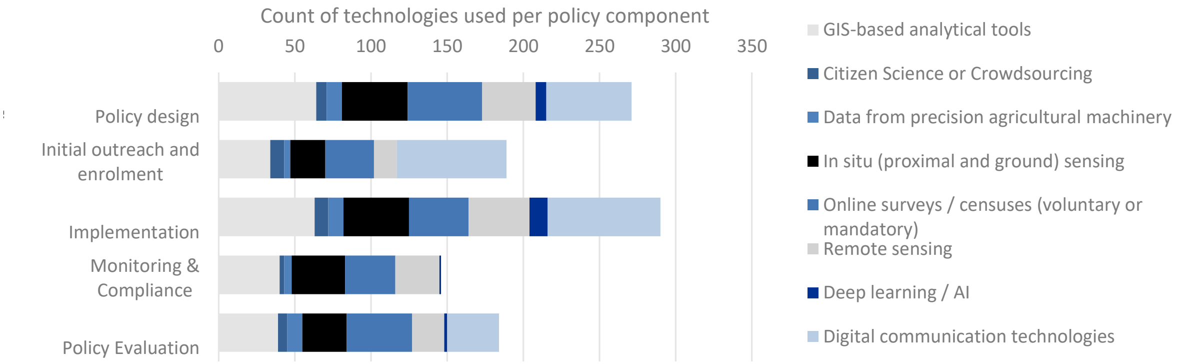
Digital technologies have been used in the New Zealand case study (Case Study 1—see Box 3.4 for an overview) both *to improve and enhance the functionality of existing analytical systems* (e.g. upgrading the NZ Water Model), and *to provide wholly new tools* (e.g. LUS classification and Physiographic Environments of New Zealand GIS layers) that support decision-making process that were not previously possible. This enables the Challenge to avoid duplication and "reinventing the wheel", while still ensuring that the tools are fit for purpose. This requires a thorough understanding of the existing analytical tools.

A mixture of old and new tools was similarly found to be the most cost-effective approach in the Dutch agricultural collectives context (Case Study 2—see Box 3.5 for an overview). Based on the experience of case study participants (see full case study for more detail), it is recommended that countries considering implementing a similar approach should:

- form a clear view about the technological requirements, including whether these will appropriately reflect (existing or desired) administrative arrangements;
- canvass a variety of options (adapting pre-existing tools, new custom built-tools, or a hybrid of both) at the outset. This could include planning for a staged introduction of new digital tools if this is considered desirable;
- plan from the beginning for the tools to be able to be adapted to new policy contexts (e.g. the introduction of more result-oriented or targeted policies).

Digital communications technologies including social media, web-based video conferencing and digital data visualisation technologies were the most commonly-used technology categories, closely followed by GIS-based analytical tools. Perhaps unsurprisingly, the emerging technologies such as Deep Learning or Artificial Intelligence is the least-used technology category, followed by citizen science or crowdsourced data and data from precision agriculture. Overall, digital technologies are currently most-used in the *Policy Design* and *Implementation* components of the policy cycle (Figure 3.3). Further information about use of different technologies within different components of the policy cycle is provided in sections 3.2.2 to 3.2.6.

Figure 3.3. Digital technologies currently used in the policy cycle components



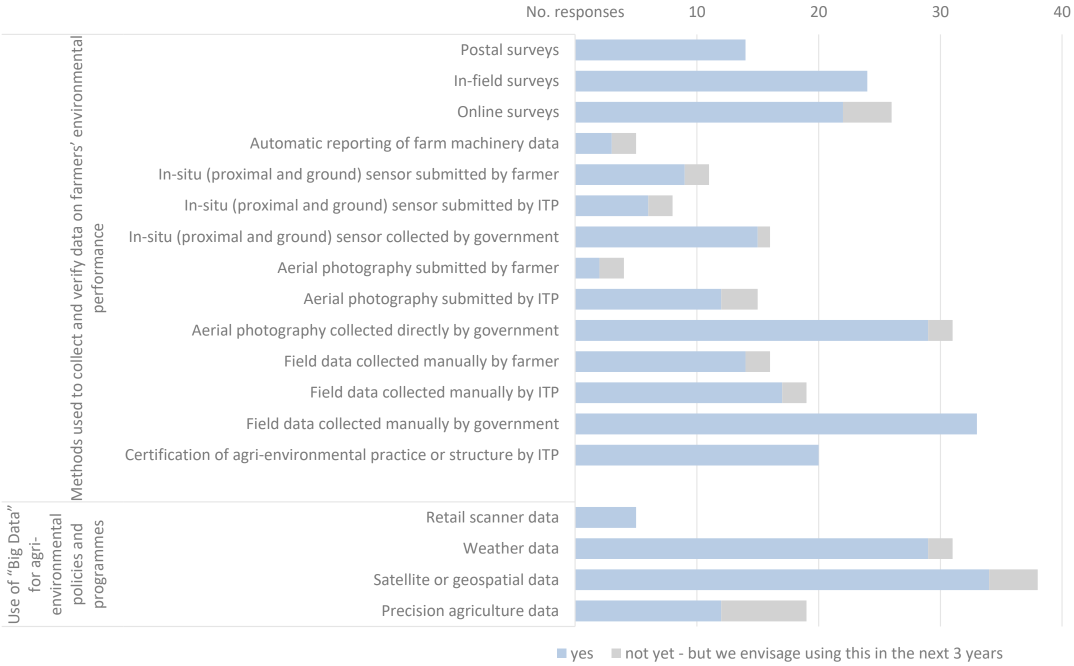
Note: Data on use of digital communication technologies is not included for the Monitoring and Compliance component; data on Deep Learning / AI technologies is not included for the Initial Outreach and Enrolment component, as the questionnaire did not include these technologies for these respective components.
Source: OECD Questionnaire.

Online surveys, aerial photography and satellite data key digital sources of data for agri-environmental policies, but traditional methods are still important

Public organisations have a long history of collecting, using, and providing agricultural data. Such data is critical for policymaking and serves a range of other valuable purposes, not least in providing aggregate information about the agriculture sector which is difficult or impossible to obtain from other sources. The digitalisation of data collection methods for agri-environmental policies is still on-going and organisations are currently using both traditional data collection methods (e.g. postal and in-field surveys) and digital methods (Figure 3.4). Manual collection of field data by government is still the single most commonly-used method. The most commonly-used "high tech" data collection methods are online surveys, aerial photography and satellite or geospatial data.

Relatively few organisations are making use of non-traditional sources of Big Data relevant to the agriculture sector: precision agriculture data (11 respondents) and retail scanner data (eight respondents).[11] Canada, Chile and Korea are the only countries for which respondents reported making use of both these data sources. One reason is that accessing those data is not straightforward. While they can provide a very high degree of granularity about agricultural production (precision agriculture) and consumption (scanner data), they are often commercially protected, making them difficult to access. In addition, they may have quality or coverage issues which may make them more difficult to incorporate into existing data analysis frameworks. Interestingly, seven respondents (mostly respondents from Canada and Chile) envisage using precision agriculture data in the next three years, but still none envisage using retail scanner data. These responses indicate that there may be an opportunity to learn from leading countries and organisations about how to make use of new data sources and integrate them with existing sources.

Figure 3.4. Methods used to collect and verify data on farmers' environmental performance and use of "Big Data" for agri-environmental policies and programmes



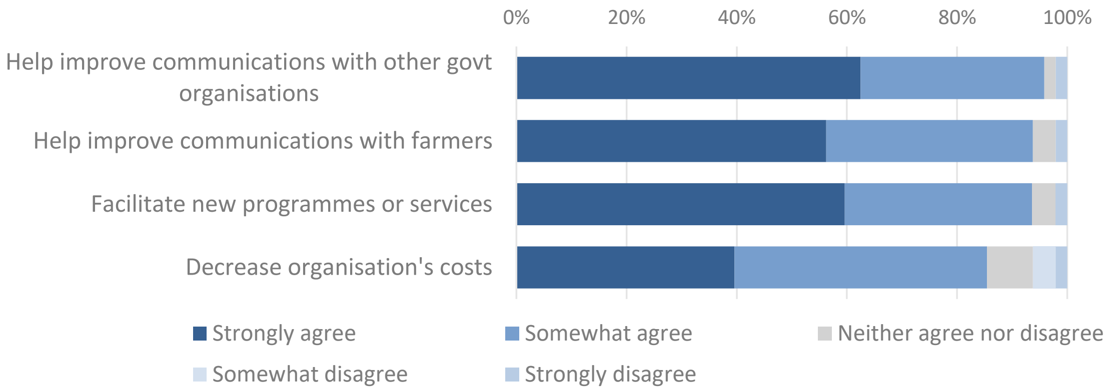
Note: ITP = Independent Third Party.
Source: OECD Questionnaire.

Most organisations have a good awareness of the benefits of digital technologies, but also see new risks

Respondents generally considered that digital technologies have a range of benefits for their organisation (Figure 3.5). The most commonly-perceived benefits are that technologies help organisations to improve their communications with other government departments or with farmers; this likely reflects that use of digital communications technologies is one of the technology categories that has the highest current use. Respondents also generally agreed or strongly agreed that digital technologies can facilitate new programmes or services and decrease organisational costs. Only a minority of respondents (18%) considered the lack of understanding of the benefits as a challenge.

There is also broad awareness (75%) that digital technologies introduce new risks. However, none of the organisations opted to provide examples of such risks, and more work is needed to better understand what new risks organisations perceive they are facing. Respondents were most commonly neutral on whether their organisation had a clear understanding of the potential for digital technologies to disrupt or change agricultural supply chains. This likely reflects the fact that there is as yet very little evidence on the magnitude of change that adoption of digital technologies by the agricultural sector will bring about.

Figure 3.5. Perception of the benefits of using digital technologies



Note: N=48.
Source: OECD Questionnaire.

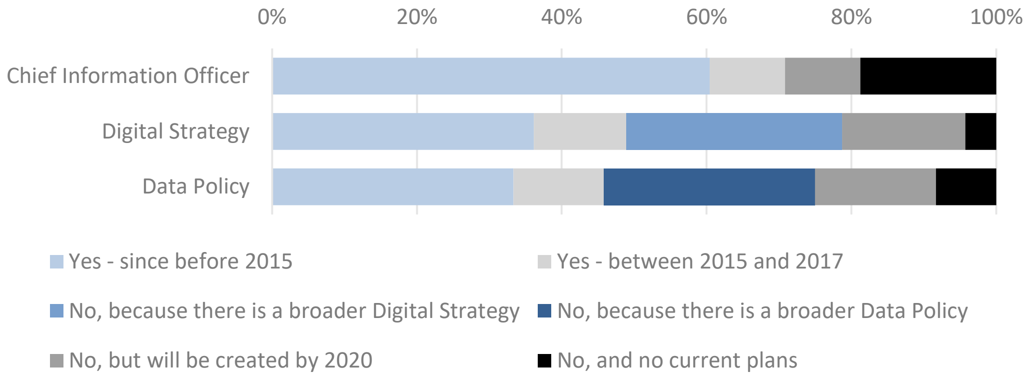
Most organisations have adopted digital strategies and data policies, and have appointed a Chief Information Officer

In the *Recommendation of the Council on Digital Government Strategies*, OECD member countries agreed to the recommendation that countries develop and implement digital strategies, and (among other recommendations) to "[e]stablish effective organisational and governance frameworks to co-ordinate the implementation of the digital strategy within and across levels of government" (OECD, 2014[4]). The questionnaire gathered data on three aspects to evaluate to what extent adoption of digital strategies has occurred for organisations administering agri-environmental policies: appointment of a "Chief Information Officer",[12] adoption of a digital strategy,[13] and adoption of a data policy.[14]

Figure 3.6 shows that most respondents (72%) had already appointed a chief information officer; several others were intending to do so within the next three years. Most (78%) had also adopted a digital strategy, or abided by the broader digital strategy set by another organisation (e.g. as part of a whole-of-government digital strategy). Finally, most (74%) had adopted a data policy or abided by a broader one set by another organisation. In addition to information gained via the questionnaire, Case Study 1 (Box 3.3) also provides a practical example of how having a data strategy can assist organisations when implementing new initiatives that make use of digital tools.

Of respondents who had not adopted data strategies, data policies, or chief information officers, most planned to adopt them within the next three years. Almost all of these respondents belonged to countries who submitted more than one response to the Questionnaire and other respondents from these countries had already adopted these institutions. Thus, there appears to be an opportunity for cross-organisational learning: organisations intending to adopt data strategies or data policies or to appoint a Chief Information Officer in the near term could examine existing institutions in similar organisations. Conversely, organisations which already have these institutions in place could use this as an opportunity to review their own institutions and work towards a cohesive approach across all levels of government.

Figure 3.6. Organisational capacity: Chief information officers, organisational digital strategy and data policies



Note: N=48.
Source: OECD Questionnaire.

Box 3.3. A data strategy for New Zealand's Our Land and Water National Science Challenge

New Zealand's Our Land and Water National Science Challenge ('the Challenge') is a government-funded research and innovation programme aiming to improve the productivity and sustainability of the New Zealand primary production sector. The many and varied research projects under the Challenge are producing a "growing diversity, complexity and volume of data" (Medyckyj-Scott et al., 2016[5]). From the start of the Challenge, it was recognised by the Challenge Chief Scientist and Leadership Team that gathering this data into a shared "data ecosystem" is one of the greatest sources of potential value added for the Challenge as a whole. In 2016, a group of experts from the New Zealand public service and the research sector collaborated to produce a "white paper" on the design of this data ecosystem. The data ecosystem is explained as "a system made up of people, practices, values and technologies designed to support particular communities of practice [in which] data is valued as an enduring and managed asset with known quality" (Medyckyj-Scott et al., 2016, p. v[5]).[1]

Lesson learned: Having a data strategy for a particular initiative can help ensure digital tools are 'fit-for-purpose'. The data ecosystem "white paper" actively considered the question of "[w]hat are the best data structures for land and water information to achieve the Challenge Mission?". It also set out a data strategy for the initiative as a whole. This helped ensure that all proposals, including those for new digital tools, actively considered both existing and recommended data structures and existing data tools.

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Lesson learned: Embrace different levels of Data Management Maturity to fit different contexts. The "white paper" also acknowledged that different actors in the initiative have different levels of Data Management Maturity (DMM).[2] It recognised that it may not be necessary to advance all (or any) participants to the highest level of data management in order to achieve programme objectives, and that it will take time to move progressively through different DMM levels. The “white paper” recommended the initiative incorporate strategic planning for transitioning through DMM levels, which can be helpful for: i) identifying the current situation; ii) identifying which level(s) need to be reached; and iii) improving the overall level of maturity while still allowing for flexibility and not imposing too high transition costs.

It is also important to recognise that moving towards more advanced levels of DMM may require attitudinal change. The “white paper” identified that “experience shows that one of the major obstacles in the cultural change is the view that data belongs to “me” and that it is not treated as an asset”, and concluded that “it is unlikely that maturity in handling data will emerge if in other ways participants lack a strong sense of community.” (Medyckyj-Scott et al., 2016, pp. 16, 29[5]).

Notes: See Box 3.4 for a brief overview of the Challenge.
1. The data ecosystem is defined to encompass: Policies regarding data management planning, data custodianship and curation, legal frameworks, and the use of externally sourced data; Procedures and processes to execute those policies and manage data; A data governance framework and organisational structures; Engagement with data consumers and stakeholders; and Technology platforms that will support data collection, storage, description, analysis, linking, delivery and curation.
2. Data Management Maturity (DMM) is a concept and framework for analysing institutional capacity to manage and make beneficial use of data assets. The DMM framework assesses data management practices in six key categories that helps organisations benchmark their capabilities, identify strengths and gaps, and leverage their data assets to improve business performance. See Medyckyj-Scott et al. (2016[5]) and https://cmmiinstitute.com/data-management-maturity.
Source: Case Study 1.

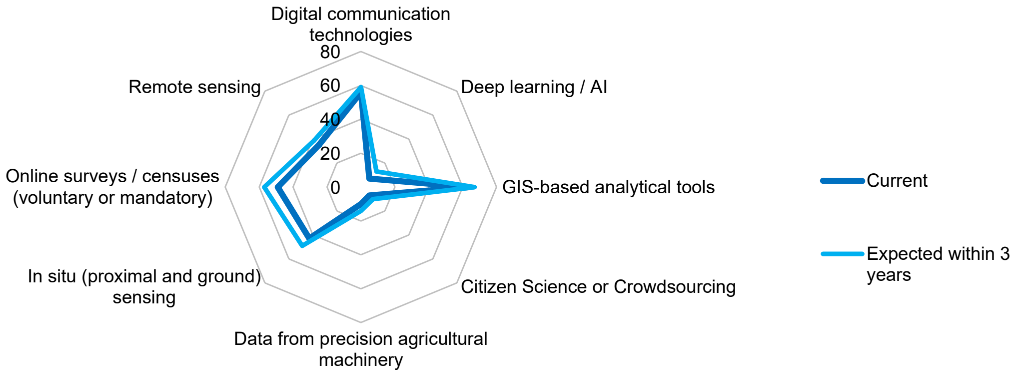
3.2.2. Improving inputs into agri-environmental policy-making

In the design phase of agri-environmental policies, one of the most fundamental challenges is understanding complex physical relationships in order to understand how policies translate into environmental impacts (Gholizadeh, Melesse and Reddi, 2016[6]). A second key challenge is to plausibly assess the likely costs and impacts of different policy options, with a view to choosing the best mechanism to achieve the policy objectives. Third, policy design generally needs to take into account input from a variety of stakeholders, which poses a communication challenge. Policy designers need to consider how they can best engage with these stakeholders, many of whom may be in different physical locations and have limited time to contribute (see section 2.2.3).

Information gaps, information asymmetries, administrative costs (*transaction costs)* and *incentive non-alignment* can each significantly constrain efforts to obtain the understanding of physical relationships needed for policy design, the preferences of individuals and groups over different policy mechanisms and outcomes, and the intentions of actors in responding to the selected policy mechanism (anticipation of which should be factored into mechanism selection).

GIS-based analytical tools, online surveys and censuses and digital communications technologies are currently the most-often used digital tools for the design component of agri-environmental policies (Figure 3.7). Of the agri-environmental programmes included in the OECD dataset, two-thirds used GIS-based tools during the design of agri-environmental policy mechanisms.

Figure 3.7. Current and expected future use of digital technologies for policy design



Source: OECD Questionnaire.

Taken together, over the next three years the main area of expected expansion is in use of technologies—remote and in-situ (proximal and ground) sensing and GIS-based applications—which will allow data to be collected at a higher level of spatial disaggregation and with greater frequency (including the possibility of continuous monitoring). Substantially increasing the spatial and temporal data resolution allows for a more precise and nuanced understanding of the impacts of agriculture on the environment and vice versa, and for highly detailed monitoring of the actions of individuals (e.g. farmers and other land managers) and the outcomes of those actions. This enables better policy-making in several dimensions:

- improved definition of agri-environmental policy objectives
- ability to implement spatially-differentiated policy mechanisms (section 3.2.4)
- ability to implement results-based policy mechanisms (section 3.3.2).

Several levels of improvements to agri-environmental policy objectives can be envisaged. First, improved data resolution can lead to a *refinement of existing environmental objectives accounting better for spatial heterogeneity*. Many existing environmental objectives for agriculture are characterised by significant scientific uncertainty, due to factors such as the complexity of physical processes, the difficulty to project environmental impacts, especially over long timescales, and the significant spatial heterogeneity of environmental impacts and of conservation measures (Rissman and Carpenter, 2015[7]). While improved data resolution cannot fully remove scientific uncertainty, it can allow for more precise estimates and for consideration of uncertainties and risks at finer scales. For example, environmental outcomes may be more certain in one area than another, which may not be evident if data spatial resolution is relatively coarse.

Second, improved data resolution can lead to *redefining objectives to better account for complex environmental interactions.* Many environmental objectives currently rely on relatively simple indicators to represent highly complex environmental phenomenon. For example, water quality objectives may be set with reference to a specific pollutant (e.g. nitrogen or phosphorous) or with reference to a specific population of interest (e.g. macroinvertebrates or a key fish species in receiving water bodies). Improved spatial and temporal data on variables of interest can improve the ability to understand how different variables interact, and could allow for setting objectives which take into account more complexity and more holistically represent environmental goals.[15]

Third, *improved data resolution can lead to redefining goals to include consideration of attenuation capacity of ecosystems and to integrate environmental goals with other goals* (e.g. economic and social goals). Environmental objectives are often defined in terms of reducing environmental pressures from agriculture. While policies are sometimes coarsely spatially differentiated according to different levels of environmental risk (e.g. different policies on highly environmentally sensitive land such as land at higher risk of erosion, land in close proximity to water bodies) or according to economic considerations (e.g. different policies in marginal areas), they are rarely based on a holistic understanding of how environmental pressures from agriculture and other land uses differ across landscapes (in particular, due to the different attenuation capacity of land and water bodies). Nor are they usually based on a holistic understanding of how policies will affect both the productivity and sustainability of the agriculture sector. The data required to underpin such holistic approaches is considerable and requires a high degree of spatial and temporal disaggregation, and moreover for data to be collected on a wide range of physical and economic variables. Case Study 1 (Box 3.4) provides an example from New Zealand's *Our Land and Water* National Science Challenge.

Box 3.4. Case Study 1: Digital tools for New Zealand's Our Land and Water National Science Challenge

The case study provides a practical example of how digital tools can be used to improve understanding of agriculture's impacts on water quality outcomes and policy options for management of water quality impacts.

New Zealand's Our Land and Water National Science Challenge ("the Challenge") is a mission-oriented government-funded, research and innovation programme, which aims to "enhance primary sector production and productivity while maintaining and improving our land and water quality for future generations". The Challenge as a whole envisages a new approach to fostering a primary agriculture sector that is both productive and sustainable. The Challenge aims to enable New Zealand to move from considering land use capability (generally driven by production potential and other factors such as off-site environmental impact) to land use suitability where economic, environmental, social and cultural factors are considered together.

The Challenge, which commenced in January 2016 and is ongoing, is comprised of three Research Themes; the second Research Theme (RT)—Innovative and resilient land and water use—is the primary focus of this case study. This RT is comprised of a number of research programmes (>NZD 1 million investment) and smaller projects (refer to full case study in Part IV for details).

Existing efforts to manage land for (environmental) sustainability are based on land-use capability (LUC) classifications.[1] Data requirements for LUC classification relate to on-site physical and environmental characteristics. In contrast, the Land Use Suitability (LUS) classification which the Challenge aims to produce integrates "information about the economic, environmental, social and cultural consequences of land use choices" (McDowell et al., 2018[8]), and thus requires substantially more, and different, data. Thus, a number of different information gaps need to be filled. Key gaps include: information about natural processes (e.g. nutrient and other contaminant pathways); and information about how producers and other land managers respond to incentives (both policy and other incentives).

These information gaps also prevent the targeting of existing policies to take into account local contexts. Further, the existing research landscape is characterised by fragmented and asymmetric information: often, data sets and digital modelling tools are accessible only by the researchers who work with them directly. This leads to duplication, confusion over the role of different models and research efforts, and impedes effective translation of research efforts into change "on the ground" (McDowell et al., 2017[9]). In addition, licensing issues with some of the datasets mean data sharing between researchers could be difficult. In a collaborative setting, the researchers can settle for a common minimum data that is accessible to all, but which may not be the most up-to-date dataset.

The Challenge is making use of a number of digital tools to address the information gaps and asymmetries identified above (see full case study in Part IV for an overview of specific tools). In some cases, pre-existing tools are being repurposed to help achieve Challenge objectives; in other cases, Challenge funding is being used to enhance pre-existing tools or build new ones. These tools constitute an important part of Challenge activities, but it is important to recognise that they are being developed and used alongside other (non-digital) activities.

Note: 1. LUC classification defined as "a systematic arrangement of different kinds of lands according to those properties that determine its capacity for long-term sustained production" (Lynn et al., 2009, p. 8[10]).
Source: Part IV, Case Study 1.

3.2.3. Connecting administrators with programme participants (farmers) and the general public

In the outreach and enrolment component of policy implementation, and also when communicating with the broader community about policies and programmes, policy makers and administrators need to identify who to communicate with, convey information in a meaningful and easily accessible way, and allow others to communicate with the policy-maker or administrator (and perhaps with each-other). There is a broad literature on the public policy benefits of digital communications technologies such as smartphone apps, social media, web-conferencing, online polls, etc. (Picazo-Vela and Gutiérrez-Martínez, 2012[11]). In the context of agri-environmental policies, these technologies can assist in:

- lowering information search costs (both for the administrator and for stakeholders) and increasing participation in voluntary programmes
- allowing for multi-directional communication between entities (policy makers, administrators, farmers, NGOs, private third parties, general public
- facilitating adaptive management
- improving public awareness of, and participation in, agri-environmental programmes (and broader environmental initiatives).

These benefits generally arise via use of web-based technologies which lower the transaction costs for the activities listed above. Another newer avenue for reducing transactions costs is to make use of algorithms, machine learning and natural language generation[16] (NLG) technologies to automate (at least partially) some kinds of communications. These technologies are particularly useful when policy makers or administrators need to communicate with a range of stakeholders, who may be interested in receiving different information or receiving information in different formats or in different styles. Examples include:

- use of web-based submissions and online dialogues to allow comment and discussion on new policies or policy reforms (Brandon and Carlitz, 2002[12])
- use of NLG to automate differentiated communications about river heights and flood risk for different stakeholders (Arts et al., 2015[13]; Han et al., 2014[14]; Macleod et al., 2012[15]; Molina, Sanchez-Soriano and Corcho, 2015[16])
- use of social media to advertise policy initiatives or opportunities to participate in policy-making
- use of teleconferencing or web-based video conferencing to allow participatory policy-making, particularly to include participants in remote and rural areas.

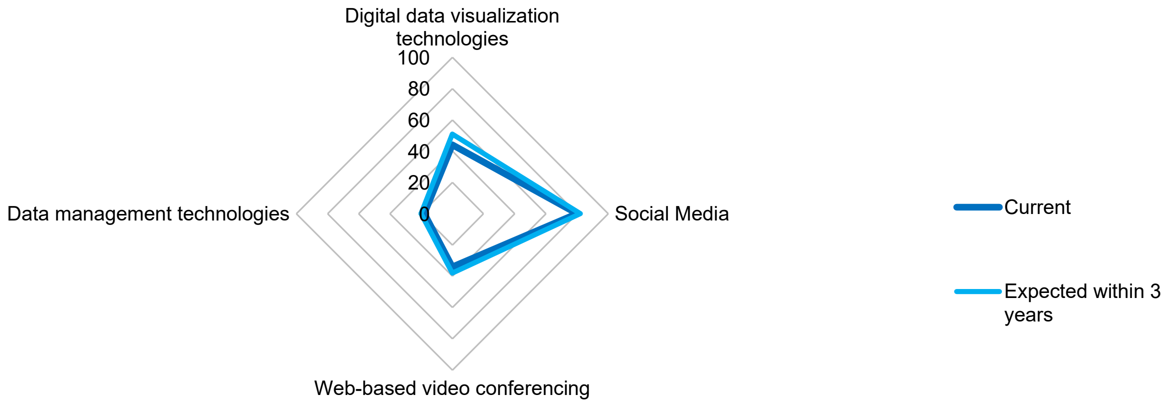
Apart from lowering transactions costs, use of web-based technologies may also allow for increased participation in policy-making simply by fostering greater awareness of policies and opportunities to become involved.[17]

Further, by increasing transparency about policy administration and encouraging multi-directional communication, digital communication technologies can also help overcome issues arising from a lack of trust between parties, often resulting from information asymmetries. In the context of agriculture, which is characterised by many actors dispersed across often vast landscapes, video conferencing and live-streaming are particularly useful in building trust between physically separated parties.

However, use of digital communication technologies also involves challenges. For example, attempts to make use of digital communication tools can be hampered by insufficient connectivity between actors—particularly in a context where farmers are located in remote areas—and by a lack of digital literacy of some stakeholders (e.g. older farmers). Also, use of social media and other online communication tools can potentially be manipulated or subject to misinformation campaigns.[18] Finally, public consultation processes can be very costly and may stymie policy implementation progress if not done well (Crase, O'Keefe and Dollery, 2013[17]).

Use of social media was by far the most commonly used category of digital technology for public communication, and currently used in 77 out of the 108 agri-environmental policies or programmes included in the dataset (Figure 3.8). Data visualisation technologies and web-based video conferencing were also used but to a lesser extent.

Figure 3.8. Current and expected future use of digital technologies for public policy communication



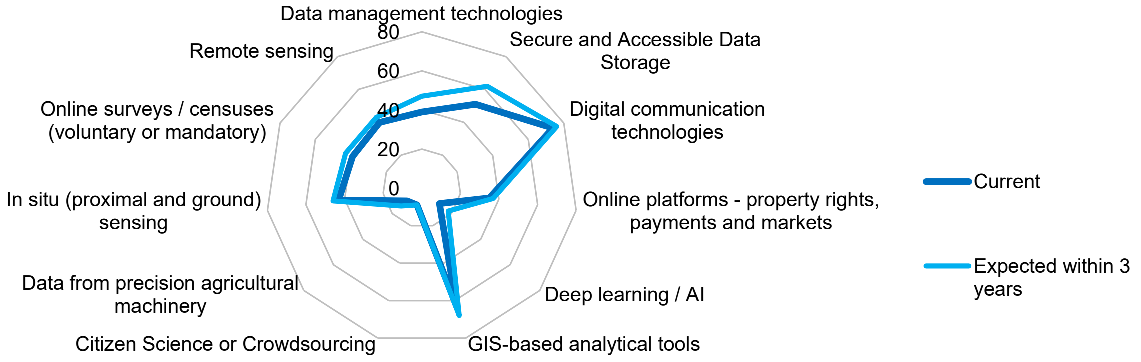
Source: OECD Questionnaire.

3.2.4. Digital technologies for policy implementation

Practical implementation of agri-environmental policies can involve a range of different activities and processes, depending on policy mechanism choice (Annex A provides an overview of agri-environmental policy mechanisms). This could involve, for example, administering payments provided to eligible farmers; executing contracts; administering tradeable permit programmes.

The OECD questionnaire provides information on use of digital technologies for initial outreach and enrolment in agri-environmental policies, as well as for policy implementation more generally (Figure 3.9). Digital communication technologies were by far the most-used technology for initial outreach and enrolment, followed by GIS-based analytical tools and online surveys or censuses. For implementation in general, digital communications and GIS-based analytical tools were the most-used technologies. Over the next three years, the most significant area of expansion is the use of secure and accessible data storage for policy implementation.

Figure 3.9. Current and expected future use of digital technologies for implementation of agri-environmental policies



Source: OECD Questionnaire.

The following sub-sections consider three specific aspects of how digital technologies can facilitate improved policy implementation. While monitoring and compliance can also be considered as part of implementation, section 3.2.5 considers use of technology for monitoring and compliance separately.

Facilitating collective governance mechanisms for landscape approaches to agricultural sustainability

Collective governance can provide an alternative to traditional mechanisms in which federal or national governments deal directly with individual farmers. They can also be useful to achieve more flexible policies. Such policy options may be desirable because they may i) foster participation and compliance by reducing the potential for inadvertent individual non-compliance due to uncontrollable natural events; ii) increase benefits of compliance (e.g. by creating conservation-focussed communities); or iii) decrease the cost of compliance by taking into account natural fluctuations (e.g. via regulatory requirements which "follow nature" by adapting to seasonal patterns) and lower transaction costs.

Digital technologies can help in all of dimensions identified by OECD (2013[18]) and others, e.g. (Prager, 2015[19]; Prager, Reed and Scott, 2012[20]) as fostering successful collectives, including: the importance of providing effective, accessible technical assistance; "intensive, transparent communication"; and collaboration between landowners, intermediaries, collective institutions and central governments. Such collective mechanisms are being implemented in the Netherlands (Box 3.5), to achieve environment-climate-biodiversity objectives in agriculture. These technologies and their accompanying administrative and legislative arrangements enable to consider the landscape as a whole while providing spatial and temporal flexibility for participating farmers and other stakeholders.

Box 3.5. Case Study 2: Digital technologies for Dutch agricultural collectives

In 2016, the Dutch government introduced a new scheme such that individual applications under the EU Common Agricultural Policy (CAP) are no longer possible in the Netherlands; all applications must be lodged by an agricultural cooperative (The Netherlands Ministry of Economic Affairs, 2016[21]). The government considered that the collective approach would: foster a "cross-farm approach"; provide greater flexibility in terms of the content, location and financial compensation of conservation activities; be simpler and less error-prone than administration based on individual applications; reduce costs and improve compliance; and be consistent with the existing social structure in the Dutch agriculture sector. In order to achieve this vision, a number of technical and administrative challenges needed to be solved. Conceptually, these challenges relate to addressing information gaps and creating co-ordination and risk management mechanisms between different actors, different scales and different legal frameworks:

- To achieve flexibility, the administrative system and the payment rules must be able to "follow nature" which requires high resolution data on where and when the relevant natural events occur, as well as the ability to track individual actions (e.g. on-farm practices) accurately in space and time.
- Achieving flexibility at the local level requires recognising that EU rules may not be similarly flexible, and therefore designing a system which allows local

flexibility while still "fitting in" with EU requirements. This introduces the risk that local flexibility will not "fit in", which needs to be mitigated.

- To achieve the desired "cross-farm" or landscape approach, the system needs to be able to track all individual efforts and assess the aggregate effect, and enable an interactive regional planning process whereby regional objectives are set taking into account individual actions, as well as vice versa.

To address these challenges, the Dutch collectives are developing a system of digital technologies: SCAN-ICT, Mijnboerennatuur.nl, and Schouwtool.[1] SCAN-ICT interfaces with the digital platforms of the Dutch paying agency, for example the Dutch Land Parcel Identification System (LPIS). This direct link makes it possible to change parcels and management activities on a short notice, without losing controllability requirements stemming from EU-legislation. Further, it ensures that the plans, claims and justifications officially submitted to the paying agency fit with the digital information the paying agency obtains from other sources. This helps improve the quality of these products, and reduces paying agency time to make a decision.

The system also includes "Quality Indicators" (QIs), which are system constraints to help prevent errors and to cross-check different elements. The QIs help demonstrate that the system is robust, and help to automate checks and reduce the risk of errors. The system was built by a "Building Team", comprising information communication technology (ICT) suppliers, the Netherlands Enterprise Agency, Dutch Provinces and BoerenNatuur. Team members worked together in an open, transparent and cooperative approach. The Building Team organises user groups and regularly consults them on their experiences using the system, collects suggestions on improvement and tests new proposals.

Note: 1. Mijnboerennatuur is an online platform which will "digitalise" communications between collectives and their participants and allow farmers to view their own data in real time as well as key documents such as contracts. Schouwtool will allow collectives to manage their inspections through SCAN-ICT. See full case study in Part IV for details.
Source: Case Study 2, Part IV.

Facilitating improved spatial targeting of agri-environmental policies

Micro-level agricultural data (e.g. farm level or field level data) is crucial for design and implementation of targeted agricultural and agri-environmental policies, in addition to improving agricultural research more generally (Antle, 2019[22]). First, it allows understanding of how policy impacts differ across dimensions such as location, production practices, industry or sector, socio-economic status. Second, it allows administrators to actually implement policies on a targeted basis: for example, targeting a policy to areas of most environmental concern or where potential benefits are greatest requires a highly-disaggreagted understanding of how farmers' decisions affect the environment. Another valuable feature for policy analysis is having data which enables tracking policy impacts through time, i.e. panel or longitudinal data.

Many studies assessing the environmental effectiveness and cost effectiveness of agri-environmental policies have recommended that a greater degree of spatial targeting could substantially improve these (Engel, 2016[23]; Lankoski, 2016[24]; Meyer et al., 2015[25]; Moxey and White, 2014[26]; Savage and Ribaudo, 2016[27]; Weersink and Pannell, 2017[28]; OECD, 2008[1]; OECD, 2012[29]). For example, Wardropper, Chang and Rissman (2015[30]) studied constraints to spatial targeting of water quality policies in the US Midwest. They found that the ability to target is constrained by lack of data, both in terms of data gaps and inability to access data on private lands or use it without making it identifiable. This conclusion is not specific to the US context, nor to the policy challenge of nonpoint source water pollution.

Digital technologies can help with both of these problems, and in fact several researchers have already designed data rich computer-based models and algorithms that could be used to implement spatially-targeted policies (Klimek, Lohss and Gabriel, 2014[31]; Rabotyagov et al., 2014[32]; Whittaker et al., 2017[33]). Governments need to recognise that access to agricultural micro data, including the ability to link different agricultural micro datasets (as well as other relevant data such as environmental data) is a crucial to produce more robust and targeted policy analysis, advice and administration.

Reed et al. (2014, p. 47[34]) note that "[d]espite significant advances in recent years, scientific understanding of the complex relationships between biophysical processes and service provision remains limited, and more is known about some services than others. Without adequate scientific understanding of causal relationships between management actions and service delivery, it may be difficult to assign payments to providers, or to demonstrate additionality i.e. not paying for something that has already been provided." It appears that the technical ability to implement spatially targeted programmes has much improved, but that achieving a very high degree of spatial resolution (or implementing results-based policies) may yet face some difficulties in certain contexts. Thus, policy makers can begin to implement targeted policies now, even if targeting is necessarily coarse due to data limitations, and can work towards improving the degree of granularity over time. Case Study 3 (Box 3.6) provides an example of how science is currently advancing in the field of gully erosion monitoring, which will allow for improved targeting of voluntary erosion remediation efforts in the Great Barrier Reef catchment, Australia.

Even as technological innovations and associated improvements in data are solving many of the previous technical challenges to implementing spatial targeting, there may be other kinds of challenges. One challenge identified by Wardropper, Chang and Rissman (2015[30]) is that institutional factors such as lack of funding and programme requirements constraint the ability to design targeted programmes (an example of a programming constraint is that the programme be voluntary or the targeting take into account national or regional goals in addition to local goals).

Another potential challenge is that farmers themselves might be resistant to targeted policies and therefore decline to participate (a problem particularly relevant for voluntary policies). However, Arbuckle (2013[38]) found evidence that, contrary to assumptions of resistance, some farmers support greater spatial targeting of agri-environmental policies. Endorsement of targeting was found to be associated with certain factors, such as "awareness of agriculture's environmental impacts, belief that farmers should address water quality problems, having experienced significant soil erosion, belief that extreme weather will become more common, participation in the Conservation Reserve Program, and belief that farmers who have natural resource issues are less likely to seek conservation assistance. Concerns about government intrusion were negative predictors of support for targeted approaches."

Use of digital communication technologies to better engage farmers and provision of digital services to farmers may help cultivate a positive attitude towards targeted agri-environmental policies. (See section 3.3.1, which discusses social impacts of monitoring and how results-based programmes can foster positive stewardship narratives for agriculture.) In particular, the potential challenge of farmer resistance may actually be a factor that digital technologies can directly help to mitigate, for example by using communications technologies and high resolution agricultural data to improve farmers' awareness of environmental issues and their contribution to them. Digitally-enabled results-based policies could therefore be an opportunity to improve programme participation and foster a community approach to improving the environmental performance of agriculture.

Box 3.6. Case Study 3: Remote sensing for targeted erosion and sediment control

The Australian and Queensland governments, in collaboration with the relevant local partners, have funded a number of related initiatives to develop remote sensing applications to assist in targeting key areas to improve the effectiveness and efficiency of efforts to control erosion and sediment loadings in agricultural catchments of the Great Barrier Reef (GBR). Advances in remote sensing technologies offer the opportunity to improve information on gully erosion at lower cost than existing methods. While remote sensing—particularly aerial images—has long been used to supplement in-field measurement, it is only recently that a range of newer remote sensing technologies have been deployed in GBR catchments or elsewhere. The Queensland and Australian governments have funded several projects aiming to assess the suitability of remote sensing technologies in this context. Key projects are:

- Gully mapping and drivers in the grazing lands of the Burdekin catchment —this project mapped and quantified gully extent and rates of change at a range of scales in the Burdekin catchment using airborne and terrestrial LiDAR[1] data.
- Monitoring Gullying Processes in the Great Barrier Reef Catchments (Photogrammetry project)—this project assessed the suitability of "digital photogrammetry[2] applied to aerial images routinely collected by state land survey agencies [for addressing] the challenges posed by gully erosion and sedimentation" (Poulton et al., 2018, p. i[35]).

Lesson learned: Use of advanced remote sensing techniques to map erosion processes over large spatial scales is technically feasible and yields improved results but is still relatively costly and challenging to undertake. Large knowledge gaps remain, and a combination of tools may be necessary to enable cost-effective mapping techniques and erosion management strategies. Further, knowledge of where and when gullies occur is not the only information gap needing to be filled. Thus, it is important to place the use of technology for a specific purpose (monitoring gullies) in the broader context of the overall policy objective (reducing negative impacts of erosion on the GBR.

Lesson learned: Improved understanding of physical processes must be balanced by economic considerations. The techniques investigated in the projects covered by this case study have the ability to significantly reduce information gaps about where and when gully erosion is occurring. This knowledge is fundamental to efforts to address the negative impacts of erosion, both for the Great Barrier Reef and more broadly for livestock producers and rural communities who rely on the productivity of land at risk from gullying.

However, there is still "very limited information about the cost-benefit of gully prevention and remediation approaches" (Tindall, 2014[36]). Targeting remediation and prevention efforts based only on the information provided by gully mapping ignores spatial differences in management costs and transactions costs, which may be substantial.[3] Information on both the benefits and costs of alternative erosion management activities is still needed to ensure efforts are targeted cost-effectively.

Lesson learned: Benefits and challenges of collaboration across organisations and across projects. Both the projects were highly collaborative and brought together researchers from a range of state and national government agencies. These projects are also part of a broader portfolio of research activities that are continuing to contribute to identifying, defining, characterising, measuring and modelling change in gully systems in key Great Barrier Reef catchments. Increasing costs associated with this this type of research and the rapid on-going technological development in the collection of ground based, remoted sensed and large spatial data requires adaption, innovation and successful collaboration of the research community. For the photogrammetry project, having access to a wider research network currently undertaking project activities within in the GBR region enabled transfer of localised knowledge which helped identify suitable case study areas. Collaborative exchange delivered cost savings in data collection for individual projects as well as useful calibration and validation data made available between different project groups. While there was a willingness for collaboration between projects, in reality researchers share their time between a number of competing activities.

Notes: 1. LiDAR (Light Detection And Ranging) is an active remote sensing sampling tool which uses the length of time a laser beam takes to return to the sensor to calculate distance.
2. As explained by Poulton et al. (2018, p. 16[35]): "Digital photogrammetry is the science of making, among other things, geometric measurements from images".
3. For example, Wilkinson et al. (2015[37]) report that the direct management cost (i.e. excluding any programme-related transactions costs) of the recommended combination of management techniques for GBR grazing lands varies between AUD 4 500 and AUD 9 000 per km of gully. Variation in cost-effectiveness per tonne of reduction in mean-annual sediment load is largely dependent on the efficiency of fencing.
Source: Case Study 3, Part IV.

Digital platforms for effective market-based agri-environmental instruments

Digital platforms can support better agricultural and agri-environmental policies by streamlining administration of agri-environmental payments (Case Studies 2 and 3) and facilitating farmer access to services (Case Study 10). They can also be used to facilitate the implementation of agri-environmental market-based instruments (MBIs).

In general, environmental MBIs are less used in agriculture, both relative to other sectors and to other types of instruments (OECD, 2013[39]) Most existing schemes involving agriculture relate to water quality (e.g. nutrient, sediment or temperature trading programmes), water quantity (i.e. cap-and-trade water rights instruments) or greenhouse gas emissions (OECD, 2013[39]; Shortle, 2012[40]).

Most agri-environmental MBIs in OECD countries make use of digital platforms in one way or another (Table 3.1).[19] These platforms provide a variety of functions, including:

- *Registry functions*—tracking the creation or registration of property rights and subsequent changes in ownership and location as trades take place.
- *Compliance functions*—for example, in a system which imposes conditions for participating such as baselines, providing a secure system for tracking buyer and seller eligibility to participate in the market.
- *Exchange functions*—digital marketplaces, online clearinghouses, online brokerage services.

- *Information and oversight functions*— for example, historical market information, market-relevant outlooks, public reporting on market outcomes.
- *Trading support tools*— for example, online simulation tools that help buyers such as regulated point sources estimate how many credits they need to purchase to fulfil their obligations, or that help a farmer estimate how many credits could be produced under alternative land management scenarios and taking into account location-specific factors.

Table 3.1. Digital platforms used in agri-environmental markets in OECD countries

Country	Programme	Environmental property right	Platform administrator
Australia	Hunter River Salinity Trading Scheme	Salinity credits	New South Wales Environmental Protection Agency
New Zealand	Lake Taupo Nitrogen Trading Program	Nitrogen allowances	Environment Waikato
Australia	State water registers e.g. Victorian Water Register ; NSW Water Register	Water-related entitlements including water access rights and water delivery rights	Victorian Water Registrar; WaterNSW
Australia	Private water exchanges e.g. Waterfind; h2Ox;	Water-related entitlements including water access rights and water delivery rights	Private entities
United States			
United States	Virginia Nonpoint Source Nutrient Credit Registry	Nitrogen and Phosphorous credits	Virginia Department of Environmental Quality
United States	Ohio River Basin Trading Project online registry	Water quality credits	Electric Power Research Institute
Australia	Emissions Reduction Fund	Carbon offsets	Clean Energy Regulator
Canada	Alberta Water Tool	Water availability	
United Kingdom	NFU Water Bank web-based noticeboard	Water available under abstraction licences	NFU Water
United States	Maryland Nutrient Trading Tool	Nitrogen and Phosphorous credits	Maryland Nutrient Trading Program, Maryland Dept. of Agriculture
United States	Pennsylvania Nutrient Credit Trading Program	Nutrient credits	Pennsylvania Infrastructure Investment Authority
United States	Nutrient Net	Various	World Resources Institute
United States	Virginia Nonpoint Source Nutrient Credit Registry	Nitrogen and Phosphorous credits	Virginia Dept. of Environmental Quality

Note: Hyperlinks to online platforms were accessed in September 2018. Dept. = Department.
Source: OECD Questionnaire, (Shortle, 2012[40]; Willamette Partnership, World Resources Institute and the National Network on Water Quality Trading, 2015[41]), authors.

There is little evidence available to quantify the specific benefits gained from using digital platforms for agri-environmental MBIs rather than non-digital counterparts such as paper-based registries or information and reporting regimes. Many agri-environmental MBIs are relatively new and have made use of digital platforms since their instigation; this makes it more difficult to isolate the specific benefits of using digital tools. Moreover, economics literature considering such MBIs generally focus on institutional design factors and do not describe implementation tools (digital or otherwise) in much detail. Nonetheless, benefits of using digital platforms to underpin agri-environmental MBIs appear to include:

- Integration between digital tools used to quantify property rights and property right registries, leading to increased robustness of the MBI as a whole. For example integration of watershed models and registries to estimate nutrient or carbon emissions reductions which form the basis of nutrient or carbon credits or to estimate water availability in tradeable water allocation regimes.

- Increased participation of buyers and sellers leading to increased market liquidity and greater "reach" for the MBI.
- Improved pricing transparency as digital platforms can be automated to provide both aggregated and detailed information on trade volumes and prices.
- Reduced administrative costs of processing trades.
- Improved ability to report (e.g. publicly or to the relevant oversight) on market outcomes.
- Improved ability to provide training to potential market participants to enable them to participate.

Table 3.1 suggests that for the majority of cases, existing digital platforms for agri-environmental MBIs are administrated by government agencies. Thus, a relevant question for governments is whether these agencies are suitably equipped (expertise, funding, etc.) to operate these platforms efficiently and effectively, or whether alternatives such as partnering with a third party or privatising the platform could improve them while maintaining their public policy objective. A first necessary step towards answering this question is to ensure that review and evaluation mechanisms for agri-environmental MBIs explicitly include an assessment of the efficiency and effectiveness of existing digital platforms.

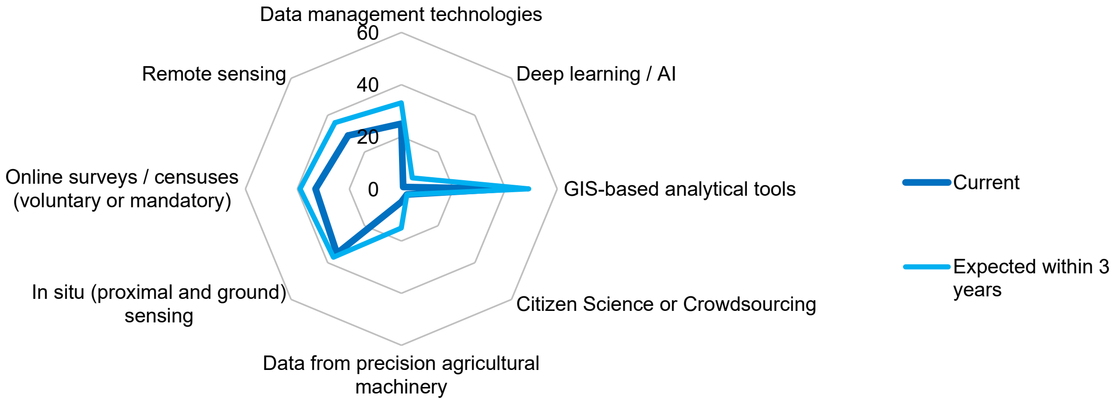
3.2.5. Digital technologies for monitoring and compliance

Agri-environmental policies which actively seek to alter farmer behaviour (whether through regulatory or market-based mechanisms—see Annex A) fundamentally work by realigning farmers' incentives through the introduction of conditional penalties or rewards which would not exist in the absence of the policy and which are intended to be dependent on famers' own actions. The presence of these conditional rewards and penalties creates the potential for non-compliance to be a farmer's preferred response – if, for example, a farmer can receive a conservation payment without actually undertaking (costly) conservation actions. This problem is one form of "moral hazard" and arises because of information asymmetries between farmers and administrators – if administrators had full information about farmers' actions they would never incorrectly apply a payment or penalty where it was not warranted.

The potential for moral hazard creates the need for the monitoring and compliance component in the policy cycle. However, these are costly activities, and therefore policy makers often opt to incompletely monitor programme participants. Digital technologies offer the potential to dramatically reduce costs of monitoring, for administrators but also for farmers. They can also facilitate different kinds of monitoring and compliance regimes (section 3.2.1 discusses this latter point).

GIS-based analytical tools are the most commonly-used digital technology currently used for monitoring and compliance of agri-environmental policies (Figure 3.10). Of the policy cycle components included in the OECD questionnaire, this component also showed the highest expected increase in use of digital technologies within the next three years, with increased use expected for all of the included technology categories except citizen science and crowdsourcing.

Figure 3.10. Current and expected future use of digital technologies for monitoring and compliance



Source: OECD Questionnaire.

Data from remote sensing, digital data from precision agriculture, and automation algorithms are some of the most promising technologies for improving the efficiency of monitoring and compliance in agriculture (Nikkilä et al., 2012[42]). Nash et al. (2011[43]) show that automation of compliance assessments for crop production or management standards (e.g. EU organic standards) is technically feasible in most cases (up to 90% of agricultural production rules). However, the authors note that, as of 2011, "it would be nearly impossible to realise this potential immediately due to the lack of availability of the required data in digital form". Case Study 4 below shows how far this field has advanced in the intervening years: the initiative detailed in the case study successfully carried out automated compliance inspections based on remote sensing for several EU CAP.

Empirical evidence on the administrative savings that can be made by use of digital technologies for monitoring and compliance is limited. However, available studies show that savings can be considerable. For example, DeBoe and Stephenson (2016[44]) studied the administrative costs of water quality trading programmes in the United States, and found that using satellite data to monitor land conversion (tree planting) required on average a quarter of an hour of administrator time, compared to around ten hours for an on-site visit. Evidence from Case Study 4 (below) shows that use of a remote-sensing based digital platform for performing on-the-spot-checks required under the EU CAP can reduce administrator costs by around 25%.

While using remote sensing data as a basis for more cost-effective monitoring and compliance appears to be extremely promising, it is worth noting that remote sensing is not necessarily suitable for monitoring all types of practices (for practice-based policies), particularly certain management practices (e.g. timing of fertiliser applications). As administrators move to update policies or programmes and monitoring and compliance strategies in light of new possibilities offered by digital technologies, the focus of agri-environmental programmes or production requirements should not be confined to only practices or results which are able to be monitored remotely. Rather, administrators should make use of several digital tools in combination (e.g. both remote and in situ sensing, as well as digital analytical tools such as models) to achieve the greatest overall improvement (of which reductions in compliance costs is just one factor) in cost-effectiveness (see Case Study 1 for an example of how a range of digital tools can be combined).

Beyond making existing monitoring and compliance functions more cost-effective, digital technologies also offer the possibility of transforming compliance approaches. These possibilities are discussed in Case Study 4.

Box 3.7. Case Study 4: Earth Observation initiatives for administration of the EU CAP

Context

The European Union Common Agricultural Policy (CAP) is the overarching system of subsidies and payment programmes for agriculture and rural areas in the European Union. The CAP is fundamentally an eligibility-based system: farmers must meet certain criteria in order to receive payments. There are three main monitoring and control tools used by the relevant competent public authorities ("National Control and Paying Agencies", NCPA): administrative checks of paperwork submitted by claimants (farmers), visual on-the-spot checks (OTSC) and Control with Remote Sensing (CwRS).

Due to the high complexity and diversity of the obligations that need to be monitored, each method has its limitations. According to DG-AGRI (Borchmann, n.d.[45]), the cost of controls to Member States in 2015 was EUR 1 125 million. The challenge for CAP administrators is therefore to minimise administrative transactions costs (both public and private) while maintaining effective standards of compliance. One crucial aspect of this is to reduce costs of obtaining information on farmers' activities.

Digital solutions: The RECAP initiative

One initiative from the European context, RECAP—Personalised Public Services in Support for the implementation of the Common Agriculture Policy, provides evidence on the potential benefits of earth observation technologies and online digital platforms. RECAP is a commercial platform (cloud-based Software as a Service - SaaS) that integrates satellite remote sensing and user-generated data into added value services for public authorities (administrators and inspectors), farmers and agricultural consultants, to improve the processes for implementing and monitoring the Basic Payment Scheme (BPS). RECAP makes use of various digital tools comprising six "components":

- The Remote Sensing (RS) component provides automated earth observation (EO) processing workflows (including algorithms) to assist paying agency inspections with respect to farmers' compliance to their CAP obligations.
- The Spatial component depicts the information generated by the RS component as well as external spatial data in digital maps, enabling users to visualise valuable information for an effective and efficient inspection process. For example, it can be used by the NCPA as auxiliary information in their risk analysis process, to help target inspections.
- The Business intelligence component is a data mining tool enabling public officers analyse large datasets stored in RECAP platform.
- The Workflow component is the core system of the platform. It provides farmers, consultants and inspectors with checklists of Cross Compliance rules applicable to the farm; guides farmers and inspectors on compliance procedures; generates notifications to farmers based on calendar of key dates; etc.

- The Software Development Kit (SDK) allows agricultural consultants and developers to develop their own “added value” services in an open approach within the RECAP platform, and deliver improved advisory services to farmers.
- The RECAP Digital Platform: Web and mobile applications interconnect the different system components in order to deliver the deliverables earlier described. They cover 5 categories; the general system requirements, the Basic Payment Scheme (BPS) eligibility/applications, farmer record keeping, the inspection process and farmer education/information. Each farmer has their own personal account on the RECAP platform where they are able to store data, records, and documents. The platform also enables NCPAs to increase the effectiveness of risk-based analysis for the selection of farms to be inspected.

Overall, the RECAP pilot demonstrated high accuracy in identifying crop types, but also showed that the suitability of remote sensing for compliance decision-making depend in part on the nature of requirements. Further, the pilot showed that RECAP tools can reduce administrators’ costs for performing required on-the-spot-checks, increase the transparency of inspections and improve the accountability of public organisations. Further specific results indicators are available in Part IV.

Source: Case Study 4, Part IV.

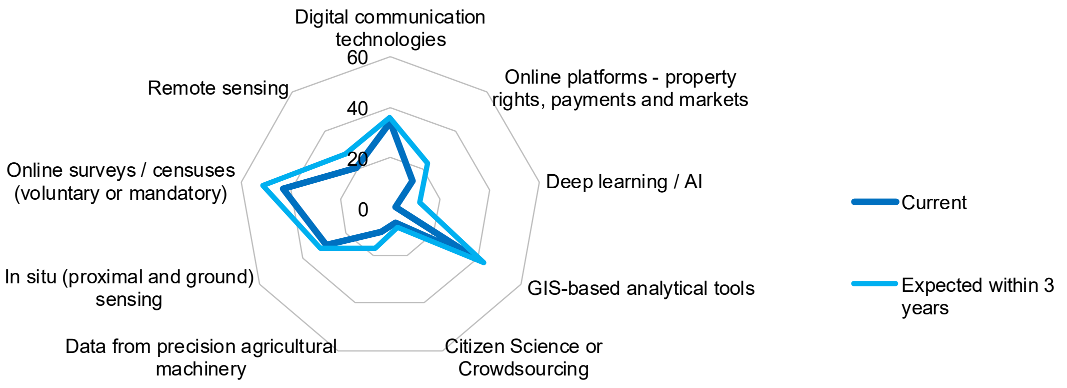
3.2.6. Digital technologies for policy evaluation

The policy evaluation component of the policy cycle entails an overall assessment of the policy mechanism, both on effectiveness and efficiency aspects (as well as other aspects such as synergies and trade-offs with other policies, unintended effects etc.). There is an extensive literature on optimal evaluation design for agri-environmental policy, which notes that in general policy evaluations are not done well, and that maintaining an adequate knowledge base for policy evaluation is a central challenge impeding development of robust, comprehensive assessments (Baylis et al., 2016[46]).

Digital technologies can assist in the creation and maintenance of knowledge bases for policy evaluation, and also help foster collaboration among relevant actors to ensure that evaluations appropriately take into account both qualitative and quantitative aspects. Insofar as digital technologies gather new knowledge or allow for improved analysis (e.g. analysis of big data), they may also facilitate calculation of a wider range of policy impacts and therefore improve the robustness of policy evaluations.

Results from the OECD questionnaire show that two digital technologies were most commonly-used for evaluation of agri-environmental policies (Figure 3.11): online surveys or censuses, followed by GIS-based analytical tools. Over the next few years, more organisations are expecting to make use of online platforms, remote and in situ sensing, online surveys or censuses and data from precision agricultural machinery for policy evaluation. Together with the implementation component, use of technologies for the evaluation component showed the greatest expected expansion in use of technologies in the next three years.

Figure 3.11. Current and expected future use of digital technologies for policy evaluation



Source: OECD Questionnaire.

3.3. Digital technologies can open new options for agri-environmental instruments

The design of existing agri-environmental policies is constrained by information gaps, information asymmetries, transaction costs and non-aligned incentives. These challenges can be so significant as to render certain kinds of policies (or policy design elements) infeasible. With the advent of digital technologies that can overcome or drastically reduce these challenges, a re-assessment of the "feasible set" of policy options is warranted; that is, digital technologies can open up new options for agri-environmental instruments.

This section focusses on three frontiers where digital technologies can facilitate expansion of the current feasible set of policy options:

- Enabling policies based on monitoring all participants rather than relying on controlling a sample of participants and strong negative incentives to compel compliance (section 3.3.1).
- Moving towards robust, cost-effective outcomes-based agri-environmental policies (section 3.3.2).
- Augmenting agri-environmental extension models with distributed knowledge networks and machine learning (section 3.3.3).

3.3.1. Technologies to enable new monitoring and compliance approaches

In the calculus of designing compliance and enforcement mechanisms, the policy-maker's objective is to ensure participating actors (farmers, in the case of most agri-environmental measures) find it more profitable to comply than not to comply.[20] When it is costly to detect non-compliance (as is generally the case), a common strategy for the administrator is to monitor only a small subset of total participants, and design penalties such that the *expected* profit from compliance exceeds that from non-compliance, according to the following formula (Becker, 1968[47]; Stefani and Giudicissi, 2011[48]):

$$p \times noncompliance\ penalty\ \geq cost\ of\ compliance$$

In this formula, "p" refers to the probability of detection, which (assuming that the administrator always correctly detects non-compliance for those agents it monitors) is equal to the proportion of the total population of participants who are monitored. Generally, this proportion is quite low – for example, under the EU Common Agricultural Policy (CAP) for the 2014-2020 period, national paying agencies are required to perform yearly on-the-spot-checks for at least 5% of beneficiaries (IACS[21] measures) or 5% of expenditure (non-IACS) measures (in addition to 100% administrative checks) (Borchman, date NA). When the probability of undergoing on-site monitoring is low, the regulator is "information poor", and the penalty for non-compliance needs to be high enough to serve as a deterrent (Macey, 2013[49]).

As discussed in section 3.2.5, digital technologies offer the opportunity to improve monitoring within existing compliance frameworks; that is, without changing policy settings such as minimum requirements about who and when to monitor, and penalties for non-compliance. However, as the above formula shows, increasing the probability of detection allows for a corresponding *decrease* in the penalty for non-compliance (other things equal). Therefore, digital technologies offer administrators the opportunity to radically recalibrate their enforcement approach.

In fact, administrators may be enabled by technology to move towards new "data intensive" compliance approaches based on high (near-100%) rates of remote monitoring. A discussion paper by the European Union's Joint Research Centre (JRC) (Devos et al., 2017[50]), considers the possibility for substituting on-the-spot-checks (OTSC) for administration of the EU Common Agricultural Policy (CAP) by a system of monitoring for checking the fulfilment of land use and land cover related CAP requirements. The envisaged system would cover 100% of relevant territory. The discussion paper describes the main components of such an approach and considers the technical and regulatory requirements needed to make it operational (see also case study in section 3.2.5).

Low-cost web-based mechanisms in which participants self-assess compliance and report on their performance, using a range of digital technologies to substantiate compliance claims is also a promising digitally-enabled compliance tool. Such portals can be linked to independent verification mechanisms such as sensor data or online registers to reduce incentives to misreport data.

Another digital technology which may enable new compliance approaches is distributed ledger technology (DLT) (e.g. blockchains). DLT allows for centralisation of information at the same time as decentralisation of access to and ownership of databases, as well as providing low-cost tools for auditing, authentication and traceability. As such, DLT, especially when used in combination with other technologies such as sensors and precision agriculture machinery, may allow more holistic compliance approaches in which intangible or credence attributes of agricultural products (e.g. social and sustainability aspects) are verified and tracked throughout agricultural supply chains. DLT could also be a tool for encouraging collective approaches in which individuals (e.g. farmers, environmentalists and even the general public) can contribute data to demonstrate compliance or achievement of programme objectives. Further, insofar as Blockchain applications can facilitate price premiums for differentiated goods (via providing robust and verifiable information and certifications to consumers), Blockchains may enable a shift from government- to market-provided incentives, which may reduce or remove the need for regulation, or change the nature of regulatory requirements. However, there are to date very few examples of such initiatives, and further work is required to investigate how distributed ledgers could enable new policy designs.

Finally, digital technologies can enable a holistic compliance approach in contexts where (environmental) regulation applies to several different kinds of entities. Sometimes regulators may have adopted compliance approaches which monitor different entities differently, for example because of legacy issues or because of heterogeneous costs of obtaining data across entities. While such a differentiated approach may continue to be warranted, digital technologies may introduce new lines of evidence for regulators for which costs are more homogeneous across different entities, or which allow a better view of the "whole picture". Box 3.8 provides an example from the context of the Murray-Darling Basin, Australia.

Box 3.8. Satellite imagery to improve compliance with water allocation frameworks

Digital technologies can help administrators to take a systematic approach to monitoring and enforcing environmental policies applying to agriculture but also involving other actors. This box provides an example from Australia, demonstrating the usefulness of satellite imagery as one tool to monitor compliance with water allocation frameworks and monitor ecological outcomes over large spatial scales.

In the Australian Murray-Darling Basin (MDB), agriculture is the largest water user (BoM, NA). However, as a result of government policy recognising the need to return more water for the environment, a new class of water users has emerged: "environmental water holders" (EWHs).[1] EWHs provide environmental flows and undertake watering activities throughout the MDB. In order for these environmental flows to fully achieve their objectives, they require protection from extraction by consumptive users, including agriculture. Therefore, the compliance regime needs to monitor different kinds of water "use" (i.e. consumptive and non-consumptive uses), over very large spatial scales, and in an environment characterised by highly varied water availability from year to year.

In recent years, several compliance incidents, including those connected with a limited number of agricultural water users, have highlighted the need for a more proactive approach to environmental water protection. While on-the-ground monitoring already exists in many areas (e.g. water meters, river gauging stations), it is difficult to gain a holistic compliance picture from these data sources alone. Recognising these limitations, in early-to-mid 2018 the Murray-Darling Basin Authority (MDBA) undertook a trial of the use of free, open and publicly available "Sentinel 2" satellite imagery to track and measure a specific environmental flow event. The trial represents the first large-scale use of satellite imagery in this context within the Murray-Darling Basin. The trial aimed to test the ability of satellite imagery to: 1) successfully track the watering event as it progressed through the river system; and 2) measure the degree to which water was present in farm dams and storages during the event, and how they changed over time, as significant changes could indicate compliance issues (since a restriction was placed on consumptive use extractions while this flow event took place).

The MDBA concluded that the trial successfully showed that remote sensing using satellite imagery provides a very important line of evidence for supporting compliance activities. These tools and their associated data offer the opportunity to observe the behaviour of water moving through the landscape, as well as water present in farm dams and storages and crop presence at a range of scales – from farm to catchment level and in close to real-time. These observations provide MDB water agencies with a new line of information, which may be used to trigger further investigation or other compliance responses as appropriate. Further work is underway to test the methods and build the systems required for application more broadly across the MDB.

Digital technologies other than satellite imagery and related data processing software also played a role in making the trial a success. In particular, community events were organised to inform stakeholders about the trial, with associated media releases and (in both digital and non-digital formats) factsheets, as well as social media posts to provide information. The trial also involved a range of actors and relied on freely available data provided by international institutions, highlighting the benefits of sharing data across borders (international data exchange) and between actors in a co-operative effort to improve compliance outcomes.

Notes: Technical details of the trial are publicly available in the MDBA report.
1. The most significant EWH is the Commonwealth Environmental Water Holder. See https://www.environment.gov.au/water/cewo, accessed February 2019.
Sources: Adapted from MDBA (2018) A case study for compliance monitoring using satellite imagery: the Northern Connectivity Event; Australian Bureau of Meteorology (BoM) National Water Account 2016.

Case Study 5 (Box 3.9) provides a practical example of how a range of digital technologies and data transparency tools can be used as part of a broader strategy to improve the flexibility and robustness of regulatory environmental programmes.

Box 3.9. Case Study 5: Digital technologies applied by USEPA to achieve Innovative Compliance

This case study provides a practical example of how digital technologies and data transparency tools can be used as part of a broader strategy to improve the flexibility and robustness of regulatory environmental programmes.

The United States Environmental Protection Agency (USEPA) implements national environmental law by writing and enforcing regulations, setting national standards that US states and tribes enforce, and assisting regulated entities to understand the requirements (USEPA, date NA). USEPA administers a range of US federal legislation relevant to agriculture, which has both regulatory and non-regulatory components (see additional description below).

During 2010-2013, USEPA self-identified a range of issues or areas for applying innovative compliance approaches, including: “gaps in information about the compliance status of regulated entities, unacceptably high rates of noncompliance, deficiencies in state enforcement of delegated programs, and substantial shortcomings in managing (collecting and transmitting) compliance-related information” (Markell and Glicksman, 2015[51]).

To address these gaps and improve the cost-effectiveness of USEPA’s compliance programme, USEPA began exploring innovative compliance tools in 2012 and activities such as the use of optical gas imaging cameras, electronic reporting, and working to improve the effectiveness of regulations and permits, have become more commonplace. Types of tools are:

- *Advanced monitoring and information technologies*: Real-time continuous monitoring generates actual measurements (as opposed to estimates), which reduces information gaps and information asymmetries between the regulator and the regulated entities
- *Electronic reporting*: E-reporting saves time, reduces error, enables automatic checks and triaging to help target monitoring and enforcement activities, reducing transaction costs of compliance and enforcement activities.

- *Transparency—public disclosure requirements*: Increased public disclosure provides incentive for entities to improve their environmental performance via reputation effects.
- *Rule and permit design—"Compliance-ready*" technology and rules with "compliance built in".[1]

Use of innovative compliance tools for agri-environmental policy implementation can broadly be separated into applications in regulatory (permit) and non-regulatory (voluntary) contexts.

In the US agriculture sector, some concentrated animal feeding operations (CAFOs) such as certain feedlots, dairies and poultry houses are "regulated by EPA under the *Clean Water Act* in both the 2003 and 2008 versions of the "CAFO rule" (40-CFR) (NRCS, date NA). These regulations underpin a permitting system known as the National Pollutant Discharge Elimination System (NPDES). Innovative compliance tools are applied for NPDES permittees via several avenues (see full case study for details), including electronic reporting; innovative compliance components in permitting; and innovative compliance tools used in rule-making.

Agricultural enterprises that are *not* required to obtain a permit may nevertheless choose to participate in a range of voluntary agri-environmental programmes. In this voluntary context, when a producer enters into a voluntary contract for provision of environmental goods, innovative compliance tools can be used in much the same manner as in a regulatory context, with compliance with the terms of the contract taking the place of compliance with a permit. Certification programmes (e.g. organic labelling) can also implement innovative compliance tools as part of the certification process. Programme administrators and producers can also make use of some of the innovative compliance tools—particularly electronic reporting in conjunction with transparency—to foster public support for entirely voluntary environmental efforts (i.e. even those which do not use contracts or any other form of legal enforcement mechanism).

This case study showed that technological change offers new possibilities for improved monitoring and compliance. However, there needs to be clear and fit-for-purpose processes for demonstrating suitability of advanced monitoring tools for regulatory purposes, which may differ from existing processes. However, this may be challenging to achieve in a context of fast-paced technological change. Given the rapid pace of technological change of relevant technologies, existing processes for vetting new technologies for regulatory purposes, particularly ones which take several years to complete, need to become more agile.

Note: 1. Recognising that enforcement action alone will not produce full compliance in every instance, this component entails promoting the use of technology, transparency, and other tools. Similarly, rules can be designed to require use of certain technology or processes by upstream manufacturing rather than attempting to regulate the use of technology by end users, e.g. auto manufacturers are required to install pollution control devices rather than requiring automobile buyers to do so (Giles, 2013[52]).
Source: Case Study 5, Part IV.

3.3.2. Result-based agri-environmental policies and modelling versus measuring

Numerous studies (e.g. (Burton and Schwarz, 2013[53]; Savage and Ribaudo, 2016[27]; Shortle et al., 2012[54]) have pointed out various flaws in agri-environmental policies which pay farmers to implement practices linked to the production of environmental services. These authors typically contrast such policies which "pay-for-practices" unfavourably with "result-oriented" policies, which reward producers directly for achieving specific environmental outcomes. However framework based a myriad of policy options are in fact available: e.g. *uniform*-pay-for-practice, *spatially-differentiated*-pay-for-practice, pay-for-*modelled-edge-of-field-performance*, pay-for-*modelled-results*, pay-for-*measured-results*. While a full elaboration of this spectrum is beyond the scope of the current project, even the brief description laid out above clearly suggests that the role of digital technologies differs across the spectrum.

Table 3.2 compares how different technology categories (refer to Table 2.1) could be used in two stylised representations of result-based programmes, and also a practice-based programme. This table is not intended to comprehensively list all the ways digital technologies could be used, but rather to compare key points of difference in technology use.

Table 3.2. Digital technologies in action- and result-based agri-environmental programmes

	Action-based programme Cost-share for installation of water quality (WQ) best management practices (BMP)	**Modelled result-based programme**: Water quality (WQ) trading	**Measured result-based programme** Farmland birds
Programme description	*Payments to individual farmers based on contracts to install and maintain WQ structures or to implement WQ management actions. Payments based on cost.*	*Market-based mechanism based on capping total amount of nutrient (N, P) emissions in a watershed and allowing trading of nutrient emission reduction credits.*	*Collective payment based on reaching objectives for bird populations at the landscape level; allocated to land managers based on individual habitat results*
Data collection technologies	Remote and in situ sensing to collect data to assess WQ state & impact pathways Online surveys & data submission portals for collecting BMP cost data Remote sensing, geo-referenced digital photographs and data from precision agriculture as model input and to monitor BMP implementation and maintenance	Remote and in situ sensing to collect data to assess WQ state and impact changes, model input Data from precision agriculture (e.g. on fertiliser applications and tillage practices) as model input	In situ sensing to collect field-level data on bird populations (e.g. nesting sites, number of birds) Crowdsourcing / citizen science apps to collect data on birds (e.g. in public spaces)
Data analysis technologies	Software for processing sensor data Watershed model (e.g. SWAT [a]) to estimate BMP effectiveness GIS-based analysis to support planning for BMP installation	Software for processing sensor data Watershed model (e.g. SWAT [a]) to estimate nutrient reductions and credit generation, and to estimate overall WQ impacts	Software for processing sensor data GIS-based analytical tools for tracking bird populations at a landscape level and collective planning of actions to maintain / improve bird habitats Machine learning / algorithms to analyse bird migration patterns
Data storage technologies	Secure storage of programme participants' personal details Cloud storage of shared data assets (e.g. maps, model data)	Secure storage of programme participants' personal details Cloud storage of shared data assets (e.g. maps, model data)	Secure storage of programme participants' personal details Cloud storage of shared data assets (e.g. maps, model data)
Data management technologies	Interoperability programs	Interoperability programs Secure credit register	Interoperability programs

	Action-based programme Cost-share for installation of water quality (WQ) best management practices (BMP)	**Modelled result-based programme**: Water quality (WQ) trading	**Measured result-based programme** Farmland birds
Data transfer and sharing: Digital communications	Online extension services / technical assistance Web-conferencing (e.g. to support processes for agreeing average BMP effectiveness parameters)	Online extension services / technical assistance	Online extension services / technical assistance Social media / apps for communication between farmers
Trading, payment and service delivery platforms	Secure e-payments	Secure e-payments Secure online access to credit register Online marketplace / auction platform	Secure e-payments Online platform tracking bird observations

Note: The stylised policies represented in this table are not intended to represent any specific existing policy.
a. SWAT = Soil and Water Assessment Tool, a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research. See https://swat.tamu.edu/, accessed September 2018.
Source: Authors.

Transitioning towards more result-based policies would appear to suggest an increasing role for sensor technologies to directly measure results. However, while this may be the case in some contexts, it may not always be: policies which pay based on some kind of outcome or performance measure are in most cases still based on *modelled* results rather than direct measurements. Water quality programmes are typical examples of policies which implement results-based payments using *modelled outcomes* (see third column of Table 3.2 as an example).

Even policies which are based on measured outcomes are likely to still make use of models in some way. For example, a policy paying for measured incremental nutrient loadings reductions in a downstream water body may still make some use of models to undertake initial validation of sensor technologies for use as approved measurement technologies in the programme, to establish overall baselines or regulatory targets, etc.

Thus, the most significant factors determining the types of technologies and their relative contributions may not necessarily be whether payments are made based on actions versus results, but rather:

- The extent to which policies are based on *modelled outcomes* versus *measured outcomes* (whether BMP performance, edge-of-field performance, or environmental outcomes which may be downstream or at the landscape level).
- The nature of the policy mechanism: e.g. trading programmes can make use of digital trading (e.g. online marketplaces), whereas a programme where the administrator pays participants directly may have more need for secure online payment mechanisms.
- The institutional setting of the policy mechanism, particularly whether the programme requires collective or coordinated action (e.g. policy takes a landscape approach) rather than only individual actions: policies taking a collective or co-ordinated approach are likely to have greater demand for digital technologies which facilitate communication between participants and which provide landscape-level analysis.

Results-based programmes generally have the feature that provision of incentives to programme participants is linked to measured or modelled results. Another important dimension of such policies is the possibility of setting programme *objectives* or *requirements* which are adaptable to environmental results. Examples could include:

- policies governing water access and use which are linked to river, aquifer or storage levels;
- habitat maintenance requirements (e.g. restrictions on mowing) directly linked to monitoring of bird populations;
- livestock management policies directly linked to monitoring of large carnivore populations (i.e. in a context where a policy goal is to restore large carnivore populations in or adjacent to a livestock area).

Such policies are promising for fostering an agricultural sector are "nature inclusive" and resilient to frequent changes in environmental conditions. However, they rely on technology to provide robust information on highly variable environmental phenomena in (near-)real-time, potentially over large areas. This will likely require establishment of wireless sensor networks or other in situ data collection technologies, as remote sensing, despite recent advances, does not yet provide continuous monitoring.

3.3.3. Digital networks, platforms, AI and machine learning for policy communication and extension

Extension services play a vital role in increasing farmers' agronomic skills and their understanding of the productivity and sustainability of impacts of their actions. Depending on the particular policy mechanism selected, extension services can be the key policy focus or can complement other aspects of policy implementation. Further, extension services can also be used to educate the broader group of stakeholders (e.g. environmental groups, the general public) about efforts undertaken to improve agricultural sustainability and about how other stakeholders can participate.

A key challenge for extension services is how to maximise effectiveness given limited resources. In many instances, extension officers may not be accessible when the farmer needs them (Nguyen and Thai-Nghe, 2016[55]), whether due to high travel costs, because ratios of extension officers to farmers are too low to service all demand or other factors.

Extension providers (both public and private) are establishing distributed digital communication networks to improve access to extension services, and also to facilitate peer-to-peer learning. Digital communication networks can reduce costs of communication, provide improved human-human interaction, especially over large distances, and improve educational outcomes (e.g. by providing interactive learning environments) (Kelly, McLean Bennett and Starasts, 2017[56]).

Machine learning goes a step further by making use of artificial neural networks to analyse specific problems faced by farmers and provide semi-automated recommendations. Recent initiatives to develop neural networks to supplement human-delivered extension programmes—exemplified by the work of Mohanty et al. (2016[57]) and Sladojevic et al. (2016[58])—are developing software for the automated classification of crop diseases using deep neural networks.

Another technology for reducing the cost of communicating with diverse audiences is the use of algorithms (e.g. natural language generation (NLG) algorithms) to automate translation of data into easily digestible communications and automated notifications of alerts (e.g. notifying farmers of pest or disease outbreaks, weather-related risks, but also notifications of extension opportunities such as webinars, field days, or training dates). Section 3.2.3 provided examples of using NLG-based automation to facilitate communication between administrators and programme participants, but automated communication can be equally useful for extension services and communicating about agri-environmental policy more generally, including with the general public.

Interactive digital platforms are another useful tool for extension services and wider communication about agri-environmental policies. Examples are shown in Table 3.3. Many of these examples are not specifically focussed on agriculture; rather, they provide for agri-environmental impacts or initiatives to be considered as part of a more holistic picture. They can therefore have the added benefit of forging common ground between agriculture, other sectors of the economy and the general public.

Table 3.3. Online, interactive platforms for extension services and communicating about agriculture and the environment

Platform	Country	Description	Website
Atlas of Living Australia	AUS	A collaborative, national project that aggregates biodiversity data from multiple sources and makes it freely available and usable online.	https://www.ala.org.au/
Agroclimatic Observatory	CHL	An interactive collection of maps and other figures that monitor drought at present, near future and in the recent past. The maps and figures can be manipulated and are linked to the original data.	http://www.climatedatalibrary.cl/IMP-DGIR/maproom/?Set-Language=en
Online suite of geospatial products	CAN	A suite of interactive agriculture-related maps, geospatial data and tools to help users make better decisions for environmentally responsible yet competitive agriculture.	http://www.agr.gc.ca/eng/?id=1343066456961
MAGIC	GBR	An interactive online map providing authoritative geographic information about the natural environment from across government. The information covers rural, urban, coastal and marine environments across the United Kingdom.	https://magic.defra.gov.uk/
Korean Soil Information System (KSIS)	KOR	KSIS is an online portal that provides soil information and recommends agricultural crops and fertiliser application amounts based on soil characteristics. The system is based on soil information and agri-environmental data collected by Rural Development Administration of Korea.	http://soil.rda.go.kr
Akkerweb	NLD	An open platform for digital services for precision farming. See Case Study 9 for further information.	https://akkerweb.eu/en-gb/
Interactive Emissions Tracker	NZL	An interactive tool summarising New Zealand's Greenhouse Gas Inventory.	https://emissionstracker.mfe.govt.nz/
EnviroAtlas	USA	A set of online, interactive tools allowing users to discover, analyse, and download data and maps related to ecosystem services.	https://www.epa.gov/enviroatlas
Sound Impacts	USA	An online portal for all of practitioners and implementers of Green Infrastructure (which could include a range of actors such as government, industry, farmers, or even a member of the public) as well as for "anyone curious" to see what efforts and investments are being made to protect and improve the natural assets of the Puget Sound area.	http://www.soundimpacts.org/projects/list/tracts/all/

Note: Web links accessed September 2018.
Source: OECD Questionnaire and authors' own work.

Notes

[1] Information gaps (imperfect information), information asymmetries and the presence of transaction costs constitute three key factors explaining why outcomes observed in the "real world" can systematically differ from predicted outcomes based on standard neoclassical economic theory, which assumes full information and (often) zero transaction costs. The first two are the subject of the strand of microeconomic theory known as *information economics* (pioneered by economists such as Hayek, Akerloff and Stiglitz), while *transaction cost economics* constitutes a separate-but-related branch stemming from seminal contributions by Coase. An extensive literature explores the implications of these three "market failures" in relation to agricultural and agri-environmental policies. See, for example, Coggan, Whitten, & Bennett (2010[64]), McCann (2013[62]), Nguyen (2013[63]), Shortle, Reed & Nguyen and Stavins (1995[61]). In addition, the conceptual framework identifies *incentive non-alignments* separately as an important factor in explaining why information gaps, information asymmetries and transactions costs persist.

[2] *Information gaps* (imperfect information) refer to the absence of relevant information: for example, the environmental impacts of agriculture (particularly nonpoint sources) have historically been prohibitively costly or technically infeasible to monitor.

[3] *Information asymmetries* occur when some information is known by some but not all relevant parties: for example, farmers know their own costs and intentions but might not have incentive to reveal this to the regulator or policymaker. Because it is costly for the agri-environmental policy administrators to obtain this information, farmers can extract "information rents" (Lankoski, 2016[24]). Information asymmetries cause problems of moral hazard and adverse selection, manifesting in agri-environmental policies as problems such as *non-additionality* and *leakage.* (OECD, 2012[29]); (OECD, 2010[65]; Börner et al., 2017[59]).

[4] There are many definitions and classifications of *transaction costs* in the literature (for example, McCann and Easter, (2000[70]); McCann et al. (2005[67]); Krutilla and Krause (2011[72])). Following Lankoski (2016[24]), this paper uses the broad definition offered by McCann et al. (2005[67]): "transaction costs are the resources used to define, establish, maintain, and transfer property rights", which includes costs arising from the design, implementation, control and evaluation of agri-environmental policy measures (Claassen, Cattaneo and Johansson, 2008[68]); (Heimlich, 2005[71]) (Marshall, 2013[69]); (McCann and Easter, 2000[70]). Transaction costs can erode the direct benefits (total welfare gain) from a policy and their distribution can affect how policies are designed. For example, if the policy maker is more concerned about costs faced by *farmers* than costs borne by government, they may face a trade-off between minimising total costs (transaction costs plus direct costs) and minimising costs borne by farmers.

[5] *Non-alignment of incentives* occurs naturally because different actors have different preferences. Also, in some cases non-aligned incentives occur because incentives created by policies or regulations can (perhaps unintentionally) be mis-aligned (i.e. policies create different incentives for different actors which conflict) or competing (i.e. several policies create conflicting incentives for one specific actor). Incentive non-alignments are one key reason why information gaps or asymmetries persist, and why they are costly to overcome. Incentive non-alignments can also cause different actors to work against each-other, rather than working together to achieve a common objective.

[6] This analysis does not assume that the solution to problems caused by information gaps and information asymmetry is to maximise information available to policy makers or administrators.

[7] See Annex B for an overview of policy components and agri-environmental policy mechanisms.

[8] Managing Authority of the Rural Development Programme for the Autonomous Region of Madeira (Autoridade de Gestão do Plano de Desenvolvimento Rural da Região Autónoma da Madeira) (Portugal).

[9] For information on respondents, including respondents' level of government, see Annex B. For example, in Canada, agri-environment is a shared jurisdiction between federal and provincial and territorial governments. Canada's provinces and territories design, deliver, and consult with their producers on agri-environmental on-farm programs. Seven provinces of Canada, and Agriculture and Agri-Food Canada, provided responses to the OECD questionnaire on the use of digital technologies for agri-environmental policies, as an assessment for the country as a whole is not possible.

[10] *Policy areas* specified were: water quality, water quantity, air quality, biodiversity, soils, climate change (on-farm adaptation) and climate change (on-farm mitigation). *Policy mechanisms* specified were: environmental taxes; agri-environmental payments or subsidies; extension services and information provision; trading schemes (environmental markets); activity prohibitions; environmental standards; environmental property rights; and environmental stewardship programmes (not elsewhere specified). Respondents were able to select multiple policy areas and policy mechanisms.

[11] These respondents were: for precision agriculture data: Canada-Prince Edward Island, Canada-Ontario, Chile-INIA, Chile-SAG, Korea-RDA, Denmark, Estonia-Ministry of Environment, Korea-MAFRA, Korea-Gyeong-gi provincial government, the Netherlands and USA-USDA NRCS. For retail scanner data: Austria, Canada-Quebec, Canada-Nova Scotia, Chile-CONAF, Chile-INFOR, Chile-SAG, Korea-MAFRA, and Switzerland.

[12] Defined as "[a] senior executive position, formally responsible for setting strategic direction for the use and management of information technology systems, including digital records management."

[13] The Recommendation does not define the term "digital strategy". The OECD used the following definition: "A 'digital strategy' is an organisational strategy which serves several functions. First, it articulates the organisation's vision regarding the contribution of digital technologies towards achieving the organisation's strategic objectives. Second, it sets the organisation's priorities for digital technology procurement and related investments (e.g. investment in staff training). Third, it sets out organisational reforms which are needed to ensure the organisation effectively and efficiently harnesses opportunities offered by digital technologies, while also appropriately addressing challenges. The development of a digital strategy can engage stakeholders ranging from the research community, other government entities, business, and civil society to regional and local governments. In some cases, organisational digital strategies may reflect or be based on broader national or government-wide strategies." Adapted from articulation of OECD (2014[74]).

[14] Defined as "[a] written document specifying a set of broad, high level principles which form the guiding framework in which data management can operate." (Source: OECD Glossary of Statistical Terms).

[15] See, for example, Robisch (2014[133]), who discussed the interaction between pollutants in the setting of water quality objectives in the context of setting Total Maximum Daily Loads (TMDLs) in the United States.

[16] Natural language generation is "the automated generation of language based on digital data processing" (Arts, van der Wal and Adams, 2015, p. S633[73]).

[17] However, Balla and Daniels (2007[66]) tested the hypothesis that introduction of web-based systems for providing comment on rule-making by the US Department of Transportation would dramatically increase the number of public comments filed and found that, contrary to expectations, overall participation by stakeholders remained approximately the same as before web-based submissions were introduced.

[18] For example, Lawrence and Estow (2017[60]) examine options to address misinformation about climate change circulated via social media.

[19] For example, all examples covered in OECD (2013[39]) use a digital platform of some kind.

[20] This is known in economic theory as satisfying the incentive compatibility constraint. In the case of voluntary mechanisms, there is a little more complexity as the administrator needs to ensure both the participation and incentive compatibility constraints are satisfied (i.e. that (enough) farmers participate *and* comply).

[21] Integrated Administration and Control System.

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Chapter 4.

Issues which may prevent digital opportunities from being realised

This chapter discusses a number of different issues which may prevent opportunities identified in Chapter 3 from being realised in practice. It discusses challenges to the successful uptake of technologies by policy makers and programme administrators and provides practical guidance in addressing them. Further, it considers new risks which may arise as digital tools are adopted to support policy in agriculture, and provides guidance on steps policy-makers and administrators can take to mitigate such risks.

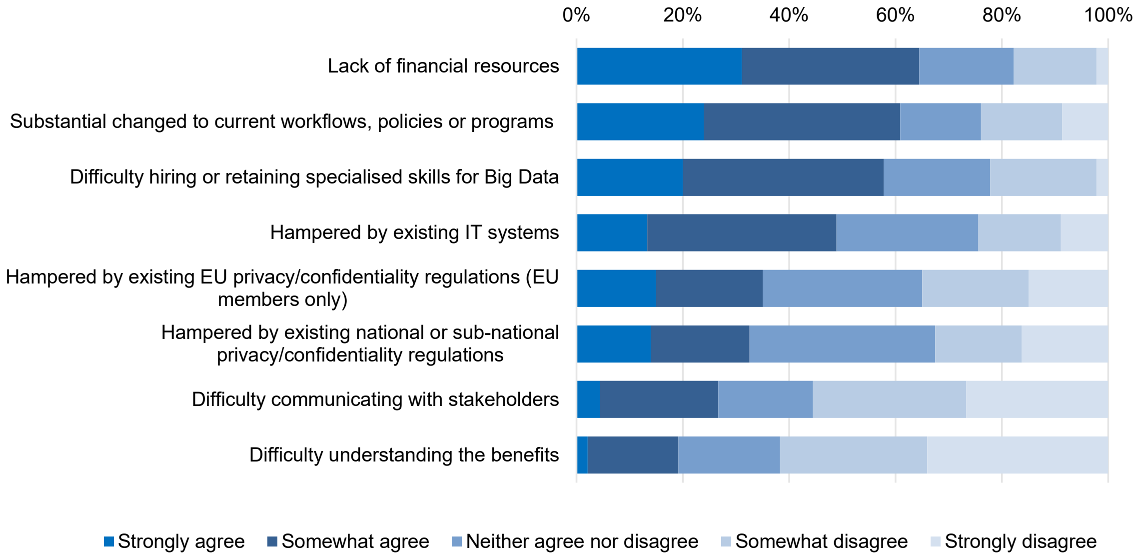
Chapter 3 provided a range of examples of how digital technologies are currently being used to improve policies, and detailed further opportunities for the future. As identified in the conceptual framework (Figure 3.1), a number of different issues may prevent opportunities from being fully realised in practice. This chapter examines different types of issues in turn:

- Practical challenges faced by policy administrators (section 4.1)
- Existing institutional and policy settings may act as an impediment (section 4.2)
- New challenges may occur as digital technologies are increasingly used to support policy in agriculture (sections 4.3 and 4.4).

4.1. Practical challenges for the use of digital technologies by policy makers and administrators

Responses to the OECD Questionnaire show that three challenges are perceived as the most important limiting factors to digital technologies use (Figure 4.1): constrained financial resources, the required substantial change to current workflows, policies or programs, and access to specialised skills required to use "big data".

Figure 4.1. Organisational challenges in relation to using digital technologies and "Big Data"



Note: N=45, except for EU question, where N=19.
Source: OECD Questionnaire.

Little information is currently available on the costs involved in reconfiguring existing IT systems, retraining staff (or other options such as hiring new staff, or outsourcing). However, some examples are provided via the case studies conducted for this report:

- Case Study 1 (Digital tools for New Zealand's *Our Land and Water* National Science Challenge) includes funding data for a range of projects, which include development of digital tools (but are not solely limited to tool development): for example, NZD 3.56 million in funding was provided for the "interoperable modelling" project, which aims to develop a modelling system populated with models which draws on national datasets and which are implemented in an interoperable modelling framework.

- Case Study 2 (ICT-SCAN system for Dutch Agricultural collectives) reports that the Dutch government provided EUR 10 million towards the initial setup cost for the IT system, and ongoing costs are estimates at EUR 1-2 million.

These estimates show that the costs of developing digital tools for policy-making are not insignificant.

Moreover, developing the skillsets and organisational capacity necessary to effectively deploy digital technologies for policies is also likely to be costly, in terms of both agency time and actual costs incurred. There is very little data available on these cost aspects; however, failing to take them into consideration will overstate the net benefits of digitalisation. While many of these costs could be considered "start-up" costs (and therefore diminish in importance over time), there are also likely to be other fixed costs, as well as ongoing variable costs associated with error-checking, testing, maintaining and upgrading digital systems. These costs as well as ongoing skills and management requirements need to be factored into overall budgeting and planning, so that digital systems underpinning policy delivery continue to function well over time.

An additional range of practical challenges for the use of digital technologies in the context of improving agri-environmental indicators (AEIs) were also identified at a joint OECD-Natural Resources Institute of Finland (Luke) workshop in May 2018 (Box 4.1). These are related to the continued inability (despite recent advances) of digital technologies to cost-effectively "fill in" existing information gaps relevant for producing AEIs. They also related to institutional challenges, particularly lack of standardisation and differing regulatory regimes leading to an inability to achieve representativeness or comparability.

Box 4.1. Challenges yet to be overcome: Evidence from OECD-Luke workshop

The OECD, together with the Natural Resources Institute of Finland (Luke) convened a workshop on '*The use of new technologies for agri-environmental indicators to support effective policy monitoring, evaluation and design*'. The workshop provided an overview of cutting-edge developments of the use of digital technology and agricultural "Big Data" to form robust and readily interpretable indicators that can be used for the monitoring, evaluation and design of agri-environmental policies. Apart from identifying a number of promising initiatives, participants identified a number of challenges that have yet to be overcome. Many of these challenges are relevant to use of digital technologies to support better agricultural policies more generally. In particular, participants identified the following:

Technological constraints and data gaps

- For tracking specific indicators like birds or pollinators, remote sensing technologies still need to be combined with in situ monitoring programs which tend to be costly to maintain (see Case Study 9).
- Indicators resulting from a combination of digital technology sources and modelling are highly sensitive to the methods used for processing and modelling the data. No consensus exists across jurisdictions on a standard set of processes and methods.

- Agri-environmental (AE) indicator models (even those using satellite data) are often based on much smaller ecological regions than are the focus of AE policies. So, there is still a need to be able to make justifiable assumptions to interpolate data.
- It is still difficult to analyse environmental performance at the aggregate level of the commodity (in part because aggregate performance is the sum of the performance of many individual actors in a range of specific contexts).

Institutional or regulatory constraints

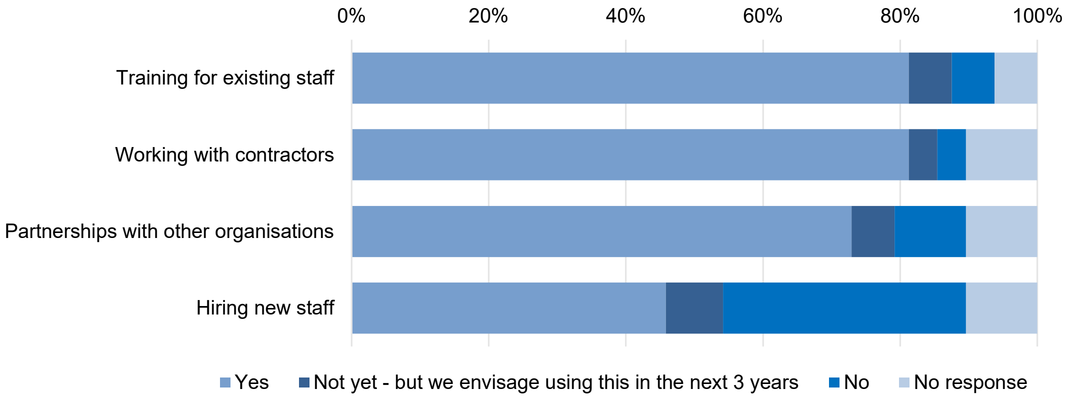
- Within the EU context, the LPIS/IACS data operate at a level of detail which can currently not be achieved with satellite data in a standardised or automated way at EU level. Moreover, within certain countries where multiple LPIS/IACS operate, LPIS/IACS data are not harmonised. There are also technical problems to keep track of a given field over time using GIS software.
- As much of the data from digital technologies are owned by farmers or private companies, lack of harmonisation of data privacy laws creates imbalanced incentives across jurisdictions for farmers to share their data.
- Data from some technologies, such as sensors are only available from farmers who have access to them. While data from these sources can be highly detailed, its representativeness at the regional or national level is questionable.
- Although digital technologies allow for improved assessments of complex physical processes and improved understanding of risks and scientific uncertainty, it is still very difficult to effectively communicate scientific uncertainty and risk to stakeholders.
- There is a need to adequately prove both the efficiency and uncertainty of new technologies before they can be used for policy, but there is not always agreement or clear processes to achieve this.
- Limits in AEI data still hinders the ability to take a holistic approach to assessing agricultural sustainability and to draw policy recommendations from this assessment.
- Non-alignment of incentives remains between researchers, the private sector and farmers: can new incentives to collaborate be created?

Sources: Presentations from the OECD-Luke Workshop, 29 May to 1 June 2018, Helsinki, Finland.

4.1.1. How are organisations responding to these challenges?

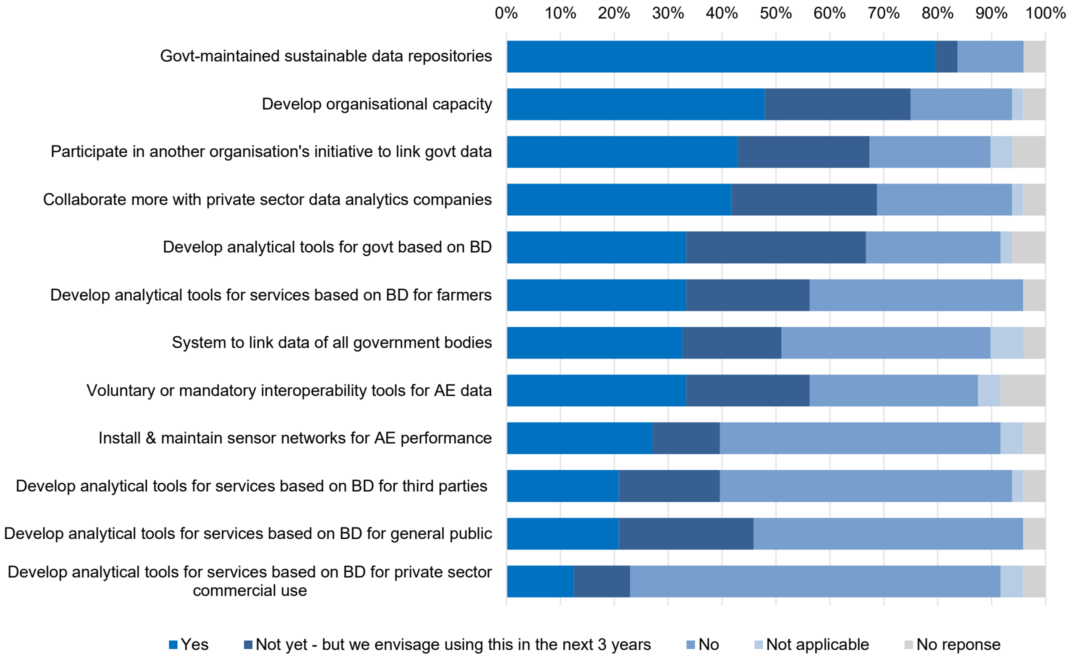
Evidence shows that organisations are also already working to tackle these challenges. The results of the OECD questionnaire (Figure 4.2 and Figure 4.3), show in particular that 80% of respondents indicated that their organisation is undertaking training for existing staff or working with contractors. In contrast, only 46% are hiring new staff; this may reflect that the majority of organisations face financial constraints and difficulty hiring or retaining the specialised skills needed to work with Big Data. These responses suggest that financial constraints and skills mis-matches are both important challenges to address.

Figure 4.2. Building capacity to work with new digital technologies and "Big Data"



Note: N=48.
Source: OECD Questionnaire.

Figure 4.3. Initiatives to increase use of digital technologies and Big Data for agriculture



Note: N=49. BD = Big data; AE = Agri-environmental.
Source: OECD Questionnaire.

The results also show that a most commonly-used means to foster use of digital technologies and big data for agriculture is to invest in government-maintained sustainable data repositories; 81% of respondents already have such initiatives underway. However, it is unclear to what extent these repositories are open to the public, including farmers. Consistent with the notion that governments should not "crowd out" private sector development, the least-common initiative among respondents was developing analytical tools based on big data for private sector commercial use.

In terms of future initiatives, creation of analytical tools based on big data for governments was the most commonly-anticipated initiatives for the near future (within the next three years), followed by increased collaboration with private sector analytics companies. Around a third of respondents have already developed analytical tools for farmers, and a further 23% were expecting to do so in the next three years. Respondents also indicated they would in future be developing analytical tools based on big data for the general public.

4.2. Institutional and policy settings can limit opportunities for policy from being realised

Throughout the preceding sections, specific pathways for digital technologies to improve existing agri-environmental policies and enable new ones have been explored. It has also been recognised that there are challenges to successfully implementing digital solutions and digitally-enabled policies, some of which have been illustrated via the case studies. This section elaborates on key institutional and policy settings which can limit the potential offered by digital technologies being realised.

4.2.1. Institutional constraints and lock-in

Institutional path-dependencies can act as a disincentive for organisations to change their processes (e.g. administrative processes) to make best use of new technologies. There can be several types of path-dependencies.

First, policy administrators might consider that the cost to be borne for the change in system would be too high. Such costs not only include the cost of setting the new digital system but also the expenditure to train staff, and time needed for them to adjust to new systems, which can vary according to staff skills and flexibility. The questionnaire highlights that a number of organisational path dependencies constrained the adoption of digital technologies and big data (Figure 4.1). These included being hampered by existing IT systems, lack of financial resources, and that substantial changes to organisational workflows, policies or programmes would be needed to make more use of digital technologies.

Second, existing environmental objectives may be specified in terms which reflect pre-existing levels of technological feasibility. For example, specifying air quality or water quality objectives in terms of average levels over a given period may preclude the use of short time-step point-in-time data or continuous monitoring which can provide a higher degree of temporal granularity (Macey, 2013[1]).

Third, many agri-environmental programmes, particularly agri-payment programmes, are designed to make use of reference levels, baselines or thresholds to determine participant eligibility, payment amounts or to establish a set of practices that a participant may receive payment for. Two important examples include:

- cost share payments which use state, regional or national averages for cost elements (e.g. USDA NRCS uses state-based payment schedules for making conservation payments under a range of programmes[1]);
- use of relatively coarse regional averages as parameters in specifying physical relationships (e.g. nutrient-removal effectiveness of different management practices; emissions factors for livestock or crop types).

Existing modelling apparatus and consensus mechanisms for establishing reference levels or parameters for agri-environmental policies or for policy-relevant research may require reform in order to be able to make use of new, higher resolution data products (demand for which would also increase demand for improved sensor networks). Such reform may be costly, particularly in regulatory settings where processes for establishing reference levels or important parameters may be codified in regulations. However, advances in algorithms and simulation techniques have lowered the cost of building more refined models including processing the data they require.

Fourth, agri-environmental regulations may set procedural requirements that preclude uptake of innovative digital technologies. A key example is regulations specifying monitoring and control procedures which require on-site "boots on the ground" monitoring. Such requirements impede the uptake of earth observation and other remote sensing technologies for monitoring and compliance activities. Further, the use of technology or performance standards and sequencing requirements[2] may also limit the realisation of opportunities to improve and expand the use of digitally-supported policy instruments. For example, demand for digital technologies to verify emissions reductions, or demand for online markets for trading environmental credits (e.g. nutrient credits, carbon emissions) may never eventuate if market-based mechanisms as a whole are stymied by technology standards or sequencing requirements (Stephenson and Shabman, 2017[2]).

Fifth, broader regulatory settings may limit individual organisations' ability to make use of digital technologies. An important example is privacy or confidentiality regulations (see next section). Thirty per cent of respondents to the OECD questionnaire agreed or strongly agreed that they were hampered by existing national or sub-national privacy or confidentiality regulations. While this data indicates that regulatory constraints are not an issue for the majority of responding organisations, nevertheless this challenge occurs for a sizeable minority. Interestingly, in several cases, one respondent from a particular country would strongly agree that national or sub-national regulations were a challenge, whereas other respondents from the same country indicated otherwise. While decisions about privacy regulations are complex and need to account for a broad range of factors, these situations may offer an opportunity for cross-organisational discussion within countries, and for national agencies to better understand exactly when and where privacy regulations are a constraint for government organisations.

Lastly, the influence of technology or data providers may create path dependencies and even the potential for lock-in. For example, some aspects of policy design could be influenced by a small group of technology or data providers, who could significantly benefit if implementation or enforcement relied on broad uptake of certain digital tools by farmers or administrators. While in some cases administrators may wish to work with technology or data providers, for example, to provide customised solutions for a specific context or problem, they should be aware of this potential and take steps to pre-empt this problem from occurring.

4.2.2. A lack of trust can be a roadblock to using digital technologies to reform policies

One of the conditions for effective policy change is to engage stakeholders strategically and build trust (OECD, 2018[3]). This can be especially difficult where different stakeholders have opposing views and non-aligned interests. In a context where policy administrators are considering making use of digital technologies to achieve policy reform, there may be different levels of resistance: for example, some stakeholders may resist the overall objective of reform, while others may accept the overall direction of reform but still have concerns related to the use of digital technologies. Additionally, digitised forms of data gathering (e.g. via UAVs or satellites) or analysis (e.g. via algorithms) may be resisted if they bring about reductions in organisational personnel or funding.

However, rather than being an additional source of conflict, digital tools and data may actually be able to foster collaboration and overcome traditional roadblocks created by conflicting views and values. These collaborations help ensure that digital tools are well-designed while at the same ensuring buy-in by all stakeholders. Further, increasing farmer access to agricultural data can in and of itself be a useful agri-environmental policy tool; as farmers increasingly understand the specific environmental impacts which result from their actions, they may become more willing to participate in agri-environmental policies seeking to reduce those impacts.

As shown in Case Study 1 (see Part IV for details), digital tools and data sharing are being successfully used in New Zealand's Our Land and Water National Science Challenge to help parties with different interests and incentives build consensus. For example, the OVERSEER® nutrient model, which is being enhanced under the Challenge and aligned programmes (e.g. to be made spatially explicit by MitAgator), has been developed using co-innovation and can be scrutinised by all interested parties. It functions as an "authoritative point of truth", but can be updated with the latest available science and incorporate innovations (e.g. new data sources from new sensor technologies).

4.3. Using digital technologies for policies raises new challenges

Use of digital technologies for agri-environmental policies may raise new challenges which, if not addressed, may limit the actual benefits obtained. In the conceptual framework (refer to Figure 3.1), several types of new challenges *caused* by use of digital technologies were identified. The following sub-sections consider challenges in the context of agri-environmental policy implementation in relation to:

- The potential for existing actors to respond to new technologies or new incentives in negative ways, or in unforeseen ways which then require a further policy response.
- The potential for new technologies to create new risks which need to be directly addressed, or cause unintended consequences which then require a further policy response.

The challenges discussed here are strongly linked to the specific types of policies used and choices about policy implementation. While broader consultation with other government agencies may be useful to ensure a "joined up" approach and synergies across different policy areas, because of this specificity, they need to be addressed by the organisations responsible for administering agri-environmental policy. Challenges that may need a broader approach are discussed in the following section.

Note that in general, evidence on the extent to which these challenges are actually occurring in practice is scant. Therefore, the following subsections explain the (potential) challenges and in some cases highlight actions governments can take either to help ensure these challenges don't eventuate, or to address them if they do.

4.3.1. Social impacts and acceptance of increased monitoring

The first challenge is that having better data on negative environmental impacts may increase social tensions between the agriculture community and the rest of society, fostering an "us versus them" mentality, rather than co-operative approaches to improve agricultural sustainability. This is particularly relevant in a non-point source context, which applies for much of the agriculture sector. At present, while there may be estimates of the sector's aggregate environmental impact (e.g. regarding water quality impairments, GHG emissions, etc.), in many cases it may be difficult to determine the individual impact of a specific farm. If the use of in situ and remote sensing facilitates measurements (or even more reliable estimates) of individual impacts at the farm level, this could be used to label farmers with poorer environmental performance as "polluters" or "resource squanderers" and create a stigma in the community (Myles, Duncan and Brower, 2016[4]). While individual accountability is an important tool for incentivising improved performance, stigmatising individuals (especially in a context where individuals may have been hitherto unaware of their performance and may take time to implement changes) can be destructive and lead to decreased social cohesion and mental health in rural communities (Gregory and Satterfield, 2002[5]).

One important strategy for policy administrators to mitigate such risks is to make use of digitally-enabled result-oriented mechanisms (or performance measurement more generally) to foster identities centred on the concept of stewardship, and to emphasise (where it is the case) that change takes time. Practically, this entails design elements such as:

- Including the objective to foster a stewardship mentality explicitly into policy or programme objectives.
- Measuring or estimating and reporting of individual or collective (depending on approach[3]) performance to the programme administrator.
- Including a mechanism for broadcasting good performance to programme participants, peers, and potentially to the public in general.
- A well-implemented, graduated compliance or enforcement framework which:
    - encourages participants to self-identify poor performance and to report this to the administrator;
    - provides room for improvement over time (as opposed to more "heavy handed" responses such as immediately rejecting poor performers from participating).

Additionally, allowing policies to be jointly designed with stakeholders (e.g. farmers, environmental groups) can help create partnerships between agricultural and environmental interests rather than entrenching dichotomies. Results-oriented programmes can be particularly useful in this respect as they "create common goals between farmers and conservationists, leading to cooperation between two conflicting groups...result-oriented schemes can [also] communicate the extent to which farmers contribute environmental services to society and, consequently, help to justify financial support to the farming community" (Burton and Schwarz, 2013, p. 632[6]).

While all of these design elements may be possible to achieve in part without the use of digital technologies, several factors suggest that digitally-enabled mechanisms are more likely to work better:

- The use of data generated by digital technologies, particularly from satellite remote sensing and wireless sensor networks, can enable a shared, scientifically-based understanding of resource concerns and results achieved. Further, the emergence of near-real-time data can inform farmers of the state of their environment more easily and more instantaneously, which helps grow their understanding of how their management actions affect the environment.

- The use of models (particularly in programmes where results are modelled rather than measured directly) that are GIS-based and able to take into account a high level of spatial heterogeneity are likely to be more accurate and able to accommodate a wide range of practices when estimating results. Also, use of GIS-based tracking of results enables assessing progress in aggregate, which can be important both for achieving landscape-level goals and for creating a community sense of ownership of those goals.
- The use of computer algorithms to calculate payments based on results could allow for payment structures that pay for multiple environmental benefits and which take into account relationships between different environmental benefits (e.g. relationships between water quality, biodiversity, and greenhouse gas emissions). This could allow payment schemes to minimise non-additional payments and reward farmers who achieve multiple benefits.
- The use of digital platforms for administering results-based schemes can enable simple communication between participants, enabling peer-to-peer learning, and between participants and the broader public, lessening an "us-versus-them" mentality and fostering a stewardship attitude, and between participants and the administrator.

4.3.2. Dynamic challenges of agri-environmental mechanisms which rely on models

Increased reliance on data and complex modelling software increases the need to be explicit about the limitations of data and models, and how these limitations vary across data sources and modelling efforts. In particular, there is a need to avoid models becoming perceived as "truth machines" by policy makers (Duncan, 2014[7]).[4]

Also, the increasingly rapid pace of technology innovation creates issues with relying on outdated tools (Duncan, 2014, p. 383[7]). Periodically iterating an entire policy as technologies update may create rigidities or large "step changes" in requirements, which are costly for farmers and which introduce or increase regulatory uncertainty. However, updating requirements in a more piecemeal way (i.e. in line with individual permit cycles, contract terms, land planning cycles, etc.) can introduce inequalities across participants (i.e. some actors are regulated under or participating in the old system, while others are under the new). Therefore, policy makers need to actively consider how to create mechanisms which allow regulatory regimes and voluntary programmes to evolve smoothly with technologies. Environmental markets are a promising tool to support the "piecemeal" approach while mitigating (at least in part) the potential for inequalities. For example, in a regulatory context, actors who are unable to meet updated regulatory requirements on site could be allowed to meet the requirements via purchasing off-site credits.[5] Also, "phase in periods"—in which consequences of non-compliance with newly-introduced rules can be gradually ramped up—can be useful to assist participants who were compliant with the old regime to transition towards the new.

Monitoring and modelling should be viewed as complementary.

Often, monitoring and modelling happen as two separate streams of work, and modelling is often described as being needed in the context of incomplete information. This implies that modelling is only needed because of data deficiencies; that is, that monitoring and modelling are substitutes.[6]

In many cases, data gaps are likely to persist: monitoring of all physical variables of interest is unrealistic, despite advances in sensors, Internet of Things devices (e.g. "smart" agricultural machinery) and remote monitoring technologies which enable much broader physical monitoring at lower cost than previously. Therefore, there will still be a need for models to attempt to "bridge" these gaps.

However, even if all necessary physical measurements *could* be obtained via monitoring, modelling may still be needed for a variety of functions, such as attributing physical impacts to non-physical drivers (particularly to policy drivers, so that policies can be evaluated), and modelling future scenarios to make *ex ante* policy assessments and improve planning. Thus, modelling and monitoring should be viewed as complementary: modelling both uses data and allows for analysis in the absence of data.

4.3.3. Policy design elements can be a pull factor for technology adoption on-farm, but there is a risk of exclusion

As discussed in detail in Chapter 3, there is substantial opportunity for policy makers and administrators to make use of digital technologies for better agricultural and agri-environmental policies. While realising such opportunities will obviously result in technology adoption by government organisations (or third parties providing services to these organisations), it may also incentivise adoption of digital technologies on-farm:

- As governments move to increasingly interact with programme participants via digital channels (e.g. requiring applications to be submitted online, making payments using e-banking services, releasing information in digital formats, providing access to online databases, providing technical assistance or extension services via apps or online platforms), use of digital technologies by programme participants (i.e. farmers) is likewise expected to increase.
- Adoption of digital technologies by the public sector may also change the way food system policies are designed, enforced and monitored. This may result in revised or new requirements for tracking and tracing, as well as better management of food safety. Such new requirements may necessitate adoption of technologies by farmers: for example, livestock farmers may be required to adopt RFID tags for all animals, and to record and submit data on animal movements or other aspects (e.g. animal health data) via digital channels. Digitally-enabled traceability schemes (e.g. Blockchain-based traceability systems) may incentivise farmers to adopt sensor technologies for collecting data to be stored in digital databases, and to make increased use of online platforms.
- If policy makers move towards more result-oriented programmes, particularly those which focus on *measured* results (as opposed to modelled results), this is likely to provide further incentives for farmers to adopt digital technologies on farm, for two reasons. First, farmers will have more flexibility in how they go about improving their environmental performance, and may make greater use of digitally-enabled input-saving practices such as variable rate technologies and highly automated on-farm processes. Second, farmers will be more incentivised to invest in digital technologies and services for measuring improvements in their environmental performance.

Adoption of technology can be costly for farmers. Apart from potentially needing to invest in the technology itself (for example, purchase of precision agriculture machinery, upgrading computer systems, etc.), there may be additional entry costs such as learning costs and adapting production processes. Thus, governments need to carefully consider the potential for adoption costs to produce a net increase in regulatory burden when considering the introduction of new standards or regulations, particularly in cases where farmers are not able to opt-out of participating in regulatory mechanisms (i.e. mandatory regulations).

A related risk is that the production of new digital tools and new knowledge from those tools does not inadvertently produce information asymmetries. This could potentially occur, for example, if only researchers involved in creating new knowledge or tools had access to them. Another potential source of information asymmetries is linkages between large multinational firms and the public sector or academia, which could result in some actors being able to access data or analysis at lower cost than others. Case Study 1 (New Zealand) shows that one way to ensure that address this risk is addressed is to take a co-innovation approach. This way, stakeholders are directly involved and production of new knowledge is readily shared with all stakeholders.

4.4. New challenges which may require a broader approach

In addition to the challenges discussed in the previous section, there are some challenges which are relevant for agri-environmental policy makers, but for which a broader approach may be required. Several reasons may underpin the need for a broader approach:

- First, the solutions to challenges faced by agri-environmental policy makers may be legislative or regulatory solutions that are the remit of other areas of government – key examples here are where solutions relate to privacy laws, competition matters, or consumer protection.
- Second, challenges associated with certain technological solutions that are useful for agri-environmental policy may also arise in other contexts. A key example here is that issues relevant to providing technological solutions to increase access to agricultural microeconomic data for policy-making also arise in relation to increasing access for the development of data-driven services for agriculture.
- Third, technology-related challenges for agri-environmental policy makers may also be faced by other policy makers: an example is that issues relevant for environmental regulation in agriculture may be relevant for other regulators, e.g. animal welfare regulators, economic regulators.

4.4.1. Potential pitfalls of "RegTech" for agriculture

As demonstrated in previous sections, agri-environmental regulators and programme administrators have the opportunity to make increased used of digital technologies in performing their functions. Administrative or regulatory decisions are increasingly based on information provided by digital tools, and the prospect of using machine learning and artificial intelligence to fully automate certain regulatory or administrative processes and decisions is now conceivable (Adams, 2018[8]; Coglianese et al., 2017[9]).

Devolution of decision-making to computers raises several important questions:

- *Transparency*: how can algorithms be designed so that agri-environmental administrators and regulators, farmers and other relevant stakeholders understand how results and conclusions are obtained?
- *Oversight*: how can agri-environmental administrators and regulators (who may have little expertise with technology) have confidence that algorithms (which may be designed by technology specialists with little knowledge of agriculture or agricultural policies) are suitable (including suitably accurate) for the purposes they are designed for? How can they determine when such algorithms are "wrong?"
- *Responsibility, right to challenge and access to remedies*: who is responsible if algorithms make the "wrong" decision? For example, if a farmer participating in an agri-environmental scheme is denied payment due to a flaw in a payment algorithm, is the farmer able to challenge this decision? What process is there to "right the wrong"?

Potential pitfalls await if these questions are not considered and answered satisfactorily. If transparency is not achieved, farmers and other stakeholders are unlikely to have confidence in decision-making processes, which may lead to unwillingness to participate in policy mechanisms (particularly voluntary programmes) or to costly challenges to regulatory or administrative regimes. If design and use of algorithms lacks suitable oversight, there is potential that algorithms may not be suitable for their intended uses. If regulators and administrators do not take responsibility when algorithms arrive at the "wrong" decision, they may suffer reputational damage and risk legal action. Moreover, farmers should not face additional costs in the event that algorithms fail.

Such considerations are not specific to agriculture. In fact, use of advanced technology by regulators—referred to as "RegTech"—first arose in the financial sector, in the aftermath of the 2008 financial crisis (Arner, Barberis and Buckey, 2016[10]). Regulators and administrators in the agriculture sector have the opportunity to learn from their peers in other sectors, and should adopt best practices for use of algorithms to support regulatory and administrative decision-making.

Technological progress and regulatory remit

A related challenge is the temptation, real or perceived, for agri-environmental regulators to expand their regulatory authority according to what the latest technology is able to measure (sometimes referred to as "regulatory role creep"). The potential for this to occur in the agriculture sector is the result of various trends including:

- Agricultural databases are becoming increasingly interlinked, which creates the ability to use data for purposes for which they were not originally intended, including regulatory purposes such as developing farm profiling (Directorate-General for Parliamentary Research Services (European Parliament), 2018[11]).
- Advances in remote sensing technologies (satellites, aerial-borne sensors) has vastly increased regulators' and administrators' ability to gather data on farmers without involving farmers themselves. This gives rise to the possibility that farmers may be monitored without being aware of it and that farmers may (whether correctly or not) perceive that they have insufficient (or no) opportunity to dispute regulatory or administrative decisions based on such data.

The solution to this challenge is not to preclude agri-environmental regulators from making use of digital technologies and agricultural data to improve their performance. Neither should it be taken as given that existing regulatory frameworks, which may in part be shaped by pre-existing technologies and data availability, should remain unchanged as technologies develop. Rather, it is recommended that agri-environmental regulators and administrators:

- Implement transparent processes to enable scrutiny of how regulators and administrators are using agricultural data and new technologies.
- Implement clear and participatory processes for considering how regulatory and administrative frameworks should evolve with technologies, and for vetting technologies for their suitability for use in regulatory contexts.

However, it is recognised that in some cases, the extent to which agri-environmental regulators and administrators have complete jurisdiction to implement these processes may be unclear; implementation of these recommendations may require a cross-government effort.

A further challenge is the impulse for policy administrators to move to limit policy coverage to *only* those farm practices which can be easily monitored using specific technologies (e.g. remote sensing). An example would be a policy which limits payments for agri-environmental practices or results which can be monitored using satellite-based remote sensing. While consideration of administrative transaction costs is a fundamental component of designing cost-effective policies, and monitoring via remote sensing appears likely to contribute to large reductions in administrative costs (see case studies in sections 3.2.5 and 3.3.1), cost-effectiveness still needs to be assessed holistically.

It is important to recognise that issues about regulatory remit and use of technology to enable regulation is unlikely to be specific to agri-environmental policy. Other regulators likely face similar issues, both within and beyond the agriculture sector. Regulators may be able to learn from each other about how to best integrate digital tools into their overall approach.

4.4.2. Access to farm-level agricultural data for policy-making

As discussed above, there are opportunities for policy makers to make better use of agricultural data to design and deliver better policies, whether by implementing better spatially-targeted policies, results-based mechanisms, new monitoring and compliance approaches, etc. To deliver such data-based policies, policy administrators and related researchers would likely require improved access to agricultural data, including the ability to *link* different datasets. This linkage may need to occur at the farmer, farm or field level in order to evaluate policy microeconomic and environmental impacts (Jones et al., 2017[12]; Petsakos and Jayet, 2010[13]).[7] Further, data may need to be shared across borders, for example, to facilitate comparative policy analysis and to underpin national, regional, and global policy-making (Legg and Blandford, 2019[14]; Carletto, Jolliffe and Banerjee, 2015[15]).

Data confidentiality requirements are often cited in the literature as a limiting factor for using micro-level agricultural and agri-environmental for policy delivery and related analysis (Martínez-Blanco et al., 2014[16]) (Tukker and Dietzenbacher, 2013[17]) (VanderZaag et al., 2013[18]). Access issues are particularly prevalent where different government (or even non-government) entities have responsibility for different aspects of the agri-environmental policy cycle (or across different policies): for example, agricultural agencies responsible for administering programmes may be unable to share farm-level administrative data with environmental regulators; agencies collecting data on rainfall, soils and water quality may be unable to link their records with data on farm decision-making, output, and profits.

Limitations on accessing agricultural data (whether for policy-making or other uses) are generally of long-standing and have been crucially important for establishing trust between farmers and government data-collection organisations. For example, agricultural censuses and surveys conducted by or on behalf of government agencies, which have long been a key source of such data, generally contain strict confidentially requirements in their enabling legislation, which limit the ability of agencies to combine data from different sources or share it with policy researchers.[8] While these mechanisms are aimed at protecting farmers' interests, they have the consequence of limiting the potential for farm-level data to be used (and re-used) for policy-making and implementation. In addition, administrative data,[9] usually gathered and held by government agencies, is an important source of information relevant for policy-making. However, access to administrative data is often even more limited than access to farm level survey or census data.

Options to improve access to agricultural data held by public organisations to improve policy

In theory, one solution to improve access to agricultural data for policy-making, administration and related research is to reduce or modify confidentiality obligations, for example by developing data-sharing agreements between different government organisations and related researchers, or by publishing de-identified farm-level data. However, these options may be unpalatable or unworkable in practice, or may not significantly improve the usefulness of data for policy. An important issue is the question of how to provide access to farm-level data that has geographic attributes that are meaningful for research and policy, without allowing identification of the farmer's identity or precise location of the farm.

Further, unilateral attempts to lessen public sector obligations to preserve privacy or confidentiality have the potential to result in erosion of public trust in these agencies. Thus, any decision to fundamentally change such obligations (whether for policy purposes or more generally) will require discussion and agreement between governments, farmers, researchers, the private sector and NGOs about important questions of data ownership and access to data—these questions are discussed in section 4.1. Government organisations may in fact have limited ability to lessen legislated confidentiality guarantees, especially in relation to existing datasets; therefore an open data approach for agricultural micro data may not be an achievable or desirable end goal.

However, where governments wish to improve access to agricultural data while maintaining confidentiality, there may be solutions which policy administrators can take to avoid the confidentiality-accessibility dilemma altogether, including:

- *Technological solutions*, such as encryption, "confidential computing" and other gatekeeper technologies, which permit greater use of farm-level data for policy purposes while using technology to preserve confidentiality (see Section 2.1.3 for an overview of these technologies).
- *Administrative or institutional solutions*, such as creating research collaborations whose aim is to improve access to and use of agricultural micro data specifically for research and policy analysis (for example, the OECD Farm

Level Analysis Network—see Box 4.2.), and providing differential access based on data sensitivity. Policy-makers can also consider use of new data collection methods which do not require direct participation from farmers. However, policy makers need to take into consideration how this might impact on the existing trusted relationships with farmers, in both positive and negative ways.

- Incentive-based solutions, including:
    - policies which use farmers' preferences to maintain anonymity as an incentive mechanism to encourage improved environmental performance through collaborative, landscape-scale initiatives and "trust-based" environmental regulations (Lange and Gouldson, 2010[19]) (Case Study 7, Box 4.3);
    - policies which provide voluntary incentives for farmers to provide data for public research and analysis (e.g. making payments or providing services such as benchmarking or advice in return for provision of data for policy purposes).

It should be noted that solutions could have elements of all of the above; they are not mutually exclusive. Moreover, the choice of solutions raises fundamental questions about how best to balance different considerations, including fostering trust between data providers and users and how to balance maintaining confidentiality or privacy with increasing access to derive greater benefits from agricultural data. While these questions may be crystallised in debates about the use of government-held agricultural data to improve agri-environmental policy, they form part of the broader debate about data governance and digitalisation.

Box 4.2. OECD Farm Level Analysis Network

The Farm Level Analysis Network (FLAN) was created in 2008 under the auspices of the OECD. It includes experts from government-related institutions, and other agricultural economics research institutes involved in the collection or analysis of micro-level data and interested in collaboration. Membership is voluntary and a representative coverage of OECD countries is sought. The OECD acts as convenor and contact between network members and delegates to OECD meetings.

Network members and the OECD share the common goal of improving the quality and relevance of policy analysis applied to the agricultural sector through the use of micro-level data, recognising the increasing need for good micro data and related analytical tools to support improved policy decision making.

The main objective of the network is therefore to support OECD policy analysis through the use of micro-data and sub-national information. The network contributes to OECD projects by providing micro-level data on a consistent basis across a number of countries, thus facilitating access to data needed for micro-level analysis. From the projects adopted in the programme of work of the OECD Committee for Agriculture, the network identifies issues that would benefit from a micro-level approach, identifies data sources and suggest innovative and adapted approaches.

Another objective of the network is to share experiences and to demonstrate how micro-level analysis can be used for policy analysis. This is achieved through communication of relevant analysis and discussion of data and analytical issues. As part of this objective, the network draws the attention of delegates to emerging policy issues, where micro-level approaches could be particularly rewarding, with a view to contributing to reflections on the programme of work in the longer term.

Source: Adapted from https://www.oecd.org/agriculture/farm-level-analysis-network/.

Box 4.3. Case Study 7: Data transparency regulations enabling Californian water quality collectives

This case study provides an example of how data regulations and coalition-based water quality monitoring regimes can be used to underpin collective governance mechanisms to address nonpoint source environmental impacts from agriculture.

California agriculture is extremely diverse, producing more than 400 commodities and spanning a wide array of growing conditions from northern to southern California. However, water discharges from agricultural operations can affect water quality by transporting pollutants from cultivated fields into surface waters. Groundwater bodies have also suffered pesticide, nitrate, and salt contamination. To prevent agricultural discharges from impairing receiving waters, the Californian Irrigated Lands Regulatory Program (ILRP) regulates nonpoint source discharges from irrigated agricultural lands. This is done by issuing waste discharge requirements (WDRs) or conditional waivers of WDRs (Conditional Waivers) to growers or groups of growers called Coalitions.

The California State Water Resources Control Board's (State Water Board) Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program[1] (Nonpoint Source Policy) directs that any nonpoint source program (such as the ILRP) incorporate monitoring and reporting. Programs must "include sufficient feedback mechanisms so that the [regional water board], dischargers, and the public can determine whether the program is achieving its stated purpose(s), or whether additional or different [management practices] or other actions are required."

This requirement to undertake monitoring of agricultural runoff and receiving water bodies and reporting constitutes an effort to reduce information gaps about the quality of these waters, as well as the impact of agriculture on water quality. This data is crucial for the California Water Boards to achieve their mission. However, these requirements are controversial to the agricultural community because they are costly to comply with and result in lessening of information asymmetries that producers may have incentive to maintain. Therefore, the challenge for California Water Boards is to balance "the need for transparency and measurable benchmarks" and maintaining acceptable regulatory outcomes with ensuring regulatory burden is minimised and respecting "the need for the agricultural community to protect trade secrets and other sensitive information" (State Water Board, 2018[20]). This challenge is not unique to this context; it arises from the characteristics of agricultural production, which uses inputs (e.g. fertiliser and pesticides) and commercially sensitive information (e.g. fertiliser application regimes) to produce valuable outputs, but which also produce environmental externalities that are costly to address.

The Water Boards have devised monitoring and reporting regimes which aim to provide data for the required “sufficient feedback mechanisms”, while minimising regulatory burden and risks for producers related to information disclosure. An example is the regime of the Central Valley Water Board (one of nine regional water quality control boards),[2] which comprises:

- The use of water quality coalitions to act as intermediaries between growers and the regulator;
- Data transparency requirements which incentivise growers to participate in the coalitions;
- A representative approach to water quality monitoring;
- Mandated and voluntary use of digital tools, including e-reporting and publicly-accessible data repositories, to minimise costs of data collection and reporting requirements.

Recent review of monitoring and reporting regime

In February 2018, the State Water Board amended and updated the WDR for growers within the Eastern San Joaquin River Watershed (within the Central Valley region) that are “Members” of a Third-Party Group. These amendments were the result of an extensive consultation process that commenced in February 2016. At the heart of the review is the broad question whether the existing regime strikes the appropriate balance between providing sufficient data to evaluate the ILRP and ensuring that the burden of monitoring regime for growers satisfies the test of bearing a reasonable relationship to the need for and benefit of monitoring. In theory, various institutional, legal or technological factors could contribute to a decision to change the existing regime, for example:

- Evaluation of existing data provided by monitoring may lead to the conclusion that the existing monitoring regime is;
- Changes in the cost of the monitoring regime due to technological innovation could reduce the regulatory burden of monitoring for growers, leading to a re-balancing of monitoring requirements;
- Methodological innovations could lead to a change in the monitoring approach towards using new and improved methods;
- Evaluation of the existing third party-based mechanism may reveal unintended consequences which need to be addressed.

Methodological innovation was perhaps the most important factor underpinning changes. In particular, the Order introduces a new indicator for monitoring potential nitrate impacts from agriculture: the *AR metric*—an indicator of the amount of nitrogen in the soil that could potentially reach groundwater as nitrate (see Part IV for details). This metric is considered scientifically robust and less prone to misinterpretation; both key factors underpinning the decision to require de-identified field-level reporting of AR data. In response to concerns expressed by some stakeholders that the existing monitoring regime is inadequate, the State Water Board also directed several revisions to data reporting requirements, in particular:

- to require more granular, anonymous field-level reporting of growers' land management practices and nitrogen application (related to the AR metric) to the Central Valley Water Board.
- to expand the requirements currently imposed only on Members in high vulnerability groundwater areas on all Members, with some limited exceptions.

Despite concerns raised by some stakeholders, the State Water Board continued to support the representative monitoring approach, considering monitoring farm discharge points as "impractical, prohibitively costly, and often ineffective method for compliance determination". Thus, despite suggestions in the relevant literature that the cost of wireless water quality sensor networks has declined sufficiently in recent years to make monitoring water quality on-farm a potentially feasible option, at least in this context this does not yet appear to be the case.

The State Water Board also continues to support the third party (coalition-based) approach. However, it recognises that "concerns with privacy and protection of proprietary information may create strong incentives in support of a framework where the third party retains most information on farm-level management practice and water quality performance rather than submitting that information to the regional water board and, by extension, making it available to the public" (State Water Board, 2018, p. 21[20]). This finding suggests several possible unintended or undesirable consequences of supporting the third party mechanism. First, this support could be seen as legitimising the view that growers have some kind of "right" to confidentiality. Second, the third party may encounter a conflict of interest in that, on the one hand, it needs to report "sufficient" detail to the regulator (which may include farm-level data and even potentially data which identifies individuals), but on the other hand, its members favour reporting of aggregated data only. While the State Water Board has been careful to clarify that it does not recognise any right to privacy in relation to field level data, grower submissions during the consultation process cited an expectation of confidentiality for growers participating in coalitions (Agricultural Council of California et al., 2017[21]), and thus the regulator needs to be continually attentive to these issues and ensure that there is appropriate regulatory oversight of the third party.

Notes

1. http://www.waterboards.ca.gov/water_issues/programs/nps/docs/plans_policies/nps_iepolicy.pdf, accessed August 2018, AR 36138-36157.
2. The State Water Board works with the regional water boards and sets state-wide standards and policies.

Source: Case Study 7, Part IV.

Notes

[1] See https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/?cid=nrcseprd1328426, accessed September 2018.

[2] "Sequencing requirements" refers to hybrid mechanisms in which, in order to participate in an economic instrument, certain other requirements need to be satisfied first. These other requirements could be technology standards, requirements to first exhaust options for on-site mitigation, requirements to purchase first from certain "pools" of credits before accessing others, etc.

[3] An example would be to provide farmers with their own monitoring device and track the collective achievement of a group rather than individual performance, unless specific group targets are not met. Case Study 7 provides such an example.

[4] An example of using a complex model for agri-environmental policy is the use of the OVERSEER® model by regional authorities across New Zealand in developing plans to manage water quality. OVERSEER® is a computer model originally designed to assist farmers and their advisors with on-farm nutrient use, for estimating nitrate losses from individual pastoral farms. See Williams et al. (2013[25]).

[5] See also section 4.4.1. This paper does not assume that iterative policy updates are necessarily desirable. In addition, Stephenson and Shabman (2017[2]) point out that combining regulatory requirements with environmental markets may create lacklustre demand for environmental credits if regulatory requirements take a sequencing approach in which buyers may only enter the market *after* having satisfied certain technological requirements.

[6] In particular, discussions of the use of modelling to support water quality policies for agriculture often centre on the notion that nonpoint sources (including agriculture) are sources for which it is not possible or prohibitively costly to measure and attribute emissions to particular sources (farms).

[7] A range of other factors also contribute to the inability to link datasets, including: the absence of common linking variables (which enable record matching) (Lubulwa et al., 2010[22]); high costs or lack of resources or expertise needed to perform the linkages (Hand, 2018[23]); and lack of interoperability between datasets (e.g. different definitions with no rule to "translate" definitions in one dataset to match up with another) (Hand, 2018[23]).

[8] The same is also often true of institutional policies governing the collection and use of farm-level data for research, and of contracts and other agreements governing the collection and use of farm-level data by the private sector; while this section focusses on the case of public agencies, much of the discussion is relevant to these other contexts.

[9] OECD (n.d.[24])defines "administrative data" to have the following features:

- the agent that supplies the data to the statistical agency and the unit to which the data relate are usually different: in contrast to most statistical surveys;
- the data were originally collected for a definite non-statistical purpose that might affect the treatment of the source unit;
- complete coverage of the target population is the aim;
- control of the methods by which the administrative data are collected and processed rests with the administrative agency.

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Part III. Data infrastructure and governance in agriculture

Chapter 5.

Realising digital opportunities in agriculture requires a data infrastructure

This chapter provides an overview of a range of factors conditioning the capacity of the agricultural sector overall (both public and private stakeholders) to embrace the digital transformation and a brief analysis of key policy issues for consideration by the governments. While it is acknowledged that a first constraint to the uptake of digital technologies is access to connectivity infrastructure, this chapter focuses on downstream issues and the use of available technologies. It is not intended to comprehensively deal with all of the relevant issues, but rather to provide an initial overview of some of the key issues of which policy makers need to be aware and to highlight areas where further work is needed.

This chapter briefly presents the "data infrastructure" which is at the core of the digital transformation of agriculture and which enables both the supply of new services in the agriculture sector and new forms of policy. The following sections then briefly consider several key issues related to digitalisation in the sector overall:

- access to farm-level agricultural data held by governments (section 5.1); and
- whether there are new roles for government in creating a data infrastructure for agriculture (section 5.2).

5.1. Realising digital opportunities in agriculture requires a data infrastructure

The capacity to create value in the food system or to create better policies using digital technologies depends not only on connectivity infrastructure (hard infrastructure), but also on the regulatory environment and institutional arrangements (soft infrastructure) which together govern access to and use of digital technologies and related data in the agriculture sector. These two elements together shape the creation of effective systems for digitalisation in agriculture, often called the "data infrastructure" or "data ecosystem" (OECD, 2015[1]). The data infrastructure is the system enabling and governing the collection, access and transfer of data (which together are referred to as data governance), as well as storage, and analysis of farm data to produce knowledge and advice (actionable insights) and feedback loops to stakeholders in the agriculture sector, including farmers as well as policy makers (Antle, Capalbo and Houston, 2014[2]). [1]

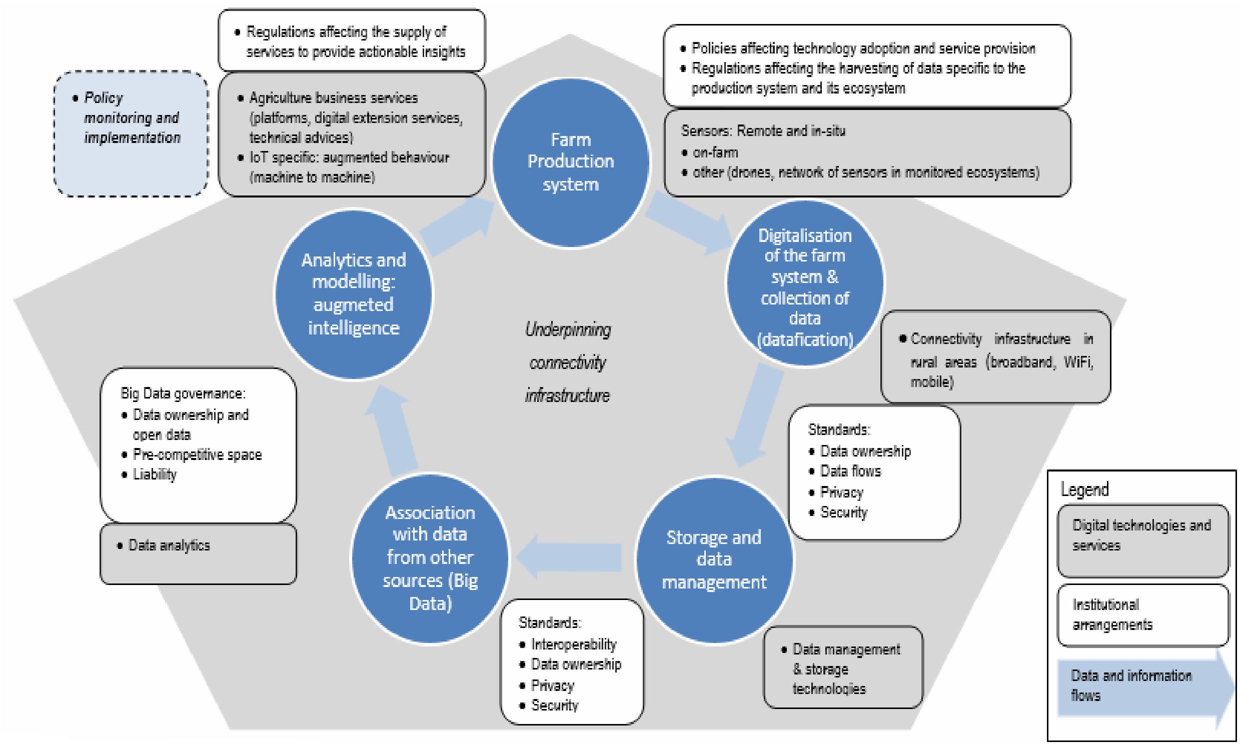
Figure 5.1 sets out this data infrastructure, highlighting the flow of data at different stages, and outlining how data is collected, combined and analysed. In this figure, the data infrastructure is characterised as a chain or cycle of data and information flows. The figure shows key flows in relation to farm production systems; the flows of information for policy is depicted at the edge of the diagram as one of several different data feedback loops. One feature of the data infrastructure is the potential for feedback loops which operate in the complete absence of human intervention, via machine-to-machine flows and automation (referred to as "augmented behaviour" in the figure).

The policy and regulatory environments at each stage of the chain influence not only that stage, but also the ability to connect to the next stage. This influences the extent to which digital tools are available to farmers as well as to other actors in the system, such as governments, researchers and private sector service providers and hence the nature and use of digital infrastructure in the sector overall. For example:

- Digitalisation of farm or government activities is affected by regulations covering access to and use of remote and in-field sensors.
- The access to and transfer of farm data as well as the ability to link it with data from other sources is affected by regulations governing the flow of digital information and interoperability of systems between stakeholders, machines or individuals (data governance).
- Storage of data is affected by regulations influencing the location of data storage.
- Management and analysis of data (big data, models, algorithms, blockchain, etc.) is affected by regulations related to the use and agglomeration of data as well as measures regulating the provision of such services.

The following sections touch upon two elements of concern in relation to the data infrastructure, potentially constraining the uptake of digital technologies in agriculture. First, access to farm-level agricultural data held by governments is discussed. Second, the discussion puts forward potential new roles for the government in the data infrastructure.

Figure 5.1. The data infrastructure for agriculture



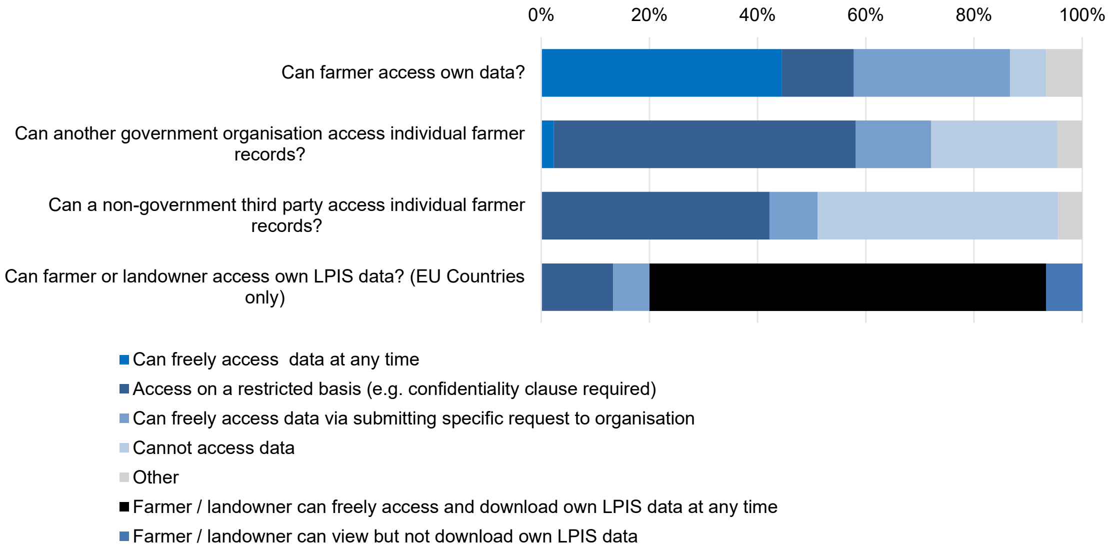
5.2. Access to farm-level agricultural data held by governments

Section 4.4.2 discussed options for improving access to agricultural data specifically for policy purposes, including policy-related research. Beyond that, there is rationale for improving access to government-held agricultural data more generally:

- For *farmers*, so they can better understand the environmental impacts of their decisions and how policies work, as well as learn from government-held information about the agriculture sector more generally;
- For the *private sector* and *researchers*, so they can develop and deliver better services for agriculture.

Data from the OECD questionnaire shows how access to agricultural data held by responding public organisations is currently differentiated based on the identity of the person seeking access (Figure 5.2).

Figure 5.2. Accessibility of farm data held by government organisations



Note: N = 47, except for LPIS question, where N=14. LPIS = Land Parcel Identification System.
Source: OECD Questionnaire.

As this figure shows, around 70% of respondents indicated that farmers are able to access their own data held by the organisation relatively freely. Ease of access to farm level data decreases markedly when actors other than farmers are considered. Access for other government organisations most commonly is provided on a restricted basis (55% of respondents); however 24% of respondents reported they do not allow any access to farm level data by other government organisations. Italy (Ministry of agriculture, food, and forestry / *Ministero delle politiche agricole, alimentari e forestali*) was the only respondent who indicated that other government organisations could freely access farm level data. Access for non-government third parties is even lower, with 45% of respondents not allowing access to such actors, and a further 41% allowing access only on a restricted basis.[2]

As discussed in section 2.1.3, recent advances in technologies to improve access to and sharing of agricultural data, as well as advances in institutions for data sharing, can help improve access to agriculture data for farmers and for the private sector, while maintaining confidentiality and privacy where needed. Questionnaire respondents were also asked whether their organisation had adopted any innovations to make agri-environmental data more publicly accessible; 34 of 48 organisations have adopted such initiatives. The majority of these initiatives were technical solutions, involving some combination of:

- Increasing the amount of open data available.
- Developing new web applications or portals for viewing or interacting with agri-environmental data.
- Investing in infrastructure which automatically generates agri-environmental data (e.g. new connected weather stations).
- Developing application program interfaces (APIs) to allow for increased interoperability and new ways to use agri-environmental data.

- Publishing data using cloud-based documents (e.g. Google spreadsheets).

5.2.1. Concluding recommendations about agricultural data held by governments

There appear to be opportunities for governments to improve access to agricultural data they hold. As shown in Chapters 2 and 3, there are a variety of solutions which can help improve access to agricultural data, while maintaining appropriate protections (e.g. maintaining data security, protecting privacy, confidentiality, intellectual property, etc.). It is not clear that one particular solution is superior; rather, governments could take a tiered approach, as follows:

- Invest in data services such as providing linked datasets to increase the usefulness of government data collections for policy-making and related research. One important aspect of this to consider is how, and when, to link farm financial datasets with physical data such as soils, precipitation, and other climate variables.
- Increase use of secure remote access mechanisms to reduce transaction costs of allowing trusted actors (e.g. policy researchers) to access agricultural micro data held by governments.
- Explore how new data sharing technologies such as confidential computing could avoid the traditional confidentiality-accessibility dilemma.
- Take a risk-based approach towards access to agricultural data held by governments: consider and clearly articulate reasons why specific data or classes of data cannot be openly provided. This could be accompanied with commitments to periodically review pre-existing legislative requirements to protect confidentiality of agricultural data.[3]

Government organisations which collect or store agricultural data could work together with data providers and data users to establish clear frameworks governing data access and use. It is important to emphasise that such frameworks should be coherent with broader policies governing such issues, as well as with underlying legislation authorising government agencies to collect agricultural data.

In seeking to improve publicly-held agricultural datasets, data-collection agencies can explore how the burden of existing data collection by government organisations can be lessened while maintaining or strengthening data collection through the use of digital technologies, including considering how digital tools could be used to gather data via alternative pathways. Data management frameworks could also support the evaluation of data quality for data from alternative sources and planning. Finally, government organisations have a role in ensuring the longevity and robustness of these data sources.

Governments should also explore ways to incentivise provision of private sector data for public use and for agricultural research. This should include consideration of providing incentives for farmers to allow their data to be shared for policy purposes; options include monetary incentives (i.e. payments for data provision) and non-monetary incentives, such as provision of regulatory safe-harbours for data providers or provision of services which use data that has been provided (e.g. benchmarking services).

More broadly, while further work is needed to evaluate existing regulatory and governance frameworks, there seems to be a role for governments to help stakeholders clearly understand different available governance arrangements and to provide clearly articulated underpinning regulatory frameworks that other users can build on.

5.3. Are there new roles for the government in the data infrastructure?

According to the type of public services required, and the institutional environment and initial conditions, enabling development of a data infrastructure might require different types of actions and roles for the government, whether as co-ordinator, as a regulator setting interoperability standards or to directly develop the data infrastructure and create markets for usage rights. The role of the government is likely to change according to how advanced those networks are, and whether the service provided can be marketable.

Provision of physical infrastructure (e.g. connectivity infrastructure, sensor networks, physical elements of tracking and traceability systems, etc.) faces traditional issues for infrastructure in network industries, particularly the question of where the role of government stops and that of the private sector starts. There might be cases requiring broader government support for the financing of network infrastructure, including in less economically important areas (areas not cultivated, of low productivity, but nevertheless important from an equity perspective or to be able to have a holistic approach to data acquisition). In particular, the creation of a network of sensors and of information needed to monitor the environment in ways that allow the provision of public services such as drought early warning systems, and to inform water policy and management, requires coverage of all geographic areas, whether cultivated or not (see example of soil moisture in Case Study 9). This could suggest a role for the government as it might not be economically viable for the private sector to develop infrastructure in some areas, which are nevertheless important for the understanding of ecosystems dynamics and forecasting.

In addition, questions about the sharing of data according to the definition and value (economic and social) provided to the different use of data produced by private systems remains an issue. Discussions at the OECD Global Forum for Agriculture in May 2018 highlighted a range of views in relation to data ownership, privacy and the types of information and derived conclusions that can be left with the private sector and those which need to be managed (governed) by public authorities. For instance, consider wireless sensors networks (WSN), which can provide data of public interest, but which could also underpin development of decision support systems which could be sold to farmers. Such WSN could produce a lot of information, especially in high density farming areas, to which services could be added to make investment profitable. However, there might still be constraints to the sharing of the data. Therefore, there may be a role for governments to develop at least the basic WSN and allow for the private sector to build on this and develop marketable services. In addition, the quality and veracity of data obtained via private application of new digital technologies to support policy-making would need to be ensured.

Three case studies presenting different elements of data infrastructures currently being developed for agriculture were explored in order to further identify some potential roles of governments, the constraints they faced and how they dealt with them. The case studies are:

- Case Study 8: Estonia e-government and the creation of a comprehensive data infrastructure for public services and agriculture policy implementation.
- Case Study 9: Connecting the dots to create a data infrastructure: the US National Soil Moisture Network.

- Case Study 10: Data infrastructure and the potential role of the government supporting the data infrastructure: the example of the *Akkerweb* in the Netherlands.

Some common lessons drawn from these case studies are presented in this section.

5.3.1. Data quality and trusted algorithms

One first element identified in which governments have a role is that the performance of the data infrastructure to support decision-making depends on the quality of data and the trust in algorithms.

Without good quality data, even the most refined algorithm will not be able to provide good information. For example, big data is the capacity to aggregate a large amount of data, but big data only makes sense if it can be used to produce quality analysis. Other new digital technologies, such as blockchain or artificial intelligence (algorithms), are sophisticated programmes, the value of which also depends on the quality of the data they use. Moreover, if bad quality data is used in automation, it can potentially have important negative consequences. However, quality data and "fit for use" data can be expensive to produce.

Governments can play a role in ensuring that good quality data is used in algorithms and artificial intelligence:

- Governments can use a range of measures to improve access to farm-level data held by government agencies, particularly in relation to access for policy and research purposes (Section 5.1).
- Governments can encourage good data management practices by participating in or leading development of high quality metadata standards.
- Governments can consider the merits of shift towards an "open first" approach to allowing access to data held by government, in which data is encouraged to be open or re-useable as a default, rather than inaccessible by default. This openness can enable users to identify and notify problems with data and serve a quality control function, as well as to help ensure the best available data is used in algorithms and artificial intelligence.

Box 5.1. Case Study 8: Estonia e-government and the creation of a comprehensive data infrastructure for public services and agriculture policy implementation

This case study illustrates how digital technologies can be used to improve the administration of government systems and the provision of public services, including in relation to agriculture, using the example of e-Estonia, an initiative by the Estonian government to facilitate citizen interactions with the state through the use of electronic solutions.

The development of the Estonian e-Government is based on the Principles of the Estonian Information Policy, adopted by the Estonian Parliament in 1998. Through this, the government initiated a digital transformation to increase efficiency of its processes as well as how efficiently it delivers public services. The Estonian government made two critical technology choices: a compulsory digital identity (ID-card, proof of concept and ecosystem built in 2004) allowing the real world to match the digital. The second choice was to develop the X-Road, the data management infrastructure based on an innovative decentralised linked government data infrastructure preventing data redundancy and using Blockchain technology to create transparency about data access.

Among a range of applications, this infrastructure is used for agriculture policy and regulations. The Estonian national paying agency has been using satellite imaging and remote sensing since 2005 and controls of mowing requirements under the EU CAP, attached to financial support from the European Commission, have been increasingly automatised from 2011. With remote sensing and automation of processes, the percentage of checks has gone from 5% on site to almost 100% performed remotely.

A range of digital services is also now available to farmers, including digital registers. For instance, whereas information was previously recoded using a paper-based system, farmers are now able to provide information via an e-register. As of August 2018, 64% of documents and 89% of notifiable animal events were submitted using the e-services register.

Finally, the Ministry of Rural Affairs has initiated a feasibility study for development of an agricultural big data system. The aim is to create a central electronic system to link and integrate existing data with analytical models and practical applications. Data linked in this system must be harmonised, compatible, updated, linked to spatial data, and transferable from the producer to the system and from the system to the producer, enabling access to potential models and applications. The system will provide useful practical information flow for the farm management decisions (e.g. machine-readable data for the precision farming machinery). The system will also enable to collect more precise farm data with less effort. This improves the quality of statistical data and enables more comprehensive analyses. This one-year duration project started in September 2018.

Source: Case Study 8, Part IV.

But beyond the data itself, it can also be important to ensure the quality of algorithms used to process it (which will also affect the quality of inputs downstream). Governments can also play a role in ensuring that algorithms are able to be appropriately scrutinised, while also recognising intellectual property or commercially sensitive elements relating to algorithm design:

- Governments can provide a model of good practice for responsible and transparent use of algorithms as a tool for public analysis and decision-making (section 4.3.3).
- Governments can build farmers' confidence in using algorithms as aids for decision-making by ensuring that algorithm designers and providers of algorithm-based AI services are subject to standard conflict of interest regulation (including declaration requirements) and that farmers are aware of these obligations. For example, if a seed or fertiliser company designs algorithms to provide planting or fertiliser application maps based on precision agriculture machinery, there is a risk that the algorithm could be designed to maximise profits to the company rather than benefits to the farmer. This underscores both the need for regulation to prevent such practices, as well as for educating the agriculture sector about relevant regulatory frameworks, and available recourse.

It is worth noting that the issue of whether farmers have confidence in use of algorithms to support policy (discussed in section 4.4.1) is similar to the issue of whether farmers have confidence in use of algorithms by service providers (e.g. farm advisory services provided by the private sector). There may be a need to invest in developing farmers' understanding of how algorithms are used (in a general sense): otherwise technologies may appear to be a "black box" and farmers may oppose policy recommendations or may not act on recommendations due to a lack of confidence or trust (for example, in a context where an agri-environmental programme uses an algorithm to develop on-farm conservation recommendations; or where a service provider's recommendations are based on an algorithm).

A second element to take into account when identifying the role of the government is that relevant regulations affecting the quality of the data infrastructure may not concern the sector itself but may relate to other sectors that produce intermediate goods and services for the agriculture sector or which buy from the agriculture sector. That is, effective policy-making for digitalisation in agriculture may require going beyond the agriculture sector. In addition to core connectivity infrastructure, the functioning of the data infrastructure requires access to goods (sensors) and services (connectivity providers, as well as business services producing actionable insights sold back to the farmer). A combination of policies and regulations beyond the agriculture sector (e.g. goods and services trade policies), as well as innovation policy more generally, can therefore influence the business strategy of actors in the data infrastructure.

5.3.2. From regulatory oversight to acting as an investor and co-ordinator

More broadly, there could be a role for the government to support the development of infrastructure for the datafication of agriculture, from regulatory oversight to acting as an investor and co-ordinator when there is a collective gain but few private incentives.

This can be particularly important in case of infrastructure in network industries, as illustrated by the Case Study 9.The opportunity costs for policy management from the lack of coordination of soil moisture data across the United States triggered an effort to promote their better integration, under the National Soil Moisture Network (NSMN) initiative. But in addition to coordination (see McNutt Verdin and Darby, (2013[3])), the initiative recommended early on that the increase in the number of monitoring sites would be the most important improvement in the overall depiction of soil moisture. Drought risk and water flows do not finish at regional borders, nor are they only an issue at the level of agriculture lands, nor only for highly productive areas: water management, policies and drought risk require a comprehensive understanding of soil water dynamics at a high resolutions across potentially large and highly varied landscapes. This suggests that there may be a role for the government as it might not be economically viable for the private sector to develop infrastructure in some areas, which are nevertheless important for the understanding of ecosystems dynamics and forecasting.

Box 5.2. Case Study 9: Connecting the dots to create a data infrastructure: The US National Soil Moisture Network (NSMN)

Two types of technologies are used for the monitoring of soil water content in the United States: direct in situ instruments and remote sensing. Each approach has strengths and weaknesses. Remote sensing has the advantage of allowing contiguous data coverage across the United States and progress in its precision has resulted in increasing use for agriculture services and policy implementation. However, data provided is still at a relatively coarse level of resolution. *In-situ* measurements group diverse types of networks. Some, such as wireless sensors networks (WSN), provide data at the farm level and can be integrated into decision systems for precision agriculture or water management. However, these are often private and systems are proprietary and focus on the farm level. In addition, the data belongs to either the farmers or the company providing the service and is therefore not easily accessible by other stakeholders, including researchers and the government.

Most data used by researchers is still mostly at the 30 km scale. These mesoscale networks, also called mesonet, have principally resulted from initiatives at the State level. As a consequence, they are distributed unevenly across the United States, with some geographic areas more densely covered than others. In addition, they are not always publicly accessible and some are protected by paywalls. While the mesonet is very useful for some applications, understanding a range of natural phenomenon requires broader coverage. In addition, understanding the dynamics of soil moisture in ways that can be useful for policy management and decision making requires more information than soil moisture data point estimates. Needed information—such as soil characteristics, composition across multiple soil depths, weather patterns, and land use information—is available but in disparate data networks and from different sources.

While a large amount of data exists and could support researchers and policy makers, it is not used to its full potential. This is due to a lack of technical capacity (data processing and management) but also to the independent and non-coordinated development of networks across the United States. The production of an accurate representation of soil moisture at an informative scale has therefore remained a challenge, and soil moisture observations have been poorly integrated into assessments of vulnerability, such as early warning systems for droughts and floods.

In 2013, the realisation by the policy and research community of the need to improve metadata and calibration and validation of soil moisture data as well as data integration resulted in the development of a Coordinated National Soil Moisture Network (NSMN) The objective is to develop a high-resolution gridded soil moisture resource, accessible to the public through a web portal. The project brought together in situ measurements of soil moisture from the federal networks, in combination with a range of other databases, including the NRCS SSURGO, which provide a unique gridded database of soil properties and satellite (PRISM) data. Challenges highlighted in the feasibility study included data transfer protocols, storage, and data gaps from intermittent connectivity to stations.

Source: Case Study 9, Part IV.

5.3.3. Governments might need to rethink the way they are operating, as well as their role as a provider of public services.

Implementing a new data infrastructure policy requires awareness of a range of issues, from how to create interoperability between agencies and between database and stakeholders, to how to ensure the protection of government data and who has a right to access it. Estonia dealt with such problems using a decentralised system and cryptography.

In addition to these technical questions, governments should also think about the use of the envisaged tool. In particular, the data infrastructure can potentially smooth communication between all stakeholders and can be thought of as serving not only policy makers and administrators, but also farmers. Moreover, while one of the roles of the government may be to gather relevant information for policy implementation, governments should take a multi-functional approach to its data collection and management, considering the merits of also including in their databases information not directly of use for policy-making, but which could be useful for farmers when combined with government data. Both the Estonia and the *Akkerweb* case studies involve systems that allow private sector access to government. It is envisaged that in Estonia the system could be based on an agreement with farmers by data type. The data infrastructure created by Estonia, clearly identifies who the data has been registered by or referred to through the eID-card.

The second issue highlighted by the NSMN case study is the need for interoperability standards. Any network or platform, whether publicly or privately administered, is developed to answer specific questions, or achieve certain purposes. Therefore, they often adopt different approaches to data creation, management and codification. As a consequence, the data produced might not be “fit for purpose” and could create biases if used in modelling and analytics that depart from the initial goals. While there can be collective gains to coordination, there might not necessarily be private incentives. In such cases, networks lend themselves to some form of regulatory oversight or a central planner.[4]

With the creation of the NSMN, an important need was for the data produced to be usable for a diversity of objectives and by a diversity of end users. The first step of the NSMN was the co-ordination of existing networks, bringing together current entities in a common format. As such, the NSMN also acted as a standard setter; effectively leveraging the full variety of existing networks and modelling efforts relied on consistent calibration and validation practices and metadata characterisation.

Box 5.3. Case Study 10: Data infrastructure and the potential role of the government supporting the data infrastructure—Example of the Akkerweb in the Netherlands

This case study provides a practical example of how an open data infrastructure can facilitate the creation and uptake of value adding services by the private sector, supporting productivity and sustainability in agriculture, using the example of the *Akkerweb* digital platform and data repository. *Akkerweb* is a foundation, founded by both Wageningen University and Research (WUR) and a farmer association, Agrifirm. Scientific knowledge and a practical approach to farmers’ problems are combined to develop successful applications. Some data and applications are made available by the WUR research team, others are added by the private sector.

In the Netherlands, a plethora of unrelated systems have been accumulating data about on-farm activities, farm performance (e.g. yield variation) and the characteristics of production assets, resulting in a fragmentation of data. In addition, while a large amount of data is being used and acquired, most is not actionable, meaning that it cannot be directly used (or re-used) for further production of information feeding into decision processes (analytics). *Akkerweb* is a digital repository and work bench upon which applications, ranging from data visualisation to analytics and decision support, can be built by both the public and the private sector.

Farmers can access a free account and add information that is securely managed on the platform. The platform provides a variety of agriculture related applications readily usable by farmers, using their data, and providing support to decision making to optimise production objectives. In *Akkerweb*, the farmer can combine his or her farm specific data with data from public sources (satellites, soil maps, weather data, parcel maps from the Netherlands Enterprise Agency (RVO) etc.) with proprietary data sources such as sampling bodies, parties in the chain, farm management systems, own sensors etc. In particular, WUR currently provides free satellite data already translated, using complex computation, into in vegetation indices (indication of the amount of vegetation, distinguishing between soil and vegetation etc.). This data is then combined with other commercial data (for example drone data) for a range of advisory services.

Farmers can also access government data. For instance, active links are available with the data store of the national Paying Agency (RVO) and with other farm management systems, to prevent double entry of data. Only the farmer has access to their own data but they can grant access to others at their discretion, making it a type of "controlled access" data governance. In this way, they can give access to their advisors to help them monitor the crops or interpret a soil analysis. Farmers are therefore free to share enriched data with advisers and other users on the platform, to obtain practical recommendations to optimise crop production. The system itself provides interoperability of data. Any data provider can link their data (e.g. soil laboratories) and make them available to farmers.

Source: Case Study 10, Part IV.

5.3.4. Path dependency, infrastructure and regulatory environment: governments have to be aware of their starting point

Finally, policy makers have to consider a degree of path dependency in policy-making and infrastructure development. In the case of the NSMN, the devolution of investment decisions to sub-national scales led to a lack of coordination and alignment of objectives that created inefficiencies in terms of data creation and management. In this context, the NSMN initiative acted as a catalyst, bringing together institutions and creating awareness about the specificity of soil moisture monitoring. But instead of recreating a new infrastructure, they decided to reuse previous, still relevant ones, but created a push for further investments in maintaining and developing it.

This approach contrasts with the Estonian case, which is very different in its intent, timeframe and scale. The government data infrastructure in Estonia was a long-term plan to build a holistic government data infrastructure. Although implementation began in 1998, the system is flexible enough to incorporate new technologies (use of the blockchain) and to add new functionalities. Estonia has a relatively small population, and while it is true that this possibly made the transition and communication about the initiative easier, this should not understate the success of this government administration make-over. While not without problems, the change has proved reliable and flexible.

These case studies demonstrate that there is not a one-size-fits-all solution for the creation of a data infrastructure. Countries need to balance opportunities for coordination and reuse of existing infrastructure with a level of flexibility and potentially changes to the role of the government.

Effective communication and collaboration is an important part of the implementation and adoption of the data infrastructure. The data infrastructure should provide the right incentives with flexibility to implement change and avoid barriers to adoption. Collaboration and communication will be needed both within the government and between the government and citizens.

In Estonia, the regulatory environment has been used to set the incentives for the implementation and use of e-government by government agencies, by centralising policy development, and allowing the Ministry of Economic Affairs and Communication to develop the principles of information policies and supportive legislation, and take over responsibility for supervision of relevant state organisations. Subsequent implementation was decentralised, with e-Government developments done mainly by responsible ministries and state agencies. Accordingly, every government department, ministry or business, gets to choose its own technology, based on commonly agreed principles.

It appears that in the case of Estonia, there have been few barriers to adoption, whether from the institutional side or from that of the users. Various factors account for this, including the population size that helped make implementation more straightforward and communication about initiatives more efficient. On the agriculture side, the fact that data provided by farmers is used to provide support, and not (as in other countries) to verify that the farmers are complying with regulations, had an important role in the level of adoption, as were the services provided digitally by government bodies.

Collaboration requires trust, and the adoption of a data infrastructure requires creating a regulatory environment guaranteeing such trust in the new system based on transparency. A clear regulatory environment about the use and protection of data is reassuring for stakeholders. For example, data security is considered to be the most important feature allowing the Estonian digital society to function. Anyone with a social security code can look up their information online, and thanks to the blockchain technology, they can see who has accessed their data and when. It is also possible to ask about any single query, which allows for a higher transparency in the services. Some core principles, adopted by the Estonian parliament as early as in 1998 and reviewed and updated in 2006 in the course of preparing the Estonian Information Society Strategy 2013, have been driving the development of the Estonian e-government, some backed by legislation (see Part IV for details of relevant legislation).

One core principle is that while the public sector has a role in leading the way towards the development of what is more broadly referred to as the *information society*, developments require co-operation between the public and private sectors, and perhaps with the public more broadly. Therefore, and in order to reassure the Estonian society about the use of their data, a range of legislation has been passed to ensure the protection of fundamental freedoms and rights, personal data and identity. In particular, individuals are the controllers of their personal data and they have an opportunity to decide how their personal data are used.

5.3.5. Governments should ensure there is co-operation and communication between stakeholders

Co-operation and communication is also needed to ensure relevance, uptake as well as prevent unintended consequences on all stakeholders. To be successful, digital technologies have to be designed based on expressed user needs and create positive outcomes from use for all stakeholders.

In order to support the shift from paper to digital, the government of Estonia supported different advertising campaigns to communicate advantages to farmers, including a more rapid identification and treatment of errors. This provided a positive outcome to the digitalisation of farmers' information. Advisory services are free for farmers, who benefitted from a smooth transition and lesser administrative burdens and a shorter time to rectify errors. In addition, as administrative processes are managed faster, payments are more rapidly transferred to farmers. The Estonian LPIS (land parcel identification system) and animal data are also used by statistical offices and for the cadastre system as well as by the environment agency, allowing for cross checks with different agencies. Benefitting directly from positive outcomes facilitates the transition to digital government services.

Another example is the NSMN which created awareness among stakeholders about first, the importance of soil moisture data not only for researchers but also for policy makers and second, about what would be possible with cooperation enabling data already produced to be better exploited simply by cutting across administrative borders. In particular, both the public and private sectors – farmers, policy makers and the community – would benefit from better preparation and resilience to drought.

Finally, the *Akkerweb* provides the example of functionality design that is based on expressed user needs. The platform also partnered with a private sector firm to develop an application for visualisation and analysis of satellite- and drone data. Farmers get access not only to vegetation indices, but to maps, for example scouting maps and task maps.

The success of a range of digital technologies relies on the integration of all stakeholders, and collaboration between the public and private sectors for the creation of information has to be fostered. For example, one success of *Akkerweb* is the strong connection with stakeholders from government, research, agriculture and the ICT sector, providing both scientific backstopping to models and algorithms, and a practical approach to functionality. Public bodies are participating in the data repository construction by linking their agriculture policy data to the platform and supporting the pre-processing of satellite data.

A final element of importance in which government has a role is to provide a regulatory environment enabling to create transparency and tackle the issue of data quality, which leads the way to making the best out of big data and ensuring trust in data-enabled decision making.

In Estonia, a new project is investigating the possibility of bringing big data to farmers. A feasibility study is currently assessing the needs and roles of stakeholders, data storage systems and evaluation of existing data quality. The concept for the big data system will include the technical, legal and economic analyses and the roadmap for implementation. The project includes training for farmers to explain the potential of big data for farm management decisions, to introduce practical applications and models and to demonstrate the technologies for precision farming. The next phase will be the implementation of the system based on the results of the feasibility study.

Notes

[1] The OECD's Directorate for Science, Technology and Innovation has an ongoing work programme examining broadband developments and related policies. This work "highlights challenges such as connecting users to fibre-based networks or coverage of rural areas" (OECD, 2008[4]). Further information is available at http://www.oecd.org/sti/ieconomy/.

[2] EU member respondents were additionally asked about access to farm level data held in EU Member country Land Parcel Identification Systems (LPIS). These respondents generally indicated that a farmer or landowner can freely access and download their own LPIS data at any time (71% of EU member respondents); however, a number of countries only allow access on a restricted basis.

[3] Note that this recommendation does not presume that an open data approach will be appropriate in all cases. Rather, it is recommended that governments consider the possibility of opening datasets as a useful conceptual starting point so that the case for confidentiality requirements can be appropriately (re-)evaluated and transparently made.

[4] World Meteorological Organization (WMO) is in the process of developing standards for soil moisture network development.

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Part IV. Case studies

Chapter 6.

Case Study 1. New Zealand Our Land and Water National Science Challenge

This case study provides a practical example of how digital tools can be used to improve understanding of nutrient sources and their attenuation pathways, and agriculture's impacts on water quality outcomes and policy options for management of water quality impacts, as part of a complex national innovation initiative.

Context: A new approach to sustainable, productive agriculture in New Zealand

New Zealand's *Our Land and Water National Science Challenge* (the Challenge) is a mission-oriented,[1] government-funded, research and innovation programme, which aims to "enhance primary sector production and productivity while maintaining and improving our land and water quality for future generations".[2] The Challenge, which commenced in January 2016 and is ongoing, is comprised of three Research Themes[3]:

- Greater Value in Global Markets
- Innovative and Resilient Land and Water Use
- Collaborative Capacity

The second Research Theme (RT) – *Innovative and resilient land and water use* – is the primary focus of this case study. The goal of this RT is "to help land managers to grow the profitability and yield of productive land uses within the allowable environmental limits by providing widely applicable science and tools to understand the 'off-farm' environmental risks associated with a specific area of land." This goal is set within the context of New Zealand's 2014 *National Policy Statement – Freshwater Management* (NPS-FM), which sets statutory requirements for freshwater bodies and requires Regional Councils to meet these objectives.[4] This RT will "evaluate, model and assess land and water resources and the environmental, social, cultural and financial suitability of land use practices. [It] will look at new technologies, concepts and enterprises that enable individual and collective land and water users and regulators to best adapt to market signals, to derive optimal value chains and achieve their primary production targets within community and regulatory limits."[5] Thus, this RT will assist land managers, communities and regulators.

To achieve its goals, the RT is comprised of a number of research programmes (>NZD 1 million investment) and smaller projects (refer to Table 6.1).

The Challenge as a whole envisages a new approach to fostering a primary agriculture sector that is both productive and sustainable; captured in the idea that "having the right enterprise in the right location at the right time will deliver the right outcome for individual property owners and catchment communities". The Challenge aims to enable New Zealand to "move from considering land use capability (generally driven by production potential and other factors such as off-site environmental impact) to land use suitability where economic, environmental, social and cultural factors are considered together" (Our Land and Water National Science Challenge, 2015, p. iv[1]).

Table 6.1. Research programmes and projects under the *Innovative and Resilient Land and Water Use* theme of New Zealand's *Our Land and Water National Science Challenge*

Research programme/project	Objective	Challenge funding (NZD million)[1]	Co-funding (NZD million) [1]
Sources and Flows	To understand the fate, transport and attenuation processes of key contaminants - nitrogen, phosphorus, sediment and microbes - within catchments and from catchments to receiving waters, in order to (i) support more informed decision-making on investment in land use activities; (ii) enable land managers and regulators to identify the critical contaminants that will result in environmental impact from specific land uses and locations, as well as acceptable limits of discharge to enable the most cost-effective and appropriate level of mitigation for their enterprise; and (iii) identify which contaminants have potential headroom[2] to allow for increased production within environmental constraints, or where catchment re-design utilising low environmental footprint land use options are required.	3.15	0.2
Land Use Suitability	To help stakeholders in land use and management evaluate different approaches for sustainable production within the constraints posed by environmental objectives (also expressed as 'managing within limits').	2.75	4.8
Next Generation Systems	To provide a framework to enable critical assessment of transformational land use systems and use science from across the Challenge to address barriers to adoption of new systems. Next generation systems is designed to work with the land-based primary sector in enabling transformative innovation under nutrient limiting conditions.	2.0	-
Assessing the Yield and Load of Contaminants with Stream Order	To determine the load (kg/yr) of catchment contaminants that come from large or small streams, and if excluding livestock from large streams (> 1-m wide, >30-cm deep) in flat catchments used for pastoral grazing would substantially decrease the load of catchment contaminants.	0.05	-
Interoperable Modelling	To develop a modelling system populated with models which draws on national datasets and is implemented in an interoperable modelling framework. This modelling system will be used nationally for integrated and spatial assessment of economic, production and environmental implications of land use and land use change.	0.9	2.66
Innovative Agricultural Microbiomes	To provide a better understanding of microbiome structure and environmental function, and the implications for (dairy) farm system productivity and sustainability.	1.8	0.2
Faecal source tracking	To identify the potential sources of faecal contamination impacting waterways to ensure appropriate and targeted mitigation steps are implemented for appropriate land use and to reduce stakeholder risk.	0.25	0.08
Cascade of soil erosion to rivers	To test he feasibility of developing physically based equations of soil erosion and sediment transport at the landscape scale.	0.4	0.2
Physiographic Environments of New Zealand (PENZ)	The physiographic approach seeks to explain 'how' and 'why' shallow groundwater and surface water quality varies across different landscapes, even when there are similar land uses or pressures in a catchment. This project provides a map that explains these drivers of water quality across New Zealand.	0.1	0.28
Benign denitrification in groundwater	To create a rapid and cost effective technique to measure and map complete benign subsurface denitrification hotspots in New Zealand agricultural catchments.	0.17	0.05
Measuring Groundwater Denitrification	To develop and validate a methodology for measuring dissolved neon. This project enables the concentration of excess nitrogen to be derived, allowing for the extent of denitrification in groundwater systems to be quantified.	0.23	0.04

Note: 1. Challenge programmes and projects are supported by approximately NZD 12 million in co-funding from government, industry and the science sector. This table lists Challenge funding and co-funding separately. The proportion funded by Challenge funding versus co-funding varies across programmes and projects. For example, the interoperable modelling programme receives only NZD 0.9 million because it has NZD 2.75 million in co-funding.

2. McDowell et al. (2018, p. 215[2]) define "headroom" as follows: "The receiving environment has headroom when the total delivered load is less than the maximum acceptable load (i.e. the ratio is less than one)."

Sources: NIWA (n.d.[3]), Our Land and Water (2018[4]), Our Land and Water (n.d.[5]).

Use of digital technologies in the *Innovative and Resilient Land and Water Use* Research theme

The problems

The key goal of the *Innovative and resilient land and water use* RT is to move to a Land Use Suitability (LUS) framework for New Zealand agriculture. Existing efforts to manage land for (environmental) sustainability are based on land-use capability (LUC) classifications. LUC classification defined as "a systematic arrangement of different kinds of lands according to those properties that determine its capacity for long-term sustained production" (Lynn et al., 2009, p. 8[6]). Data requirements for LUC classification therefore relate to on-site physical and environmental characteristics. In contrast, the Land Use Suitability (LUS) classification which the Challenge aims to produce integrates "information about the economic, environmental, social and cultural consequences of land use choices" (McDowell et al., 2018[2]), and thus requires substantially more, and different, data than was needed previously. Thus, achievement of this Research Theme's objective requires a number of different *information gaps*[6] to be filled. Key gaps include:

- Information about natural processes (e.g. nutrient and other contaminant pathways), including their spatial and temporal characteristics.
- Information about how producers and other land managers respond to incentives (both policy and other incentives).

These information gaps also prevent the targeting of existing policies to take into account local contexts. For example, whereas many researchers note that nutrient or other contaminant loss factors (from agriculture and other sources) vary widely depending on location-specific factors, current implementation of New Zealand's *National Policy Statement of Freshwater Management* (2014) applies uniform contaminant loss factors "to all areas of land as there are not the tools or frameworks available to link contaminant losses from different parts of a landscape to different levels of water quality impacts downstream."[7]

Further, the existing research landscape is characterised by *fragmented and asymmetric information*: often, data sets and digital modelling tools are accessible only by the researchers who work with them directly. This leads to duplication, confusion over the role of different models and research efforts, and impedes effective translation of research efforts into change "on the ground" (McDowell et al., 2017[7]). In addition, licensing issues with some of the datasets mean data sharing between researchers could be difficult. Case study participants observed that in a collaborative setting, the researchers can settle for a common minimum data that is accessible to all, but which may not be the most up-to-date dataset.

Digital solutions

The Challenge is making use of a number of digital tools to address the information gaps and asymmetries identified above. In some cases, pre-existing tools are being repurposed to help achieve Challenge objectives; in other cases, Challenge funding is being used to enhance pre-existing tools or build new ones. These tools constitute an important part of Challenge activities, but it is important to recognise that they are being developed and used alongside other (non-digital) activities.

Table 6.2. Digital tools developed under the *Innovative and Resilient Land and Water Use Research* theme

Digital tool	Challenge research programme	Brief description of tool	Data used by tool (if applicable)	Status as of September 2018	Benefits of tool
Data collection tools					
Land, Air, Water *Aeotearoa*, Ministry for the Environment	National register of measures, interoperable models and data ecosystem white paper	Metadata standards to facilitate the supply and use of environmental data between Challenge modelling tools and central and regional government repositories	National coverage of point data for land and water quality parameters	The Challenge provides advice and funding to continues this work to ease the handover of Challenge modelling and tools	To steward the Challenge's modelling and tools and create a legacy beyond the life of the Challenge.
Digital analytical tools					
Framework	Sources and Flows	Framework provides a conceptual link between contaminant source, transport from land to water via surface and subsurface pathways and attenuation during transport processes. The Framework is placed within a hydrology sub-framework that is applicable to all contaminants. The Framework is agnostic to spatial and temporal scales.	National scale climate, flow and water quality data	The conceptual framework development has been completed. Three contrasting case study catchments have been chosen for testing the robustness and applicability	The biophysical Framework allows linkages to other non-biophysical frameworks and components such as cultural, economic and social. This linkage shall be piloted in one of the case study catchment in 2018-19 to allow the community envisage the perceived values of such linkages. Because they are not bundled into a tool, the Framework layers could be used and manipulated to suit the stakeholder and end-user needs.
MitAgator	Aligned programme [a]	A spatial farm tool that maps critical source areas of contaminant losses to water and provides estimates of the cost-effectiveness of measures to mitigate their loss	National scale soil and climate data. Farm management data provided by industry standard model – Overseer (www.overseer.co.nz)	Released July 2018 (www.ballance.co.nz/Mitagator)	Enables farmers to estimate the likelihood and cost-benefit of reaching an allocation limit.

Digital tool	Challenge research programme	Brief description of tool	Data used by tool (if applicable)	Status as of September 2018	Benefits of tool
National physiographic classification	Physiographic Environments of New Zealand (PENZ)	The main outputs will be: 1. Classed process-attribute GIS layers that depict the spatial coupling between process signals in water and landscape attribute gradients. GIS layers will include: • Hydrological Process-Attribute Layer [b] • Redox Process-Attribute Layer [c] • Physiographic Map (combined hydrological and redox process layers) 2. A web-based interface for farmers and industry[d]	National scale landscape attribute data (from pre-existing GIS layer for geology, soil, topography, climate data, land cover, water flow and quality data [e] Finer scale soil mapping, LiDAR, radiometric imagery data to augment national scale data [e]	A physiographic classification (Physiographic Environments of New Zealand) is currently being created for 7 regions in NZ [f]. The web-based interface for farmers and industry to access physiographic science is initially being developed for NZ's Southland region as part of a government grant. Development and design of the web-based interface is being guided by farmers, industry groups and extension staff.	Provides an opportunity to target and implement mitigations that are environmentally- and cost-effective by explaining, at the process level, 'how' and 'why' water quality and composition vary under similar levels of land use intensity.
Land Use Suitability digital tool	Land Use Suitability	A concept and prototype GIS-based tool for analysing land-water systems. The first application of the concept examines productivity within environmental constraints and produces three indicators: • Productive potential: a classification for what a land parcel can do and the value it can return • Relative contribution: how much contaminant a land parcel is reaching a site of impact, relative to others, after taking into account attenuation • Pressure: whether or not a water body is exceeding the allocated load (as set by an objective)	National scale climate, water flow and quality and land use capability data.	Concept has been published and a prototype tool has been developed and tested in one region (Southland). The tool will be extended nationally in 2019, and augmented with other attributes (e.g. social and cultural).	Provides an objective measure of land use relative to an environmental objective at a land parcel and catchment scale. Informs policy that seeks to address what environmental objectives can be achieved beyond implementing measures to reduce losses, but sustain, the current (and potentially underperforming) land use.

Digital tool	Challenge research programme	Brief description of tool	Data used by tool (if applicable)	Status as of September 2018	Benefits of tool
OVERSEER science and capability	Aligned project under this research theme	Enhancements to NZ's OVERSEER® nutrient budget model (www.overseer.co.nz), the industry standard for estimating N and P losses from different enterprises.	Farmer, consultant, or researcher inputs are augmented by nationally available databases on soil and climate.	Model was first developed in the mid 1990's and is freely available.	This work will continue to develop new science for incorporation into NZ's OVERSEER® model. The Challenge is specifically funding work to make Overseer interoperable with other catchment scale models.
River Environment Classification digital stream network layer	Supports Challenge research *but is not funded by Challenge*	Upgrades existing River Environment Classification digital stream network GIS layer to significantly improve the spatial definition of the network.	Point elevation data and remote sensing information from LiDaR surveys	The first iteration of this new network layer was completed for both North and South Islands and made publicly available in June 2018.	Facilitates development of the NZ Water Model, a sophisticated computer model framework that will enable users to accurately predict how much freshwater is available, where it has come from, and how quickly it moves through New Zealand catchments.
National Catchment-scale Source-Delivery-Attenuation modelling	Used by Sources and Flows *but was developed prior to the Challenge*	A national scale, scenario-based water quality modelling tool that allows modelling of contaminant (N, P, and sediment) loads from catchments to water bodies.	National scale water quality data from river, farm scale data from a farm scale model OVERSEER	The model has been applied to entire NZ to understand critical knowledge gaps across the country.	Tool allows identifying areas where insufficient information exists in characterising land management and its impact on water quality.
Data management tools					
Interoperable modelling framework	Interoperable Modelling	Nationally-recognised modelling platform for assessment of environmental, production and economic implications of land use and land use change. The platform (Deltashell) will be populated with models and national datasets.	Models are to use the best available data from central and regional government (see Land, Air, Water, *Aeotearoa*)	Programme initiated.	Provides a modelling framework that can be used for a variety of purposes, including regulatory limit setting, land-water management, and contaminant accounting at farm and catchment scales. This will reduce costs, duplication and uncertainties caused by using different models for different purposes, and foster collaboration and a shared understanding of environmental and economic impacts of different land use options.

Digital tool	Challenge research programme	Brief description of tool	Data used by tool (if applicable)	Status as of September 2018	Benefits of tool
Digital communication tools and service delivery platforms					
Land, Air, Water *Aeotearoa*	National register of measures	Hub and advisory service that displays and explains the state and trends associated with air, land and water quality data from regional authorities (www.lawa.org.nz)	All data collected by regional authorities, limited in the first instance to water quality, but to be extended to other domains when data availability and quality allows.	Initiated June 2018. Initial scoping to June 2019 with the intention of it being augmented from July 2019 with a list and location of catchment management groups who have or are using measures to mitigate the effects of land use on water quality, the performance of measures and advice on what measure to use to meet an environmental objective.	Stakeholders (farmers, industry, regulators) will have greater confidence in implementing measures to improve water quality to meet a limit. Advice will emphasise what, where and when to implement measures.

Notes: a. Aligned programmes are those that offer support and significantly advance the Challenge mission. Aligned programmes/projects are identified through the Research Landscape Map and formally documented *vis-à-vis* their milestones/deliverables and to what key performance indicator they advance.

b. HPAL provides landscape controls over: 1. Water source (where does the water in a stream or aquifer originate from); 2. Recharge mechanism (the broad scale mechanism/process by which water reaches an aquifer or stream); 3. Water pathway (fine scale mechanism/process controlling the pathway water takes – bypass flow, overland flow, lateral drainage and deep drainage).

c. RPAL for soil and aquifer reduction potential controls: 1. Denitrification; 2. The solubility, leachability and mobility of redox sensitive species.

d. The output to produce a web-based interface is funded by The Ministry for Primary Industries through the Sustainable Farming Fund. This is aligned with the OLW PENZ project which delivers the science output while the web-based interface aims to make the science (physiographic map) more accessible to farmers and primary industry groups to inform farm management decisions.

e. Hydrochemistry and water quality data for surface and groundwater (PENZ test set, LAWA); Climate (Temperature, precipitation, ispscape); Hydrology (REC); Soil (Fundamental Soil Layer, S-Map); Geology (QMap, NZLRI); Topography and Elevation (8m Digital elevation model, LiDAR); Land Cover (LCDB4.1); and additional regional datasets (Land use, Radiometric, soil chemistry).

f. Northland, Auckland, Waikato, Bay of Plenty, Manawatu-Wanganui, Canterbury, and Southland.

Source: Authors, based on information supplied by case study participants, Our Land and Water National Science Challenge (2016[8]) and Rissmann et al. (2018[9]).

Table 6.2 provides a description of the main digital tools being developed or enhanced under the *Innovative and Resilient Land and Water Use* Research Theme, using the classification of digital technologies presented in the project main report (Table 2.1 in the main report). This table includes several tools which are being advanced through co-innovation (Box 6.1) at the same time as the Challenge tools and which support the Challenge research programmes, but which do not receive Challenge funding. This table does not provide an exhaustive list of *all* digital tools developed using Challenge funding, as the project is ongoing.[1]

Box 6.1. Our Land and Water co-innovation approach

A central tenet underpinning the Challenge is that its objectives will not be achieved unless Challenge participants and stakeholders work together collaboratively (Our Land and Water, 2018, p. 4[4]). Recognising that there is insufficient documented evidence of the benefits of collaboration, the Challenge includes a range of specific efforts to measure these benefits and advance understanding of how collaborative processes can be improved.[1] The Challenge implements a new way of working, termed "co-innovation", which replaces the existing "funder-provider" model. Co-innovation is defined as "individual land managers, primary production sectors, *iwi*,[2] communities, policy makers and scientists all working collectively to identify priority issues and create enduring solutions." (Our Land and Water National Science Challenge, 2016, p. 4[8]).

Co-innovation involves a much closer relationship with stakeholders than existing approaches. The intent is that this closer relationship will produce research that is fit-for-purpose, relevant and will be used and championed within stakeholder networks.

The Challenge defines several different dimensions (and example metrics) of co-innovation:

- Co-design: Research questions are developed with stakeholders and signed off as relevant. The Challenge maintains a record of co-designing all programmes with stakeholders.
- Co-development: This generally involves scientists physically co-locating with stakeholders and stakeholders co-investing. Across the wider research landscape we have seen an increase in the frequency of collaboration by 66% (from 1.6 institutes per research programme in 2015 to 2.6 in 2017), while Challenge-funded programmes maintain an average of 5.3 collaborations.
- Co-production: Investment in and extension of outputs into outcomes is sustained by stakeholders co-authoring Challenge documents. During the first two years of the Challenge, more than 50% of academic outputs were co-authored with stakeholders.
- Co-innovation: Outcomes are promulgated by stakeholders, for example a close working relationship with science enables a stakeholder to reach sensible water quality limits

The Challenge aims to test the hypothesis that using co-innovation in science can lead to quicker, more robust and enduring outcomes. In particular, it aims to halve the time taken for an idea to be at its maximum level of use from 16 years (Kuehne et al., 2017[10]).

However, some participants noted that because co-innovation is inclusive and deliberative, the process may in fact take longer compared to a situation where researchers develop a solution with little to no input from users and then "push" the solution to users. This raises a question about whether there is a trade-off between designing solutions which are "better" (in the sense of being more robust, enduring or fit-for-purpose) versus "quicker", and how to measure these different dimensions in order to evaluate and compare different innovation approaches. The Challenge will also be testing this aspect of co-innovation.

Notes: 1. See in particular work done under the third Challenge Theme—Collaborative Capacity.
2. Iwi is "the focal economic and political unit of the traditional Māori descent and kinship based hierarchy".
Source: http://archive.stats.govt.nz/methods/classifications-and-standards/classification-related-stats-standards/iwi/definition.aspx, accessed August 2018.

Managing data and interaction between digital tools: a vision for a data ecosystem

The many and varied research projects under the Challenge as a whole, and within the *Innovative and resilient land and water use* RT specifically, are producing a "growing diversity, complexity and volume of data" (Medyckyj-Scott et al., 2016[11]). From the start of the Challenge, it was recognised by the Challenge Chief Scientist and Leadership Team that gathering this data into a shared "data ecosystem" is one of the greatest sources of potential value added for the Challenge as a whole. In 2016, a group of experts from the New Zealand public service and the research sector collaborated to produce a "white paper" on the design of this data ecosystem. The data ecosystem is explained as "a system made up of people, practices, values and technologies designed to support particular communities of practice [in which] data is valued as an enduring and managed asset with known quality" (Medyckyj-Scott et al., 2016, p. v[11]) and defined (Medyckyj-Scott et al., 2016, p. 5[11]) to encompass:

- Policies regarding data management planning, data custodianship and curation, legal frameworks, and the use of externally sourced data;
- Procedures and processes to execute those policies and manage data;
- A data governance framework and organisational structures;
- Engagement with data consumers and stakeholders; and
- Technology platforms that will support data collection, storage, description, analysis, linking, delivery and curation.

The data ecosystem is proposed to be "supported, enabled and facilitated by a federated infrastructure in which data may be collected from traditional sources and new technologies, curated, published, analysed, modelled, linked, used and reused but accessed through a single point of access, from its authoritative point of origin, with discovery and visualisation tools" (Medyckyj-Scott et al., 2016, p. 21[11]).

Efforts to date have focused on developing a standard for metadata. However, the Challenge recognises that the issue will cost more than it can afford and that the solution must endure beyond the life of the Challenge (due to end in 2024). Therefore, the Challenge has engaged with central government agencies to act as repositories for data and modelling efforts, such that outcomes can be driven from the legacy of Challenge science.

Lessons learned

Lesson 1. Multi-dimensional integration of digital and other tools is needed to ensure efficiency and effectiveness

Interoperability[2] is an important consideration when building new digital tools or enhancing existing ones, and has long been identified as a key factor for efficiency and effectiveness. However, this case study demonstrates that more is needed than interoperability to ensure efficiency and effectiveness: digital technologies need to have *clear roles with definable "added value" relative to other tools and relative to policy and programme objectives*. This is encapsulated in the notion of making digital tools *integrated*, both with other tools and with other programmes or initiatives than the one under which they are developed. Dimensions of this integration include:

- clearly articulating how a new tool complements existing tools, including by considering whether a policy or programme objective can be achieved via leveraging an existing tool (potentially with enhancements) versus building a new tool;
- acknowledging that digital technologies are only one part of a broader solution;
- acknowledging that multiple digital tools are needed to accomplish complex policy objectives (e.g. models at different timescales, digital platforms to enable different users to use the same data or model for different purposes, etc.);
- considering potential uses of technologies that are broader than the current programme or initiative, and what design features will help ensure the re-usability of digital tools (in addition to re-use of data).

Case study participants identified two institutional design features that were instrumental in assisting the Challenge to achieve this integration:

- *The co-innovation approach*: as outlined in Box 1.1, the Challenge uses a co-innovation approach which actively includes a diverse range of stakeholders, right from the beginning of project design and throughout projects. This enables the relevance of research questions and likely outputs to be tested 'up front'. It also increases the ability of Challenge participants to identify what type of new tools might be needed (e.g. digital tools or other tools), whether new tools are genuinely additional to existing tools (i.e. because creators and users of existing tools are included in the design process), and how different tools relate to each other.
- *The data ecosystem 'white paper'*: the question of '[w]hat are the best data structures for land and water information to achieve the Challenge Mission?' was actively considered from the outset of the Challenge. This helped ensure that all project proposals, including proposals for new digital tools, actively considered both existing and recommended data structures and existing data tools.[3] As part of this process, the data ecosystem team conducted a collaborative workshop in 2015 (i.e. before the formal commencement of the Challenge) about digital tools to ensure stakeholder's experiences with existing tools, particularly in relation to challenges, were taken into account (Medyckyj-Scott et al., 2016, pp. v, 11[11]).

Lesson 2. Monitoring and modelling should be viewed as complementary

Often, monitoring and modelling happen as two separate streams of work, and modelling is often described as being needed in the context of incomplete information. This implies that modelling is only needed because of data deficiencies; that is, that monitoring and modelling are substitutes.[4]

In many cases, data gaps are likely to persist: monitoring of all physical variables of interest is unrealistic, despite advances in sensors, Internet of Things devices (e.g. “smart” agricultural machinery) and remote monitoring technologies which enable much broader physical monitoring at lower cost than previously. Therefore, there will still be a need for models to attempt to “bridge” these gaps.

However, even if all necessary physical measurements *could* be obtained via monitoring, modelling may still be needed for a variety of functions, such as attributing physical impacts to non-physical drivers (particularly to policy drivers, so that policies can be evaluated), and modelling future scenarios to make *ex ante* policy assessments and improve planning.

Thus, modelling and monitoring should be viewed as complementary: modelling both uses data and allows for analysis in the absence of data.

Lesson 3. Ensure new digital tools do not create new information asymmetries

While the Challenge aims to produce a range of digital tools and information products which address existing information gaps, there is also the need to develop digital tools and effective stakeholder engagement strategies to ensure that production of new knowledge does not inadvertently produce information asymmetries. (This could potentially occur, for example, if only researchers involved in creating new knowledge or tools had access to them. The Challenge acknowledges this risk and addresses it via its co-innovation approach.

Lesson 4. Creation of dynamic, updatable digital tools can lessen the need to “reinvent the wheel” and better match users’ needs

Reflecting the dynamic nature of many factors relevant to land management decisions, there is strong demand for up-to-date information. Previously, many tools were relatively static, making them less useful and prompting periodical attempts to “reinvent the wheel” (to make tools which better suit users’ needs, which may have changed). Therefore, tools that can allow for rapid update of information better match demand for information, and as such are likely to be used more, both now and in the future.

Lesson 5. Embrace different levels of Data Management Maturity to fit different contexts

There are different levels of Data Management Maturity (DMM);[5] it may not be necessary to advance all (or any) participants to the highest level of data management in order to achieve programme objectives. Also, it will take time to progressively move through the different levels of DMM. Strategic planning for transitioning through these levels (including planning for different stakeholders—whether individuals or organisations—to move through levels at different speeds) can be helpful for: (i) identifying the current situation (i.e. which participants are at which level), (ii) identifying which level(s) participants eventually need to reach for the programme or policy goal to be achieved, and

(iii) improving the overall level of maturity while still allowing for flexibility and not imposing too high transition costs.

It is also important to recognise that moving towards more advanced levels of DMM may require attitudinal change. For example, the Challenge's Data Ecosystem white paper (pp. 16, 29) identified that "experience shows that one of the major obstacles in the cultural change is the view that data belongs to "me" and that it is not treated as an asset". The authors concluded that "it is unlikely that maturity in handling data will emerge if in other ways participants lack a strong sense of community."

Lesson 6. Ensure initiatives generate "additional" benefits by using a mix of old and new technologies

Digital technologies have been in this case study used both *to improve and enhance the functionality of existing analytical systems* (e.g. upgrading the NZ Water Model), and *to provide wholly new tools* (e.g. LUS classification and Physiographic Environments of New Zealand GIS layers) that support decision-making process that were not previously possible. This enables the Challenge to avoid duplication and "reinventing the wheel", while still ensuring that the tools are fit for purpose. This requires a thorough understanding of the existing analytical tools.

Lesson 7. Digital tools can be used to foster collaboration and overcome traditional roadblocks created by conflicting views and values

Development of new digital tools often requires greater collaboration between different individuals and organisations, and across disciplines. Also, there needs to be strong links between new or enhanced tools developed within the initiative (in this case, within the Challenge) and other tools (e.g. NIWA digital stream network layer).

Digital tools are being successfully used to help parties with different interests and incentives to build consensus. For example, the OVERSEER® nutrient model, which is being enhanced under the Challenge and aligned programmes (e.g. to be made spatially explicit by MitAgator), has been developed using co-innovation and can be scrutinised by all interested parties. It functions as an "authoritative point of truth", but is able to be updated with the latest available science and incorporate innovations (e.g. new data sources from new sensor technologies).

Lesson 8. Digital tools can enable new information-rich policy paradigms rather than simply improving the granularity of existing information-poor paradigms

Many existing approaches to land use planning and managing environmental impacts are fundamentally based on a recognition that there are substantial information gaps and that assumptions are needed to bridge those gaps (Macey, 2013[12]). Land use capability (LUC) planning is one important example of these existing approaches. While the LUC approach provides "an indicator of the productive versatility of land parcels for a range of land uses and identifies key constraints such as erosion" (McDowell et al., 2018[2]), the focus is on determining what a given land parcel is capable of producing. This approach does not explicitly account for spatial linkages or for policy objectives such as objectives relating to downstream receiving water bodies. Because information on aspects such as nutrient transfer pathways and landscape attenuation capacity has been missing, existing watershed management policies tend to be based on LUC assessments and generally apply uniform approaches to different land-use types. While improved data can help these approaches to become more granular and allow for some degree of targeting (e.g. to focus mitigation or remediation efforts on areas where erosion potential is highest), it is difficult to explicitly take into account complex spatial and dynamic relationships within the LUC framework.

Digital tools such as those being explored in the Challenge can enable new approaches such as the land-use suitability (LUS) approach which *are* able to explicitly account for these complex spatial and dynamic relationships. Such holistic approaches, while still in their infancy, hold out the promise of designing policies which take into account a much greater degree of complexity, including the ability to evaluate synergies and trade-offs between multiple policy objectives.

Notes

[1] "Mission-oriented policies can be defined as systemic public policies that draw on frontier knowledge to attain specific goals or "big science deployed to meet big problems", https://ec.europa.eu/info/sites/info/files/mazzucato_report_2018.pdf, accessed June 2018.

[2] http://www.ourlandandwater.nz/, accessed June 2018.

[3] http://www.ourlandandwater.nz/assets/Uploads/Research-Book-OLW-2019.pdf, accessed June 2018.

[4] Our Land and Water Revised Plan 2015, p.35. The NPS-FM is an overarching national policy for freshwater management, whose objective is "that the overall quality of freshwater within a region is maintained or improved and Regional Councils have to meet its statutory requirements. The NPS-FM links to the National Objectives Framework (NOF) that outlines the water quality objectives that Regional Councils have to meet, along with the proposed Environmental Reporting Bill increasing the demand for enhanced environmental monitoring and reporting." (p.14)

[5] Source: http://www.ourlandandwater.nz/the-challenge/innovative-resilient-land-and-water-use, accessed August 2018.

[6] Refer to Chapter 2 of main report, which presents the conceptual framework for analysis and identifies that information gaps, information asymmetries, transactions costs and misaligned incentives as sources of fundamental problems for agri-environmental policies, which digital technologies can help ameliorate or overcome.

[7] http://www.landandwater.kiwi/Projects/Theme%202%20Sources%20and%20Flows.docx, p.7.

[1] See also the Challenge Research Landscape Map, available online at: http://www.ourlandandwater.nz/resources-and-information/strategy-and-plans/, accessed August 2018. This document details 350 related Challenge-related projects of >NZD 50 000, some of which involve digital tools.

[2] Interoperability can be defined as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" (Geraci, 1991[13]).

[3] Table 3 in Medyckyj-Scott et al. (2016, p. 11[11]) enumerates existing digital tools that the Challenge will interact with.

[4] In particular, discussions of the use of modelling to support water quality policies for agriculture often centre on the notion that nonpoint sources (including agriculture) are sources for which it is not possible or prohibitively costly to measure and attribute emissions to particular sources (farms).

[5] Data Management Maturity (DMM) is a concept and framework for analysing institutional capacity to manage and make beneficial use of data assets. The DMM framework assesses data management practices in six key categories that helps organisations benchmark their capabilities, identify strengths and gaps, and leverage their data assets to improve business performance. See (Medyckyj-Scott et al., 2016[11]) and https://cmmiinstitute.com/data-management-maturity, accessed September 2018.

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Chapter 7.

Case Study 2. Digital technologies for Dutch agricultural collectives

This case study provides a practical example of how data management and transfer technologies can be used for the effective and efficient operation of collective governance mechanisms that focus on achieving environment-climate-biodiversity objectives in agriculture. These technologies and their accompanying administrative and legislative arrangements enable achievement of these objectives in a way that considers the landscape as a whole while providing spatial and temporal flexibility for participating farmers and other stakeholders.

Context: The policy environment and the Dutch collective approach

The EU Common Agricultural Policy (CAP) is the key legislative instrument governing payments made to Dutch farmers. Historically, national paying agencies have administered payments based on claim applications made by individual farmers. In 2014, the EU Rural Development Regulation (Regulation (EU) No. 1305/2013, Article 28[1]) provided for agri-environment-climate payments (one type of payment under Pillar II of the CAP) to be made to groups of farmers or groups of farmers and other land-managers, in addition to paying farmers individually.

In 2016, the Dutch government introduced a new scheme such that individual applications are no longer possible in the Netherlands; all applications must be lodged by an agricultural collective (Netherlands Ministry of Economic Affairs, 2016[1]). The government considered that the collective approach would:

- foster a "better-targeted and cross-farm approach", focused on creating good habitat conditions for rare species and regional water quality protection, rather than pursuing farm-level commitments (Mulders, 2018[2]). The government considers this landscape approach is needed to address declines in farmland biodiversity (individual applications could be "detrimental to regional goals");
- provide "greater flexibility in terms of the content of conservation activities, their exact location and their financial compensation";
- be simpler and less error-prone than administration based on individual applications; leading to reduced costs and improved compliance; and
- be consistent with the existing social structure in the Dutch agriculture sector which "has a long tradition of agri-environment co-operatives".

In practice, this approach works as follows:[2]

- The *provincial government* contracts with individual co-operatives for selected agri-environmental targets over a six-year period. Both *national and provincial governments* participate in the definition of the targets. The co-operatives are the beneficiaries of CAP subsidies. The Paying Agency undertakes official EU-required controls (administrative and financial checks), and pays the subsidy to the co-operatives.
- The *co-operatives* contract with individual farmers for the provision of conservation targets, and develop guidance for individual payments and for the "distribution" of any penalties imposed on the co-operative in the event that the targets specified in the contract between the co-operative and the Paying Agency are not met. The co-operative works with farmers as well as other stakeholders such as conservation organisations to both decide on and deliver the conservation activities which will deliver on the targets. The co-operative also takes care of accounting, annual reporting (to the Paying Agency) and controls for individual contracts with farmers (e.g. on-the-spot-checks).[3] The contracts with individual farmers in aggregate provide for fulfilment of EU requirements in the collective's contracts; however they may also include additional management activities which go beyond what is required under the CAP. These additional management activities may be included, for example, to make area-based national policies more effective.

- An umbrella organisation, *BoerenNatuur*, provides guidance and technical support to the 40 agri-environmental co-operatives.[4] In particular, *BoerenNatuur* has developed digital platforms – described below – which the collectives use to administer contracts and payments, and to track the progress of individual conservation efforts that contribute towards the overall targets. This digital platform is directly linked to the digital platform of the paying agency.

Use of digital technologies to support the effective and efficient operation of the collectives

The problems

In order to achieve the vision for the collectives, a number of technical and administrative challenges needed to be solved:

- One important aspect of achieving *flexibility* is to design the administrative system and the payment rules to be able to "follow nature". This requires rules and administrative procedures to be specified with reference to a date range or to when natural events (e.g. movement or nesting of birds) occur, rather than with reference to specific dates. In turn, this requires high resolution data on where and when the relevant natural events occur, as well as the ability to track individual actions (e.g. on-farm practices) accurately in space and time.
- Another important aspect of achieving *flexibility* at the local level is to recognise that EU rules may not be similarly flexible, and therefore to design a system which allows local flexibility while still "fitting in" with EU requirements. This introduces the risk that local flexibility will *not* "fit in", which in turn requires additional risk mitigation mechanisms such as buffers between the maximum payment the paying agency is allowed to pay according to EU rules and the actual payment the collective asks for.
- To achieve the desired *"cross-farm" or landscape approach*, the system needs to be able to track all individual efforts and assess the aggregate effect, and enable an interactive regional planning process whereby regional objectives are set taking into account individual actions, as well as vice versa.

Conceptually, these challenges relate to *addressing information gaps* and creating *co-ordination and risk management mechanisms* between: 1) different actors who may have misaligned interests; 2) different scales which may have different levels of flexibility and over which objectives might differ; and 3) different legal frameworks which may (without these mechanisms) be inconsistent.

The solutions: SCAN-ICT—an IT system for the collectives

To address these challenges, the Dutch collectives are developing a system of digital technologies (SCAN-ICT, *Mijnboerennatuur.nl*, and *Schouwtool*). These tools interface with the digital platforms of the Dutch paying agency, for example the Dutch Land Parcel Identification System (LPIS).[5]

The SCAN-ICT was developed and built by SCAN (a foundation of collectives in agri-nature management, established to prepare the implementation of the collective AECM), as an assignment from the Dutch government (both Ministry and provinces).

Ownership of the digital platform lays at the 40 collectives together, working together in *BoerenNatuur*. It is obligatory for the collectives to make use of the SCAN-ICT. The SCAN ICT contains:

- Administration and contracts for farmer participants.
- Digital registration of the type of management on the land parcels of the participants (practically speaking: draw management unit on map and link to management activities or package).
- Reporting of completed management activities from participants during the year, including notification to be made to the paying agency.
- Preparation of the management plan on a landscape and parcel level.
- Preparation of the collective claim for all the parcels in a habitat.
- Preparation of payment justification for all the parcels in a habitat.
- Payments of farmer participants.

Due to the direct link with the digital platform at the paying agency, SCAN-ICT makes it possible to change parcels and management activities on a short notice, without losing controllability requirements as a result of EU legislation. Further, it ensures that the plans, claims and justifications officially submitted to the paying agency fit with the digital information the paying agency obtains from other sources. This helps improve the quality of these products, and therefore it costs less time at the paying agency to make a decision.

How was the system built?

The Dutch government provided EUR 10 million over four years for the collectives to develop the SCAN-ICT system. Case study participants estimated the ongoing annual costs of the system to be around EUR 1-2 million.

The system was built by a "Building Team", comprising information communication technology (ICT) suppliers, the Netherlands Enterprise Agency, Dutch Provinces and *BoerenNatuur*. Team members worked together in an open, transparent and co-operative approach. The Building Team organises user groups and regularly consults them on their experiences using the system, collects suggestions on improvement and tests new proposals.

What does the SCAN-ICT system do?

The system is composed of three components described in turn below:

- *SCAN Office* provides for administration of contracts with farmer participants. It contains relevant farmer data (e.g. contact details), digital contracts, payment specifications for each participant, email correspondence between the Collective and the farmer participants. The SCAN Office system is a pre-existing tool obtained via a licencing agreement and was customised to some extent for the collectives' specific requirements.
- *SCAN GIS* is a geographic information systems (GIS) environment used to register the management units (e.g. land parcels) for each different participant and link these to management activities (termed "management packages"). It was custom-built on the basis of a pre-existing tool. Data in SCAN GIS is exchanged regularly

with the Paying Agency to ensure consistency between SCAN GIS and the Dutch LPIS. This component provides high resolution data and information in a range of GIS layers, such as parcel information, the kind of management a farmer and a collective agreed upon, and the specific requirements for such a management.

- *SCAN Financial* is used for financial administration and payments to farmers. It was developed separately in part because the *SCAN Office* system does not have a financial component, and also to ensure maximum security for financial payments.

As of June 2018, employees of a collective have their own SCAN-ICT account and only have access to the data of their collectives' participants. Participants themselves currently do not have access, but this functionality is envisaged.

The SCAN-ICT system operates separately to and duplicates information gathered by the Paying Agency (Netherlands Enterprise Agency, NEA) within the Integrated Administration and Control System (IACS) which is relevant for the contract of the collectives. (Most important is the parcel information in the LPIS; specific information on farmers is not duplicated.) Data in SCAN GIS is exchanged and reconciled with the Paying Agency on a regular basis to ensure consistency between the two systems. At this stage, NEA does not allow direct access to its system.

While this separation entails some duplication of data, it has the following benefits, which case study participants considered far outweigh the costs of duplication:

- The collectives use the SCAN-ICT system to collect and store more information than the Paying Agency needs to view. In particular, the SCAN-ICT system records data relevant to items in individual contracts with farmers (e.g. on-farm agri-environmental practices) which are not required by EU legislation.
- Information available to the Paying Agency would be used in EU-level controls conducted by the Paying Agency. For example, as the contract and amount of payment to a farmer by a collective is a private law agreement, this information is not submitted to the paying agency. This makes it possible for a collective to pay more to a certain farmer for a certain activity than the maximum agreed upon in the Dutch Rural Development Programme.

The protocol for information exchange between the NEA and the SCAN system is based on web services and standard messages. The exchange of reference information such as the LPIS reference parcels (AAN – Agricultural Area Netherland) and the farmers' fields (from farmers' CAP application) is based on the Dutch standard message system, the *EDI-CROP message*, which has been incorporated into the UN/CEFACT e-CROP message standard[6]). For the SCAN information exchange, extensions have been developed by SCAN and NEA.

This EDI-CROP messaging protocol is widely used in the Dutch agriculture community, for all kind of purposes, for example in farm management systems, shared data hubs such as JoinedData, and *Akkerwweb*, and by the agriculture co-operations and service providers and software developers.

Thus, the information exchange between SCAN and NEA is fully aligned with other information exchanges in the Dutch agriculture community and is based on national (AgroConnect) and international standards (UN/CEFACT). Some of the software developers participating in the SCAN GIS system are also involved in app development for Dutch farmers. In many of these apps, sharing and using geo data from and with the NEA parcel registration system is an important functionality.

The system also includes "Quality Indicators", which are constraints on data entry in the system to help prevent errors and to cross-check different elements to ensure consistency and ensure that management plans for individual participants (e.g. farmers, landholders) are "fit for purpose" (e.g. that practices are suitable for the land type on which they are to be applied; that they fit with regional or landscape level objectives). The addition of Quality Indicators is useful to demonstrate that the system is robust, and to help collective employees who administer the system to automate checks and reduce the risk of errors.

Further, interoperability protocols were developed to enable the SCAN-ICT system to interface with the Netherlands LPIS. This allows for automatic reconciliation between the two systems, minimising the costs of duplication and the risk of the systems becoming "out-of-sync".

Ongoing developments

Mijnboerennatuur.nl **—a digital communication platform for collectives and farmers**

Mijnboerennatuur is an online platform which will "digitalise" communications between collectives and their participants. It will allow farmers to log into a separate application to view their own data in real time as well as key documents such as contracts. Once this platform is fully operational farmers wishing to have changes made to their data will be able to notify their collective within the application (in addition to existing contacts methods such as telephone or email). The collective can then either decline this notification, or approve it and send it on to the Paying Agency. This feature will make two-way communication between collectives and farmers simpler.

Schouwtool—a digital tool to manage inspections

Schouwtool will allow collectives to manage their inspections through SCAN-ICT, both the planning process as well as administering the results of the on the spot checks, done by the collectives themselves. External inspectors can log into their agenda and see when and where to go to conduct inspections, as well as what needs to be inspected. They can also administer the results into the tool. This allows for the inspection system to become more cost-effective.

Lessons learned

Lesson 1. The SCAN-ICT system and related digital platforms assist pre-existing collective governance institutions to "go further"

The Netherlands has a long history of collective governance mechanisms in agriculture (Jongeneel and Pollman, 2014[3]). However, while previously agri-environmental collectives did help farmers to co-ordinate their conservation efforts, in practice most contracts under the CAP were still with individual farmers. The SCAN-ICT system and related digital platforms *enable a landscape approach* by providing a cost-effective way to track and aggregate information on individual conservation contracts and actual efforts on a landscape scale, and present information in an accessible and easy-to-understand format (e.g. by visualising data in GIS map layers) so that all stakeholders can be "on the same page".

Also, historical individual contracts (and even early collective contracts) did not provide flexibility; conservation actions were fixed for the duration of the contract (typically 5-6 years). In contrast, the new model allows for a collective to adjust its management plans up until 14 days before a planned activity is to take place. According to Jongeneel and

Pollman (2014, p. 6[3]), it is only due to the “especially developed ICT structure” of the collectives that this *flexibility* is made feasible.

Lesson 2. The SCAN-ICT system can pave the way for result-oriented agri-environmental policies

Many researchers have pointed out that moving towards policies which are more **results-oriented** (as opposed to action- or practice-oriented) has the potential to deliver gains in policy efficiency and effectiveness (Burton and Schwarz, 2013[4]).

The high level of spatial resolution of the SCAN-GIS system and the ability to add information on different aspects via different GIS layers (e.g. information on different types of environmental outcomes, such as impacts on biodiversity and water quality) could pave the way for implementing such results-oriented policies. However, effective results-oriented policies rely on having adequate information (either monitored or modelled) on results, and (depending on scheme design) the ability to link results at different scales (e.g. linking on-farm or edge-of-field results with broader outcomes such as impacts on ambient water quality). The basic principles of the collective approach are adopted in the CAP 2020-2027. However, case study participants considered that the SCAN-ICT will probably need to be adjusted depending on the focus of different new schemes.

Lesson 3. The SCAN-ICT system facilitates confidence and trust between actors and across different administrative levels

As described above, the Dutch collective model uses the institution of the collective and the system of collective contracts and individual subcontracts to re-distribute roles and responsibilities, and to provide additional flexibility to the administration of agricultural payments and agri-environmental schemes. This system of contracts, payments and (potential) sanctions entails the well-known problems of information asymmetries, risk of hold-up, transaction costs and co-ordination failure.

The SCAN-ICT contributes to solving these challenges firstly by providing a single system that delivers information to different parties according to their different needs. Note that this system is *not* based on principles of Open Data *per se*; rather, the system delivers what can be considered “targeted transparency”: for example, Paying Agencies are not able to access the system directly, and while farmers will be able to view their own data, they cannot view that of other individuals. This targeted transparency builds up the position of trust and authority of the collectives, in that the collective is the institution in the system who has the *most* information.

Second, the inclusion of Quality Indicators and LPIS interoperability builds confidence and trust by reducing the risk of errors or the risk of the SCAN-ICT system becoming “out of sync” with the LPIS. Again, this contributes to building the reputation of the collectives as well-managed, professional organisations.

Third, the system allows for real-time accounting for myriad of individual actions (as well as changes to planned actions), which, as noted in Lesson 1, is crucial for implementing the desired flexible and landscape-based approach of the Dutch model. Real-time tracking and aggregation allows for clear communication between different administrative levels, and across the many participating farmers, again increasing confidence and trust in the collectives as an institution, and in the system as a whole.

Lesson 4. The "Building Team" was essential to implementing well-functioning digital tools that met administrative and user requirements

ICT suppliers, the NEA, provinces and *BoerenNatuur* work together in a "building team" to collaboratively develop, implement and refine the SCAN-ICT systems. The building team also convenes "user groups", in which users are asked to share their experiences using the SCAN_ICT systems with the building team, as well as their suggestions for improvements and opinions on new proposals. The building team works to continuously improve the systems.

Case study participants identified that one of the advantages of the building team was that it was quite small and physically situated nearby the builders of the paying agency, which made communication between the two groups more effective. Furthermore, the chairman of the collective in which area the builders lived, was one of the main builders and testers.

Lesson 5. The staged approach—first building SCAN-ICT and then the Mijnboerennatuur.nl and Schouwtool platforms—has worked well in the Dutch context

Case study participants identified that a staged approach to implementing the SCAN-ICT and related tools worked well in the Dutch context. In particular, this approach:

- Allowed the building team to be kept relatively small, which contributed to the success of the building team's collaborative approach.
- Allowed building new tools or refinements at a later stage to improve the existing system (rather than building separate tools at the same time).
- Made specific projects or milestones easier to achieve; participants felt that if all elements were pursued at the same time, the risk of not finishing some or all elements is much larger.

Lesson 6. A mixture of old and new tools was the most cost-effective approach in the Dutch context

The SCAN-ICT system is a mixture of pre-existing tools (SCAN Office) and new, custom-built tools (SCAN Financial). At the start of the initiative, different options were evaluated, and the mixed approach was selected. Case study participants commented that the experience of using both pre-existing and custom-built tools shows that:

- Generally, a new system is more prone to faults than customising a pre-existing system.
- Using pre-existing systems allows system users to learn from system providers.
- Working with several different providers (i.e. for the different SCAN components) is not always easy but has the benefit that providers have deep, specific product knowledge.

It is not expected the same conditions will prevail in other contexts. Therefore, the recommendation is that other countries considering implementing a similar approach should:

- Form a clear view about the technological requirements, including whether these will appropriately reflect (existing or desired) administrative arrangements;

- Canvass a variety of options (adapting pre-existing tools, new custom built-tools, or a hybrid of both) *at the outset*. This could include planning for a staged introduction of new digital tools if this is considered desirable (see also Lesson 5).
- Plan from the beginning for the tools to be able to be adapted to new policy contexts (e.g. the introduction of more result-oriented or targeted policies).
- Involve stakeholders in the development of new policy-options and tools.

Notes

[1] Regulation (EU) No. 1305/2013, Article 28(2): *Agri-environment-climate payments shall be granted to farmers, groups of farmers or groups of farmers and other land-managers who undertake, on a voluntary basis, to carry out operations consisting of one or more agri-environment-climate commitments on agricultural land to be defined by Member States, including but not limited to the agricultural area defined under Article 2 of this Regulation. Where duly justified to achieve environmental objectives, agri-environment-climate payments may be granted to other land-managers or groups of other land-managers.*

[2] For a detailed description of roles and responsibilities, see The Netherlands Ministry of Economic Affairs (2016[1]).

[3] Co-operatives are responsible for: administration of farmer participants; digital registration the type of management on the land parcels of the participants (practically speaking: draw management unit on map and link to management activities/package); reporting of completed management activities from participants during the year; inspection of realization of management activities; preparation of collective claim (to be submitted to the Paying Agency); preparation of payment justification; payments of farmer participants. See https://www.boerennatuur.nl/english/, accessed May 2018.

[4] See https://www.boerennatuur.nl/english/, accessed May 2018.

[5] "A Land Parcel Identification System (LPIS) is an IT system based on aerial or satellite photographs recording all agricultural parcels in the [European Union] Member States. It is a key control mechanism under the Common Agricultural Policy (CAP) designed to verify eligibility for area-based subsidies" (European Court of Auditors, 2016[5]). Note there is legal obligation for the LPIS to be maintained by the Paying Agency; in part, this provides motivation for the collectives to have a separate ICT system, even though this duplicates some of the LPIS data.

[6] See https://www.wur.nl/upload_mm/6/f/9/0e55dbbc-4874-4e6c-9399-cfee01a1c27a_Presentatie%20Webinar%20FarmDigital%20Frans%20van%20Diepen.pdf, accessed September 2018.

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Chapter 8.

Case Study 3. Gully erosion monitoring in Australia's Great Barrier Reef catchments

This case study provides a practical example of how remote sensing technologies and data or analytical products generated using these technologies can improve the effectiveness and efficiency of gully erosion and sediment control programmes.

Context: Tackling water quality impacts of sediment transport in Great Barrier Reef catchments

Australia's Great Barrier Reef (GBR) is an international icon of great value and is listed as a World Heritage Area. However, the health of the reef has been in decline for many years now, due to a variety of environmental pressures. One important pressure is the transport of nutrients (nitrogen and phosphorous) and sediment downstream from GBR catchments into the GBR lagoon (Jacobs, 2014[1]).

Recent studies have identified that "gully erosion is a dominant contributor of sediment, particularly in the Burdekin and Fitzroy catchments" of the GBR. In addition, gully erosion is also a problem for livestock graziers, as it degrades the condition of the land, reducing productivity (Tindall, 2014[2]).

In recognition of the significant negative impacts caused by gullies, the Reef Trust Gully Erosion Control Programme was established in 2016, through which the Australian Government allocated AUD 7.5 million (exclusive of GST) towards "projects across the four targeted natural resource management regions in Queensland, to fund community groups and organisations to work with private landholders to remediate high risk gullied areas".[1] Also, in order to be able to track how erosion and sediment management initiatives are impacting transport of sediment to the GBR, the Paddock to Reef Integrated Modelling, Monitoring and Reporting Program (P2R) was established, with funding jointly supplied by the Australian and Queensland Governments.[2] As explained by Darr and Pringle (2017, p. 1921[3]), "the catchment loads modelling component of this programme estimates average annual loads of key pollutants for catchments draining to the GBR, and assesses changes against baseline levels due to improvements in land management practices. As well as reporting progress against water quality targets, the models are used to guide investment priorities."

Use of digital technologies to improve gully erosion mapping

The problems

While substantial resources have been allocated to gully erosion prevention and control initiatives (as described above), these funds are finite and must be used as cost-effectively as possible. Information on where gullies are located, and how they (and sediment transport downstream) are changing over time, is fundamental to being able to target prevention and control efforts to where they will be most cost-effective. The modelling component of the P2R initiative (used to track overall progress towards sediment-related goals for the GBR) similarly relies on having accurate information on a range of complex physical processes, including sediment erosion and transport. However, until recently, this information has been scarce and costly to obtain. According to Tindall (2014[2]):

> *There has been limited work undertaken to comprehensively map gully locations, and to quantify and monitor gully erosion processes in GBR catchments at scales or resolutions appropriate for land management decision-making. Where mapping studies have been conducted, the information has been of limited use due to low accuracy, scale limitations or the maps being of limited geographic extent.*

Darr & Pringle (2017, p. 1920[3]) similarly note that:

> *"Previous attempts to map gully density within the GBR catchments have been conducted by either intensively mapping gully erosion for relatively small isolated*

> *areas where gullies are prominent, or by defining the extent of gully erosion at a number of sample sites and then using predictive models to estimate gully density across much larger areas. Due to scale limitations, low accuracy or limited geographic extent, both these approaches have produced maps with limited usefulness for modelling water quality improvements. Consequently there is a need for a methodology that can improve the confidence in gully density maps over broad areas, in a timely fashion, and at a spatial scale that enables the modelling of water quality improvements due to on-ground investments, and allows prioritising of remediation strategies in the GBR."*

These problems are not unique to sediment erosion in GBR catchments. They relate to fundamental challenges caused by *information gaps*, and the *high costs* involved in gathering the required information using *traditional data sources and collection methods*, particularly over very large spatial scales (see conceptual framework in Figure 2.1 in main report).

Digital solutions

Advances in remote sensing technologies offer the opportunity to improve information on gully erosion, at lower cost than existing methods. While remote sensing—particularly aerial images—has long been used to supplement in-field measurement, there is a range of newer remote sensing technologies that, until recently, had not been deployed to map gully erosion, in GBR catchments or elsewhere. The Queensland and Australian governments have funded several projects that aim to assess the suitability of a range of remote sensing technologies in this context. Key projects are:

Gully mapping and drivers in the grazing lands of the Burdekin catchment (Project RP66G)

Funded by the Department of Environment and Heritage Protection's Reef Water Quality (RWQ) Science Program and led by the Queensland Department of Science, Information Technology, Innovation and the Arts' (now Department of Environment and Science) Remote Sensing Centre (RSC), this project mapped and quantified gully extent and rates of change at a range of scales in the Burdekin catchment using airborne and terrestrial LiDAR[3] data.

Airborne LiDAR survey (ALS) typically ranges in cost from around AUD 60-100 per km^2, depending on providers, sensor and flying specifications, area acquired and post-processing requirements. This makes airborne LiDAR a relatively expensive option, however, with appropriate industry standards and effective survey control both within and between multi-date acquisitions, and appropriate sampling design, it remains an effective and accurate approach for detailed characterisation of gully morphology and relative changes over time. The RP66G project captured a number of locations in a sampling strategy aimed a multi-date, detailed gully change monitoring approach. Some issues were encountered in the project with data quality and post-processing, highlighting the need for the establishment of industry standards and potentially the development of guidelines for the capture of ALS specifically intended for gully change monitoring. The RSC has addressed some of these issues by developing an end-to-end ALS processing system which standardises ALS data acquired from multiple providers and a range of specifications, improving the ability to make change estimates over time. However, deriving gully extent information from ALS remains a challenge and automated classification approaches should aim to quantify uncertainty in any estimates of gully change, particularly when evaluating the effectiveness of remediation efforts. Importantly, the RP66G project progressed research into quantification of uncertainty in change estimates derived from airborne and ground-based or terrestrial LiDAR (TLS). The work has culminated in a recent publication by Goodwin et al. (2017[4]) which compared survey control data, ground based LiDAR and airborne LiDAR to quantify and report uncertainty in change estimates derived from these technologies. The authors concluded that:

> *"ALS can detect large scale erosional changes with head cutting of gully branches migrating…" while "TLS captured smaller scale intra-annual erosional patterns largely undetectable by the ALS dataset…" and therefore "suggests TLS and ALS surveys are complementary technologies and when used together can provide a more detailed understanding of gully processes at different temporal and spatial scales, provided the inherent errors are taken into account".*

This project "[p]rovide[d] spatially-comprehensive mapping and monitoring of gully erosion in the Burdekin catchment to improve knowledge of where gullies occur and to attempt to better understand the processes and drivers of gully erosion, particularly in the grazing lands of the catchment" (Tindall, 2014, p. i[2]). The improved mapping, produced at 5km and 1km resolutions, was achieved by "visual [i.e. manual] observation of satellite and aerial imagery and predictive modelling".[4] A mapping guideline (Darr, Tindall and Ross, 2014[5]) was also developed to support ongoing application of this approach in other parts of the GBR grazing lands and potentially other locations facing similar challenges. The project also published a number of data outputs (e.g. gully presence maps and digital elevation models) on departmental websites under a Creative Commons licence.[5] These outputs serve multiple needs, including:

- providing improved information for targeting erosion prevention and remediation efforts;
- supporting grazing extension programmes aimed at improving grazing land management to improve sustainability of the grazing industry in GBR catchments;
- helping to improve water quality models (e.g. the P2R models) which are used to assess progress in achieving environmental objectives for the GBR.

Building on the work of the RP66G project, Darr and Pringle (2017[3]) applied the project's techniques to build grid-based presence maps[6] (GBPM) of gully erosion at 1 ha spatial resolution. They then linked these maps with "a range of landscape attributes such as slope, distance-to-stream and soil erodibility to produce a predictive model that has the ability to generate gully density maps for all GBR catchments" (p. 1920[3]).

Monitoring Gullying Processes in the Great Barrier Reef Catchments (Photogrammetry project)

Funded by the Australian Department of Agriculture and Water Resources and led by CSIRO, this project assessed the suitability of "digital photogrammetry[7] applied to aerial images routinely collected by state land survey agencies [for addressing] the challenges posed by gully erosion and sedimentation" (Poulton et al., 2018, p. i[6]). The outputs of the project are:

- An assessment of the suitability of digital aerial photogrammetry for mapping and monitoring of gully erosion processes in the GBR Natural Resource Management (NRM) regions.

- High resolution ortho-rectified images, digital surface models (DSMs) and associated ground elevation model (GEM) and water flow maps to help landholders, NRM groups and researchers identify locations of high erosion risk requiring evaluation, monitoring or intervention.
- Documentation of specifications required for future air photo capture to enable DSM generation at appropriate resolutions for gully mapping and monitoring at other locations across Australia.

Poulton et al. (2018, p. ii[6]) provide an overview of the technical process to produce the DSM and GEM:

> *[H]igh performance computing and digital photogrammetry was employed to generate radiometrically calibrated image mosaics and to create a digital surface model (DSM) capturing landscape and watershed features including gullies. Aerial data was acquired at a native image resolution of 0.1 m for two case study regions covering 520 km^2 in the Upper Burdekin and Bowen-Bogie catchments in Queensland. Surface infrastructure and vegetation was removed from the DSM using automated computer algorithms to generate a ground elevation model (GEM). This GEM is applied to the generation of a flow path prediction model that simulates water flow across a landscape surface. These GEMs were compared with high resolution (± 2.5 cm accuracy in elevation) survey points distributed within both study areas and correlated with aerial laser scanning (ALS) and terrestrial laser scanning (TLS) surveys within the confines of selected gully sites. Analysis of the GEM for the surveyed sites found that 48% of the photogrammetric elevations in the Upper Burdekin site, achieved < 0.1 m vertical error in detecting the ground surface, with 81% of locations within 0.3 m of the surveyed measurements. Both study areas exhibited 14% of sites with > 0.5 m vertical error, a product of filtering and interpolation error due to shadowing by standing vegetation.*

This description makes clear that a number of different digital technologies are combined to produce the final project outputs, including:

- Digital photography to acquire aerial images.
- High performance computing and digital photogrammetry to process aerial images to produce elevation measurements.
- Algorithms to remove surface infrastructure and vegetation, as described above, and also to interpolate ground surfaces for areas below dense tree canopy.
- Digital flow path modelling.

This study concluded that "[t]he technology is cost effective and capable of capturing high resolution (sub metre) data for large regional areas with acquisition and processing at AUD 35-70 per km^2 for resolutions of 0.5-0.2 m and is compared with current acquisition of [aerial laser scanning] ALS at AUD 50-100 per km^2" (Poulton et al., 2018, p. ii[6]). The cost structure displays economies of scale, as fixed costs of deploying an aircraft to the region of interest account for a large portion of the cost (Poulton et al., 2018, p. 39[6]). Further, since aerial photographs are routinely taken by government agencies for a range of purposes, the cost of acquiring imagery for a specific purpose (in this case, gully erosion mapping) could be at least partially shared across different users. Finally, use of satellite data, the costs of which are declining rapidly, is promising for the future.

However, photogrammetry does have certain drawbacks, including that the cost of acquiring imagery is weather-dependent (as photographs cannot be taken through clouds), and that it is not an accurate method in areas of higher vegetation cover and is still unproven in detailed gullied environments. Further, case study participants noted that the ability to take advantage of routine acquisition of data by government depends on data collection protocols providing sufficiently high quality data,[8] currently, government acquisitions do not capture the data with appropriate specifications for deriving accurate high-resolution DEMs and therefore are not readily applicable. Additionally, many government captures do not provide overlapping photography at all due to new sensors and cost reductions (*pers. comm.* Dan Tindall, Queensland Department of Environment and Science & Joint Remote Sensing Research Program Remote Sensing Centre, August 2018).

Lessons learned for the application of remote sensing and predictive modelling technologies for erosion mapping in agricultural lands

Lesson 1. Use of advanced remote sensing techniques to map erosion processes over large spatial scales is technically feasible and yields improved results but is still relatively costly and challenging to undertake. Large knowledge gaps remain, and a combination of tools may be necessary to enable cost-effective mapping techniques and erosion management strategies

In the synthesis report for the RP66G project, Tindall (2014, p. 78[7]) concluded:

> *Gully mapping across large areas using remotely sensed imagery is challenging. It relies on having a consistent, repeatable and mappable definition of gullies which can be applied at multiple scales and across multiple image capture platforms. Simple, pragmatic and efficient methods are required to ensure consistency in the application of any mapping approach. Outputs must balance available resources for mapping against end-user requirements. A key outcome of this project has been the development of a guideline for catchment-scale gully mapping in Queensland. The guideline provides clear definition, guiding principles and efficient methods for manual and semi-automated mapping of gullies.*

Similarly, for the photogrammetry project, Poulton et al. (2018, pp. 41-42[6]) concluded that:

> *While aerial photogrammetry cannot provide the level of surface detail of ground based RTK [real time kinetic] GPS, it is currently an economical method for delivering a high resolution GEM and associated surface flow path prediction model at a regional scale when compared with alternative technologies.*
>
> *DOMs [digital ortho mosaics] and RGB images and in particular the flow path model overlay are powerful communication tools for use in discussion with researchers, agricultural and natural resource managers and wider community groups. Integrating photogrammetry techniques for generating a DSM and GEM with routine aerial acquisition by state and commercial agencies will provide additional layers of contextual information to existing aerial photographic images. Application of aerial photogrammetry in deriving a ground elevation model for evaluating changes at a coarser resolution and for larger regional catchments will help inform landscape managers and enable better targeting of resources for prevention or remediation in areas subject to erosion processes.*

Nevertheless, a number of challenges remain. The key challenge for all aerial techniques studied is how to improve interpretation of ground surfaces, especially in areas with high vegetative cover. Therefore, a mix-methods approach appears to be the most cost-effective: use of photogrammetry techniques for large areas with low vegetation cover, supplemented by (more expensive) ALS or TLS techniques where detailed gully profiles are required or in areas where dense vegetative cover predominates.

Part of the challenge in tracking changes in erosion levels over time is that historical data (e.g. photographs) may be difficult to locate and are often of poor quality.[9] This highlights that the usefulness of initiatives to track erosion (and other physical processes which occur over similar timeframes) is dependent on having a sufficiently high quality time series data. Therefore, even those initiatives which are now acquiring high quality data may take some time to yield precise results.

As noted above, while the RP66G project made use of new technology in the form of LiDAR data and new predictive modelling, it still relied on *visual* (i.e. manual) inspection of satellite and aerial photography to identify and classify gullies. The project did investigate the possibility of automating processing of LiDAR data to accurately map and quantify gully extent and volume; however, Tindall (2014, p. 73[7]) commented that [t]he automated method used to classify gully extents for individual dates was not be robust enough to reliably compare and map change in gully extents between dates and over time." The authors noted (p.81) that machine learning approaches suggested by others may warrant further inquiry, but that this was beyond the scope of the current project.

Darr and Pringle reported that their project (based on the RP66G methodology), as of 2017, used approximately 1.4 full-time staff equivalents to map and quality check on average 4 200 km^2 per month, achieving 87% accuracy when checked against field observations. At this rate, the authors estimated approximately five years would be required to fully map the remaining 300 000 km^2 of the GBR catchments. Thus, while more efficient than other manual techniques, this is "not a quick process" for basins as large as those in the GBR catchment (Darr and Pringle, 2017, p. 1925[3]). These authors also identified that a further step would be to automate the mapping process using machine learning techniques, but, as with the RP66G project, this has yet to occur.

The RP66G project and photogrammetry project authors also identified that a range of other emerging remote sensing technologies could be useful to improve mapping efforts, and recommended these be explored in further research.[10]

Further, knowledge of where and when gullies occur is not the only information gap needing to be filled. Other crucial areas of inquiry are to understand the "fate and timing of sediment delivered from gullies" and to develop "the most appropriate technologies and approaches for managing and monitoring gullied areas" (Tindall, 2014[2]). The RP66G project concluded that:

> *Emerging technologies such as ground-based laser scanning, imagery and LiDAR capture from Unmanned Aerial Vehicles (UAVs), sediment tracing and digital soils mapping all present opportunities to help improve our understanding of gully processes to enable effective management strategies for improving land condition and water quality in the grazing lands of the GBR. (Tindall, 2014[2])*

Thus, it is important to place the use of technology for a specific purpose (monitoring gullies) in the broader context of the overall policy objective (reducing negative impacts of erosion on the GBR), and ensure that there is a balanced approach to investigating different questions.

Lesson 2. Improved understanding of physical processes must be balanced by economic considerations

The techniques described here have the ability to significantly reduce information gaps about where and when gully erosion is occurring. This knowledge is fundamental to efforts to address the negative impacts of erosion, both for the Great Barrier Reef and more broadly for livestock producers and rural communities who rely on the productivity of land at risk from gullying.

However, there is still "very limited information about the cost-benefit of gully prevention and remediation approaches" (Tindall, 2014, p. 14[2]). A holistic assessment of costs should include both the actual implementation costs of different approaches as well as the transactions costs of programmes which aim to increase uptake of management actions by land managers. Targeting remediation and prevention efforts based only on the information provided by gully mapping ignores spatial differences in management costs and transactions costs, which may be substantial.[11] Information on both the benefits and costs of alternative erosion management activities is needed to ensure efforts are targeted cost-effectively. Tindall et al. (2014, p. 82[7]) recommend that "where possible, science and monitoring efforts be combined with on-ground efforts and economic modelling to improve knowledge of where and when to expend resources for gully management."

Work to evaluate the relative costs of different erosion management activities and programme-related transactions costs is ongoing.[12] However, in a recent audit of measures taken to address issues affecting the GBR, the Queensland Audit Office found that, as of June 2018, the Queensland government "cannot measure the degree of practice change or assess the value achieved from its investment of public funds. The Office of the Great Barrier Reef is currently negotiating with industry groups to gain access to the data the departments need and should have access to" (Queensland Audit Office, 2018, p. 9[8]).

Lesson 3. Benefits and challenges of collaboration across organisations and across projects

Both the RP66G and photogrammetry projects were highly collaborative and brought together researchers from a range of state and national government agencies, including CSIRO, Department of Agriculture and Water Resources, Queensland Department of Department of Science, Information Technology, Queensland Department of Natural Resources and Mines, the National Environmental Science Programme and Innovation and North Queensland Dry Tropics Regional NRM group. These projects are part of a broader portfolio of research activities that are continuing to contribute to identifying, defining, characterising, measuring and modelling change in gully systems in key Great Barrier Reef catchments. This research utilises a range of data collection methodologies and techniques (e.g. airborne and terrestrial laser scanners and ground based and aerial photogrammetry) each with unique strengths, weaknesses and costs associated with collecting and data processing.

Increasing costs associated with this type of research and the rapid on-going technological development in the collection of ground based, remoted sensed and large spatial data requires adaptation, innovation and successful collaboration of the research community. For the photogrammetry project, having access to a wider research network currently undertaking project activities within the GBR region enabled transfer of localised knowledge which helped identify suitable case study areas. Selected sites were aligned with existing ground measurements undertaken by research collaborators in the region. In this case, collaboration facilitated opportunities to access data sources from past and current projects (e.g. aerial and ground based LiDAR, gully location mapping, aerial and ground photography, satellite imagery) as well as experience gained by those researcher's familiar with use of the different technologies. Collaborative exchange delivered cost savings in data collection for individual projects as well as useful calibration and validation data made available between different project groups. Spatial data collected and generated by the photogrammetry project is to be made available to ongoing projects within the GBR study region.

While there was a willingness for collaboration between projects, in reality researchers share their time between a number of competing activities. Opportunities for the wider research community, particularly different organisations, to meet face to face regularly are infrequent. Within a twelve-month period one successful workshop was held which brought together a larger group of researchers with wide-ranging experience in technologies and methodologies for quantifying gully systems. Focused discussion and a sharing of experience targets not only a knowledge exchange between researchers but helps quantify information on the appropriate technology for a particular application and helps to inform the wider research and government agencies.

Notes

[1] Source: http://www.environment.gov.au/marine/gbr/reef-trust/gully-erosion-control, accessed June 2018. Queensland is the Australian state in which GBR catchments are located.

[2] Source: https://www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/, accessed August 2018.

[3] LiDAR (Light Detection and Ranging) is an active remote sensing sampling tool which uses the length of time a laser beam takes to return to the sensor to calculate distance. It is a key technology to obtain data used to construct Digital Elevation Models (DEMs) and derive metrics of vegetation height, structure and cover. For a simple explanation, see https://gisgeography.com/lidar-light-detection-and-ranging/, accessed August 2018.

[4] "The 5km resolution mapping combined high resolution mapping, a predictive model of gully presence and visual observations of gully prevalence across the entire catchment. Gully presence was mapped in 7 classes relating to the amount of gullying present, where gullying was observed. The 1km resolution mapping was achieved entirely through visual interpretation of a 1km grid, each grid divided into one hundred, 100m x 100m cells to provide a count or percentage of gullying evident in each 1km grid cell. Mapping was targeted at key areas identified in the 5km map as having high gully presence." (Tindall, 2014, p. i[2])

[5] See Tindall et al (2014[7]), Table 21.

[6] Grid-based presence mapping is a technique which a process which "allows an operator to map the presence or absence of gully erosion within a grid cell, using custom-built geographic information system (GIS) tools, aerial photography and uniform grids." (Darr and Pringle, 2017, p. 1920[3])

[7] As explained by Poulton et al. (2018, p. 16[6]): "Digital photogrammetry is the science of making, among other things, geometric measurements from images. Digital aerial photogrammetry attempts to reconstruct three-dimensional surfaces from overlapped (stereo) aerial images. The process of digital aerial photogrammetry is as follows: acquire aerial image data, triangulate images, generate three-dimensional surface models and orthoimages. The main processing tasks are performed by means of a digital photogrammetric system. Additional process steps are applied to further analyse the outcomes and create specific derivative products."

[8] Poulton et al. (2018, p. 10[6]) note that "[p]rovided sufficient digital data for panchromatic – nadir (forward and backward view) and 4-band multispectral nadir (backward views) are retained and the collection method follows standardised and rigorous protocols detailed in Section 2.1.3 and Appendix 3 [of this paper], future aerial acquisition may provide a source of low cost data needed to produce and periodically update fine scale digital surface models (DSMs) aiding erosion risk management."

[9] Tindall (2014, p. 79[7]) observe that "[m]apping changes in gully extents using historical imagery is challenging and resource intensive, particularly for large areas. Locating historical imagery for a particular location requires extensive investigation of air photo archives to find suitable imagery that can be geo-located accurately to be able to reliably compare change over time. Identifying gullies in older imagery, and also in some new imagery, can be extremely difficult, resulting in a large degree of subjectivity in mapping outputs."

[10] "New technologies are emerging such as Unmanned Aerial Vehicles (UAVs) and space-borne stereo imagery. DAFF has previously demonstrated the application of UAVs for capturing imagery and generating digital surface models over a gully remediation trial on Spyglass Research Station in the Burdekin. Outputs still require testing and validation but the results did show some promise. It is suggested that further investigation of UAV technology for mapping and monitoring gullied areas be considered. With regards to space-borne stereo imagery, RSC has an agreement with the Chinese Satellite Applications Centre for Surveying and Mapping (SASMAC) who operate the ZY-3 satellite. This satellite has high resolution stereo-imagery capable of producing 4m digital surface models" (Tindall, 2014, p. 81[7]). See also section 5.1 "Future Opportunities" in Poulton et al. (Poulton et al., 2018, pp. 43-44[6]).

[11] For example, Wilkinson et al. (2015[9]) reports that the direct management cost (i.e. excluding any reports that the direct management cost (i.e. excluding any programme-related transactions costs) of the recommended combination of management techniques for GBR grazing lands (consisting of fencing around gullies, gully channel revegetation with native perennial tussock grasses, use of check dams or other sediment traps to prevent gullying, and managing grazing pressure to avoid vegetation clearing and restore perennial pastures) varies between AUD 4 500 and AUD 9 000 per km of gully. Variation in cost-effectiveness per tonne of reduction in mean-annual sediment load is largely dependent on the efficiency of fencing.

[12] See, for example, *Demonstration and evaluation of gully remediation on downstream water quality and agricultural production in GBR rangelands,* http://nesptropical.edu.au/index.php/round-2-projects/project-2-1-4/, accessed August 2018.

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Chapter 9.

Case Study 4. Earth Observation initiatives for administration of the European Union Common Agricultural Policy

The objective of this case study is to provide practical examples from the European context of how digital technologies can improve systems which pay farmers for producing ecosystem services.

Context: Reforming the CAP's administration

The European Union (EU) Common Agricultural Policy (CAP) is the overarching system of subsidies and payment programmes for agriculture and rural areas in the European Union. The CAP pursues a range of objectives,[1] and accounts for over 40% of the European Union's annual budget.

Schmedtmann and Campagnolo (2015, p. 9326[1]) provide an overview of the administrative mechanisms of the CAP:

> *To ensure that CAP funds are spent appropriately, Member State Authorities have to comply with legal management and control mechanisms…Each Member State is responsible for subsidy administration and control, which are carried out by a National Control and Paying Agency (NCPA).*
>
> *In order to obtain area-based financial support [direct payments], farmers are required to submit an application to their NCPA early in the year, where they declare the precise location of all of their agricultural parcels, as well as the crop type. The National Agency is responsible for controlling at least 5% of those declarations and penalizing farmers who submit incorrect information by performing so-called On-The-Spot (OTS) checks. For area-based subsidies, an agricultural parcel must be controlled at two different levels: both the declared crop and area must be correct. The [European Commission] in turn controls the NCPAs. When discrepancies between the control result and the reality are found, a Member State is penalised and has to return to the EU part of the subsidies that were distributed to farmers.*
>
> *The complex process of subsidy control requires computational tools: NCPAs rely on Integrated Administration and Control System (IACS), which includes a [Land Parcel Identification System] LPIS. The main functions of those spatial databases are localization, identification and quantification of agricultural land via detailed geospatial data, in order to facilitate the distribution of CAP subsidies.*

Following the 2013 CAP reform, EU farmers are able to apply for direct payments through the Basic Payments Scheme (BPS) (OECD, 2017[2]). These payments are intended to act as a safety net in the form of a basic income support. Cross compliance and Greening are two mechanisms (referring to specific obligations) that are linked to this payment to ensure more environmentally-friendly farming approaches and deliver continued food security and safety in Europe. The introduction of cross compliance and greening measures introduces additional complexity for programme administrators.

Use of digital technologies to streamline CAP administration

The problems

The CAP is fundamentally an eligibility-based system: while the conditions have changed over the years (particularly with the decoupling reforms in the mid-2000s), farmers must still meet certain criteria in order to receive payments. As in regulatory contexts more generally, the eligibility system introduces a potential *incentive misalignment problem*: while the administrator has incentive to discover whether the farmer meets the criteria, absent the threat of sanctions,[2] a farmer would prefer to receive the payment without incurring costs needed to achieve eligibility for the payment. This creates incentives for farmers to preserve *information asymmetries* between themselves and the administrator (i.e. the farmer knows his or her own action but may have incentive to prevent the administrator from accessing that information). The reform of the CAP to include environmental greening and cross compliance requirements, which may be costly for farmers to meet, exacerbates this potential. Therefore, a system of monitoring, controls and sanctions is needed to ensure the effectiveness of the payment as an incentive mechanism for improving the sustainability of European agriculture.

As outlined above, there are three main administration and control tools used by the relevant competent public authorities ("National Control and Paying Agencies", NCPA): administrative checks of paperwork submitted by claimants (farmers), physical on-the-spot checks (OTSC) and Control with Remote Sensing (CwRS). Due to the high complexity and diversity of the obligations that need to be verified, each method has its limitations. As a result, existing administration and control regimes entail high *transaction costs* for public administrators as well as private transaction costs and administrative burden for farmers. For example, according to DG-AGRI (Borchmann, n.d.[3]), the cost of controls to Member States in 2015 was EUR 1 125 million, which equates to 5.2% of total public CAP expenditure.

The challenge for CAP administrators is therefore to minimise administrative transactions costs (both public and private) while maintaining effective standards of compliance.[3] One crucial aspect of this is to reduce costs of obtaining information on farmers' activities.

Digital solutions: The RECAP initiative

The use of digital technologies, particularly earth observation technologies and online digital platforms, offers the potential to provide improved monitoring of agricultural activities at lower cost than existing administration and control methods. While there are numerous initiatives research and testing of digital solutions aimed at reducing the costs of administering the CAP while increasing information on farmers' activities,[4] this case study centres on one initiative from the European context: the *RECAP—Personalised Public Services in Support for the implementation of the Common Agriculture Policy (CAP*), an Horizon 2020 project funded under the *ICT-enabled open government* (H2020-INSO-2015-CNECT) call (Grant Agreement 693171), which aims to provide practical evidence on these potential benefits.

The initiative commenced in May 2016 with 30 months duration, involving 12 partners.[5] The overall budget of the project is EUR 2.7 million (EUR 2.1 million requested EU contribution). It is based on the following interrelated objectives:

- To develop improved e-public services that enable a better implementation of the CAP and simplify administrative procedures, integrating open and user-generated data.
- To develop personalised public services that support farmers to better comply with CAP requirements.
- To increase the transparency of compliance monitoring procedures related to CAP.
- To enable the reuse of data (open and user-generated) by agricultural consultants and developers for delivering their own added value services for farmers.[6]
- To pilot test the services in an operational environment with the participation of end users in five countries (Greece, Lithuania, Serbia, Spain and the United Kingdom).

- To assess the usability, effectiveness and impact of the proposed services in delivering the public administrations' goals, and provide feedback into a set of recommendations for future use of these approaches to deliver more effective and applied public administration.

RECAP is a commercial platform[7] (cloud-based Software as a Service (SaaS)) that integrates satellite remote sensing and user-generated data into added value services for public authorities (administrators and inspectors), farmers and agricultural consultants, to improve the processes for implementing and monitoring the BPS. RECAP has three interrelated results indicators:

- Increasing the efficiency and transparency of public authorities' procedures implementing and monitoring the CAP by enabling *effective and efficient remote monitoring of farmers' obligations* (including automation of compliance checks for some requirements) through the use of open earth observation (EO), user-generated data (geotagged and timestamped photos) and purpose-built algorithms. The RECAP pilots aim to reduce administrator costs by at least 25% (Table 9.2).
- Providing *personalised services to farmers for their better compliance with the CAP environmental standards* (Cross Compliance (CC) and Greening Measures). The RECAP pilots aim to reduce farmer administration costs related to BPS claims by at least 25% (Table 9.2).
- *Stimulating the development of new added value services by agricultural consultants* and developers who can create add-ons to the main platform and make use of the data collected.

RECAP digital components

To achieve these deliverables, RECAP makes use of various digital tools or "components", explained below (see also Table 9.1).

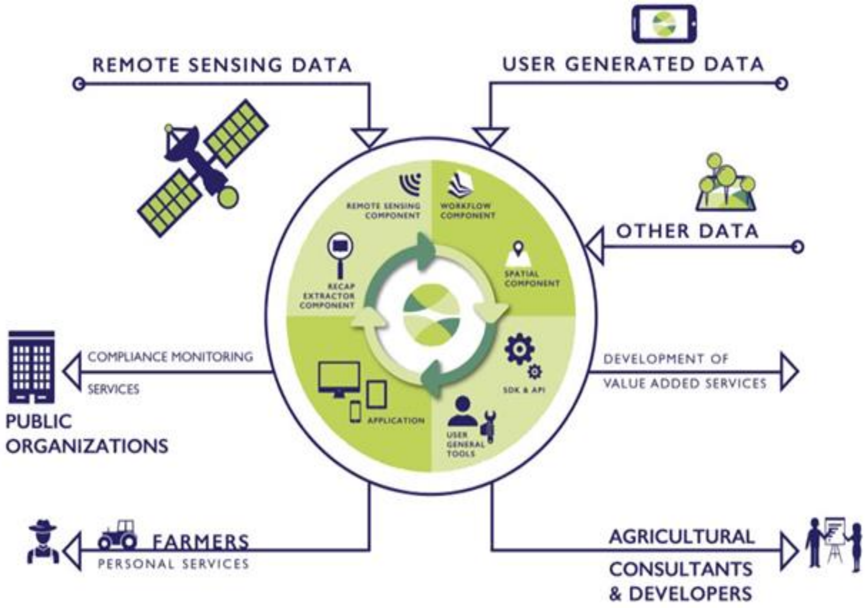
Remote Sensing component

The RECAP Remote Sensing (RS) component provides automated earth observation processing workflows to assist paying agency inspections of farmers' compliance with their CAP obligations. The methodology is founded on the accurate crop type classification via applying a machine learning algorithm to a time-series of combined Sentinel-2 imagery and relevant vegetation indices. The monitoring of compliance was algorithmically addressed for specific Cross-Compliance and Greening requirements[8] (Box 9.1).

The practicality of the output RS information ranges from direct decision making (e.g. for crop diversification) to simple indicators of potential noncompliance (e.g. for minimising soil erosion), depending on the complexity of the individual CAP obligation. The RS component comprises three principal processing chains:

- crop type mapping (classification)
- runoff risk analysis
- identification of stubble burning.

Figure 9.1. RECAP initiative components



Source: RECAP initiative case study participants.

The relevance of the developed RS solution to the CAP monitoring challenge is essentially based on the accuracy of the crop type classification. Accuracy was assessed by comparing classification based on satellite data obtained in two iterations[9] against validated ground truth data obtained by pilot inspections in selected subsets of the dataset.[10] As an example, the accuracy results obtained in the Spanish pilot are presented in Table 9.1.Validated results showed an overall crop type mapping accuracy in the range 80-90% for the identification of 9-13 different crop types, depending on the pilot, which explain more than 90% of the regional agricultural zone (Source: *Personal communication*, case study participants, July 2018).

Table 9.1. Accuracy of RECAP Remote Sensing component crop classification, Spanish pilot

	Producer's accuracy [1]		User's accuracy [2]	
Crop type	Iteration 1	Iteration 2	Iteration 1	Iteration 2
Soft Wheat	92%	95%	89%	93%
Corn	91%	94%	85%	93%
Barley	91%	94%	90%	92%
Oats	77%	87%	86%	92%
Sunflower	84%	89%	88%	93%
Broad beans	72%	84%	86%	95%
Rapeseed	92%	91%	94%	95%
Vinification vineyard	79%	85%	83%	80%
Cherry trees	74%	74%	73%	100%
Shrubby grass of 5 or more years	64%	72%	80%	85%

Notes: 1. Producer's Accuracy is the map accuracy from the point of view of the mapmaker (the producer). This is how often are real features on the ground correctly shown on the classified map or the probability that a certain land cover of an area on the ground is classified as such.
2. The User's Accuracy is the accuracy from the point of view of a map user, not the mapmaker. The User's accuracy essentially reveals how often the class on the map will actually be present on the ground.
Source: Draxis Environmental (2019[4]).

Overall, the crop classification algorithm was assessed to provide satisfactory results: 75-85% accuracy, even for datasets that include satellite imagery only until mid-late June. This is very important, since paying agencies require accurate information at the time of the farmers' applications, in order to better target their sampled on-the-spot inspections to parcels that constitute potential breaches of compliance.

Crop classification from the RS component was provided also with the crop type as declared by the farmers. This functionality is key for paying agencies, as (together with the ground-truthing accuracy); it allows probabilistic identification of potential non-compliance. The RECAP team developed a "traffic light system" to convey this probabilistic assessment in an intuitive way.[11] Where the ground-truthing accuracy of the RS classification is high, but the RS classification disagreed with the declared classification, this indicates potential non-compliance (untruthful declaration).Towards the completion of the project, validated results were received for each of the three pilots as follows:

- *Spain*: Of 107 random parcels inspected, 105 were classified correctly.
- *Greece*: Inspectors visited only parcels that were selected by the smart sampling methodology; that is, parcels classified with high confidence to crop types other than the one declared, which are considered as potential breaches of compliance. It was shown that 76 out of 85 inspected parcels were indeed wrongly declared and correctly classified.
- *Lithuania*: The validated dataset acquired through the Lithuanian Paying Agency inspections revealed an actual overall accuracy of 76.2% in late June and 80% in late August out of 3 319 parcels inspected.

The crop type classification accuracy, and hence the usefulness of the RS component for CAP administrative decisions for which crop-type is relevant, depends on three parameters:

- Percentage of truthful declarations
- Cloud coverage
- Parcel size

In one of the case studies—Navarra, Spain—where 90% thematic accuracy was achieved, all these parameters were optimal. This means more than 97% of truthful declarations, limited cloud coverage, and an average parcel size of 2 ha, which is considered sufficiently large for a Sentinel-2 based classification.

When a considerable percentage of declarations are not truthful, then similar crop types, both in spectral characteristics and phenology—e.g. wheat, barley, oats—might not be well discriminated. Hence, merging of such crop types into spectral coherent clusters (e.g. cereals) would be necessary for an adequately accurate result. Therefore, the thematic accuracy of the crop identification products depends on the type of information one is aiming for. For example, the usefulness of the clusters in assessing a crop rotation requirement depends on the degree to which farmers could implement a crop rotation *within*, as opposed to *across*, clusters.[12]

Crop classification accuracy also depends on the size and shape of the parcel, with classifications for larger parcels and parcels with straighter borders tending to have higher accuracy than smaller parcels or parcels with more irregularly-shaped boundaries. The parcel area is important since accuracy depends on the number of image pixels that fall within the parcel boundaries. Sentinel-2's 10 m pixel size equates to 50 image pixels in 0.5 ha of land. An analysis conducted, comparing the accuracy of classification in conjunction with the parcels' size, showed that having 50 pixels of information provides accurate results, whereas for smaller parcels the decision is both less confident and less accurate.

Box 9.1. Evaluation of remote sensing (RS) and machine learning (ML) tools to classify crop types and monitor environmental requirements

RECAP case study participants commented on the practicalities of using RS information and machine learning to successfully classify crop types and identify compliance with environmental requirements (e.g. GAEC, greening):

> *"Different description of crop types would imply different spectral signatures for the crop classes and thereby different classification results. Additionally there are differences in the percentage of correctly declared cultivated crop types that accordingly affect the training of the machine learning algorithms. In Navarra, Spain declarations are almost completely correct and therefore results are excellent. In Greece, however, there is a significant percentage of falsely declared crop types that affects the classification accuracy. Nonetheless, the algorithm is indeed robust; in the sense that if 20% of declarations are wrongly stated this would roughly mean only 5% reduction in accuracy. Finally, in countries such as Lithuania, where cloud coverage is significant throughout the year algorithmic modifications are necessary. For example, it was found that a different machine learning algorithm performed best for the Lithuanian case.*
>
> *The main pillar of the agriculture monitoring scheme is the accurate crop type classification. The practicality of the classification is straightforward. However, RECAP attempted to specifically address the compliance of farmers to their actual CAP obligations (GAECs, SMRs, Greening). For some CAP obligations, such as Greening 1, crop classification is indeed all that is needed to decide on the compliance of the farmers. Now, for other obligations such SMR 1 (Reduce water pollution in nitrate vulnerable zones), the RS component of the RECAP platform provides a risk assessment on the soil loss and runoff to nearby watercourses, for each parcel. This is indeed a prerequisite for the farmers in order to comply with SMR 1, but the rule also extends to manure spreading obligations that cannot be addressed by remote sensing. Therefore, even though the remote sensing information provided with respect to SMR 1 is useful, it is not complete for compliance decision making."*

Source: Case study participant, Dimitrios Petalios (CREVIS) (June 2018).

Spatial component

The spatial component depicts in digital maps (set in several layers) the information generated by the RS component as well as external spatial data, which are listed below. These maps enable users to visualise valuable information for an effective and efficient inspection process (Paying Agencies (PAs), inspectors) (Table 9.2 provides an example of how the PAs view the spatial component). The produced maps include:

- Time-series of Sentinel-2 true color composites and vegetation indices (viewing only)
- Natural habitat sites
- Nitrate Vulnerable Zones

- Botanical Heritage Sites
- Watercourse maps
- Slope map
- Administrative boundaries and settlements
- Land Use/ Land Cover Maps
- Land Parcel Identification System (LPIS)
- RS-derived parcel specific thematic information (i.e. crop type mapping, polluted water runoff risk assessment, identification of stubble burning, soil erosion, etc.). This is displayed in the form of a list when interactively selecting the parcel of interest.

Figure 9.2. RECAP spatial component

Paying Agency view of Remote Sensing results in the region of interest, with the relevant parcel information

PARCEL INFORMATION	
PARCEL ID	880300712001
FIELD NAME	880300712001
AREA	10.9011 ha
ASPECT	203.81210 °
BURNT	No
CROP TYPE	Hordeum
CROP TYPE CONFIDENCE	Green
CROP FAMILY TYPE	N/A
CROP FAMILY CONFIDENCE	N/A
CROP SEASON TYPE	1
CROP SEASON CONFIDENCE	Green
DECLARED CROP TYPE	Hordeum
GAEC 1	Applicable

Source: RECAP initiative of case study participants.

The remote sensing results and the information provided by the Spatial component can be used by the PA as auxiliary information in their risk analysis process and identify the farmers that are more likely not to comply, so that they could proceed with more targeted inspections. Specifically, the PAs are able to draw a bounding box on the map, covering the area of interest, and for which they will receive the remote sensing analysis results.The crop classification information is also provided to the farmers through their own profile. Therefore, if their parcel is classified to a different crop type than the one declared and with high confidence, then they could opt to change their declarations if they agree with the classification.

Business intelligence component

The Business intelligence component is aimed at the PA officers only. It is a data-mining tool enabling public officers to analyse large datasets stored in RECAP platform. PAs will be able to make use of available data and create key performance indicators (i.e. CAP objectives) and relevant reports, enabling them to set targets and move towards a more result-oriented CAP support. Additionally, this tool allows PAs to extract valuable information from such vast datasets and to uncover previously unknown patterns that may be relevant to current agricultural problems, thereby helping farmers and managing organizations to transform data into business decisions and ensure a better implementation of the CAP.

Workflow component

The workflow component is the core system of the platform, working as the link between the different parts of the system. Specifically, it brings together information that is processed by all components to the user in a way that is easy to understand. It functions as an orchestrator for the RECAP business logic, the communication with the data storage, the Application Programming Interface (API), the receipt of information from outside sources and the validation process. For example, it provides farmers, consultants and inspectors with checklists of Cross Compliance rules applicable to the farm, based on information from the BPS application submitted by the farmer; it guides farmers and inspectors with personalised information on the procedures to follow regarding the compliance procedure; generates notifications to farmers based on calendar of key dates.

Software Development Kit

The Software Development Kit (SDK) allows agricultural consultants and developers to develop their own "added value" services in an open approach within the RECAP platform, and deliver improved advisory services to farmers. The SDK enhances the role of the platform, both by enabling consultants to develop their own services on top of the RECAP platform using design tools, libraries and communications with the database under an open approach; and also by supporting any technical integration with external systems.

The RECAP Digital Platform—Web and mobile application

The RECAP platform interconnects the different system components in order to deliver the deliverables earlier described. Being co-created and co-produced with its end-users, it covers five categories; the general system requirements, the Basic Payment Scheme (BPS) eligibility and applications, the farmer record keeping, the inspection process and the farmer education and information. The main features covered per category (table rows) and user group (table column) are presented in Table 9.2.

Table 9.2. Main features of the RECAP Platform (web application), by user group

Farmers	Consultants	Paying agencies	Inspectors
Farm management	Farm management	Inspector assignment	Inspections management
Cross Compliance checklist	Cross Compliance checklist	Inspections management	Inspection scheduler
Greening Calculator	Greening Calculator	Communication between farmers and PAs	Farmer's data management
Farmer's log/ Farmer's Inspection	Farmer's log/ Farmer's Inspection	Document repository	Document repository
Communication between farmers and PAs or Inspectors	Communication between farmers and PAs/ Inspectors	Spatial component	Communication between farmers and Inspectors
Notifications/ Reminders	Notifications/ Reminders	Remote Sensing component	Spatial component
User roles	User roles	Business intelligence analysis tool (Extractor component)	
Spatial component	Spatial component		
Report problem	SDK component		

Note: SDK = Software Development Kit.
Source: RECAP initiative case study participants.

Apart from the web-based application platform, two mobile interfaces are developed; a smartphone-optimised interface dedicated to the farmers' needs and another one focusing on the inspectors' needs. The mobile application is mainly for the data collection on the farmer's field either from the farmer or from the inspector during on-the-spot checks (to overcome connectivity challenges, the mobile application also has an offline mode – when operating in offline mode, data will be uploaded to the RECAP database once the mobile application is re-connected to internet).

On the RECAP platform, each farmer has their own personal account where they are able to store data, records, and documents that need to be obtained or retained. This can be presented to inspectors during an inspection. The RECAP platform allows the farmer to filter complex cross compliance rules and see only those relevant to their farm. There are also alerts for actions to be taken and potential non-conformities. These alerts provide farmers access to checklists and workflows through a mobile and web interface (the RECAP platform). The PA is responsible for updating and certifying the checklist(s).

Satellite imagery is available for all users of the platform. However, PAs are able to see the "big picture" (all parcels within the user-defined area of interest), while farmers and consultants see cropped imagery that includes only the farmers' parcels.

The digital platform also enables PAs to increase the effectiveness of risk-based analysis for the selection of farms to be inspected through the help of the Remote Sensing component, which uses a combination of open and user-generated data. The RECAP platform allows the PAs to select a farm for inspection and retrieve farm profile data and previous inspection results, which will be available both to the PAs and to inspectors. Overall, RECAP delivers a platform to public administrations so that they carry out inspections more efficiently, more accurately and more quickly.

Implementing the RECAP pilot

The RECAP platform is currently being tested and validated in an operational environment in five countries—Greece, Lithuania, Serbia, Spain and the United Kingdom—with the active participation of public organisations, agricultural consultants, and farmers. The platform is comprised of five different workflows (one for each country pilot), due to the differences between the pilots and the CAP rules interpretation.[13] Based on this, the RECAP platform is developed as an integrated system, composed of core functionalities that are commonly shared across the pilots, with additional pilot-specific functionalities are built on top of these core functionalities.

Pilot implementation in Spain, Greece, and Lithuania is focusing on *delivery of public services*, with the participation of four public organisations (Paying Agencies and Agricultural Advisory Services) which are members of the project consortium (INTIA, OPEKEPE, NMA, and LAAS). In the United Kingdom, the pilot implementation focuses on *delivery of personalised services from agricultural consultants* (partners STRUTT & PARKER).

The Serbian Pilot (INO) case is focused on *organic agriculture*, with organic certification bodies, organic farmers and public bodies to overlook that organic certification is in line with legal requirements (Official Gazette RS 30/2010; fully aligned with EU regulation on organic farming – Regulation EC 834/2007). The RECAP platform will support the entire process of subsidy provision for organic farmers, certification agencies, agricultural consultants and for the public authorities tasked with implementing, managing and controlling this payment scheme. Serbia being an EU candidate country (2012), has started accession negotiations in 2014 and is committed to transpose and implement the acquis[14] on agriculture and rural development by the date of accession. RECAP platform will be positioned to support monitoring aspects of relevant subsidies within the Instrument Pre-Accession Assistance in Rural Development (IPARD) and providing assistance for the implementation of the acquis concerning the CAP.

The outcomes of the Pilot contribute to the achievement of the strategic impacts of the RECAP project: the stimulation of the creation, delivery and use of new services coupled with open public data; the delivery of more personalised public services that better suit the needs of users; the reduction of the administrative burden of citizens and businesses and the increased transparency of and trust in public administrations. The achievement of the impacts was measured through the monitoring of a set of result and impact indicators (Table 9.3.

Table 9.3. Result and impact indicators for the Pilots

Indicator	Measurement technique	Total target value	Target achieved
Number of farmers in pilots	Demonstration in 5 pilot sites	635	Yes
Number of cross compliance inspections carried out remotely with RECAP	Demonstration in 5 pilot sites	305	Yes
Number of on the spot checks carried out with RECAP	Demonstration (RECAP vs Business As usual Scenarios) in 5 pilot sites	115	Yes
Reduction of administrative cost for payment agencies	Demonstration (RECAP vs Business As usual Scenarios) in 5 pilot sites – Evaluation of Results	>25%	Generally yes, see discussion below
Reduction of administrative burden for farmers	Demonstration (RECAP vs Business As usual Scenarios) in 5 pilot sites – Evaluation of Results	>25%	Generally yes, see discussion below

Source: RECAP initiative case study participants.

A monitoring and evaluation system (qualitative and quantitative tools) was used to ensure on the one hand the proper development of the Pilots to achieve the expected outcomes, and, on the other hand, to allow assessment of whether the specified result and impact indicators have been achieved and obtain relevant inputs for the RECAP solution sustainability and future adaptations.

The first three targets (number of farms participating in pilots, number of cross-compliance inspections carried out using RECAP, number of OTSC carried out using RECAP) have all been achieved. Upon completion of the pilot, participants were surveyed about their perceptions about the extent to which the RECAP platform reduces administrative burden and facilitates compliance. Selected results from this survey (RECAP Consortium, 2018, p. section 4.2[5]) are:

- 61% of farmers participating in the RECAP pilot somewhat agreed or strongly agreed that the RECAP platform *increases their understanding* of CAP Cross-Compliance (CC) rules, and 55% somewhat or strongly agreed that the platform *decreases the likelihood of their breaking CC rules*.
- 42% of agricultural consultants participating in the pilot reported that the *necessary time for preparing Basic Payment Scheme (BPS) application will be shorter using the platform*; and the corresponding time reduction is >25% for 60% of this subset; the remaining 44% considered that time spent preparing applications would not change. Similar results were found in relation to time spent checking adherence to CC rules.

- 51% of participating farmers considered that their necessary *time for preparing a Basic Payment Scheme (BPS) application would be shorter using the platform* (and 64% of this subset of farmers considered that the corresponding time reduction would be greater than 25%); compared to 44% of farmers who considered the time spent would not change, and 5% who considered their time spent making an application would be longer. Similar results were found in relation to time spent checking adherence to CC rules.
- 82% of organic farmers somewhat or strongly agree that the platform increases their understanding of compliance with Organic Certification and Organic Subsidies; 77% believe it will help them to follow organic certification requirements, and 91% believe that using the system will reduce time for presenting evidence of compliance with Organic Certification requirements.
- 74% of inspectors somewhat or strongly agree that the platform makes the CC procedure more transparent, while 68% believe the platform increases the accuracy of OTSC for CC;
- 62% of inspectors consider the time spent inspecting a farmer would be shorter using RECAP, and of these, 60% considered the time reduction would be greater than 25%. Similar results were found in relation to the number of plots inspected per day.
- 58% of inspectors somewhat or strongly agree that the platform allows for the reduction of administrative burden for inspectors.
- 100% of certification bodies somewhat or strongly agree that the platform will assist them with Organic Certification and that it reduces administrative burden.

Future plans for RECAP and beyond

The outcomes of the RECAP pilots were presented at the European Unon’s 2018 INSPIRE Conference.[15]

While the RECAP initiative formally concluded in 2018, there are a number of further EU initiatives which, like RECAP, aim to simplify and modernise administration of the CAP.

Box 9.2. Further EU collaborative initiatives for innovative tools for CAP 2020+

The RECAP initiative, which commenced in 2016, is a forerunner in what has become a very active research and innovation space within the European Union. Since that time, a number of collaborative initiatives have commenced, which aim to encourage new tools and processes for modernising and simplifying the CAP in the next programming period (beginning 2020) and beyond. Key initiatives are:

- *Pilot4CAP* is a platform for sharing Pilot projects for the new CAP2020+, hosted and coordinated in the G4CAP Web application. This platform calls for sharing and reporting of publicly known new or ongoing pilot projects performed in preparation for the new CAP 2020+. Projects on the following subjects can be entered: IACS, OTSC, LPIS, Land Use, Land Cover, (IT or other) services making use of imagery such as Sentinel optical, Sentinel radar, VHR/HR satellite, aerial photo, RPAS or High Altitude drones (HADs).

- The *Sentinels for Common Agricultural Policy (Sen4CAP) project*, launched in May 2017, aims at “providing to the European and national stakeholders of the CAP validated algorithms, products, workflows and best practices for agriculture monitoring relevant for the management of the CAP. The project will pay particular attention to provide evidence how Sentinel derived information can support the modernization and simplification of the CAP in the post 2020 timeframe. Sen4CAP has been set up by ESA in direct collaboration and on request from DG-Agri, DG-Grow and DG-JRC.”

Sources: https://g4cap.jrc.ec.europa.eu/g4cap/Default.aspx?tabid=354; http://esa-sen4cap.org/

Lessons learned

Lesson 1. Earth-observation tools powering accessible, user-specific platforms offer the opportunity to substantially reduce transactions costs of administering the Common Agricultural Policy

As the results from the end-of-pilot survey showed, pilot participants (farmers, agricultural consultants, inspectors, certification bodies and national paying agencies) all generally considered that the RECAP platform would reduce administrative burden. In some cases, reductions in administrative costs (generally measured as time spent on various administrative activities) were considered to be greater than 25%.

Lesson 2. By using spatially-explicit earth observation and other data on a wide range of agricultural and environmental variables, RECAP paves the way for more nuanced, targeted agri-environmental policies

Beyond lowering the administrative costs of implementing existing CAP programmes and requirements, RECAP-style digital platforms based on earth observation data enables public authorities to better monitor the implementation of agricultural and agri-environmental policies, and paves the way for more targeted policies in the future. In particular, the provision and availability of highly-differentiated spatial data (e.g. by parcel) on agricultural practices and landscape characteristics (e.g. slope, proximity to receiving waters, soil type, etc.) at high temporal frequencies will allow agencies to pursue more spatially and dynamically flexible policies that were previously infeasible due to data constraints.

Lesson 3. Digital tools such as the RECAP platform can increase the transparency of inspections and the accountability of public organisations, resulting in greater robustness of, and trust in, public agencies

The RECAP platform provides access to frequently updated satellite data and to functions for inspectors or farmers so that they may upload geotagged, time-stamped images to support administrative checks of eligibility and compliance. Thereby, farmers have continuous access to further farm-related details within a secure and transparent framework. Further, farmers can use the images uploaded in a number of ways: e.g. share them with advisors and seek assistance or rectify non-compliance or prevent such a case occurring in the future.[16] RECAP is therefore a tool that assists fair, transparent and detailed inspections.

Lesson 4. RECAP uses a co-operative approach to ensure the efficiency and effectiveness of its technical solutions, and interoperability with other solutions

RECAP helps to foster a less adversarial administrative context by "building bridges" between public administrators and farmers through the use of innovative Earth Observation solutions and related tools. It is based on a *user-driven approach* with its solutions having been designed and developed alongside the end-users and stakeholders, under a co-creation and co-production scheme.

The collaborative approach also encourages *proactive participation of farmers in the overall monitoring procedure*, giving them an active role in the data collection process, enhancing close communication and co-operation with public administration. This innovative approach sets up a monitoring system that informs, guides and notifies farmers on their obligations towards the BPS regulations, instead of penalising them for non-compliance when inspections take place.

Finally, RECAP also offers an Application Programming Interface (API) allowing to other platforms to use the RECAP data or contribute data to the RECAP database. This allows for *interoperability* and *interconnectivity* with other platforms or applications offered by PAs as well as ensures further integration with other systems developed (or to be developed) by agricultural consultants. In this way, RECAP allows for the *"only once" principle*, according to which information submitted once by the farmers need not be asked for again by another service of the administration.[17]

Lesson 5. Innovative digital solutions such as RECAP can underpin new private sector business models

The innovative solutions that the RECAP platform provides to agricultural consultants give rise to new business opportunities. Provided with the Software Development Kit, agricultural consultants are offered certain functionalities allowing them to search and use data stored in the RECAP platform; to integrate search results into their applications supporting farmers' claims; and to manage RECAP configuration and objects. Overall, RECAP can be used as a tool to underpin the day-to-day work of agricultural consultants to provide valuable advice to farmers.

Notes

[1] In particular, the CAP aims to:

- "support farmers and improve agricultural productivity, so that consumers have a stable supply of affordable food
- ensure that European Union (EU) farmers can make a reasonable living
- help tackling climate change and the sustainable management of natural resources
- maintain rural areas and landscapes across the European Union
- keep the rural economy alive promoting jobs in farming, agri-foods industries and associated sectors" (European Commission, n.d.[6]).

[2] And abstracting away from questions of additionality (i.e. whether farmers prefer to act in a way that is consistent with the policy even in the absence of the policy).

[3] Here, we do not consider the overall cost-effectiveness of the CAP policy as a whole: such a consideration would require consideration of all relevant costs and benefits, not simply the administrative costs of the monitoring and control system and the benefits of maintaining effective standards of compliance.

[4] For example, the *checks by monitoring* approach developed by the Commission as an alternative to traditional checks on-the-spot, the Horizon 2020 *SEN4CAP* project. See Box 6.2.

[5] Draxis Environmental S.A. (Leader) (GRC), Instituto Navarro de Technologias e Infraestructuras Agroalimentarias SA (ESP), Payment and Control Agency for Guidance and Guarantee Community Aid, National Paying Agency of Lithuania (LTU), Viesoji Istaiga Lietuvos Zemes Ukio Konsultavimo Tarnyba (LTU), Strutt & Parker LLP (GBR), Inosens Doo Novi Sad (SRB), University of Reading (GBR), National Observatory of Athens (GRC), Iniciativas Innovadoras Sal (ESP), ETAM S.A. (GRC) and CREVIS SPRL (BEL).

[6] This objective is related with the Software Development Kit (SDK). The SDK provides RECAP platform users (in particular agricultural consultants responsible for farmers registered in the platform) with tools that help them build new added-value services upon the RECAP platform. This functionality enables the use and reuse of open data. For example, agricultural consultants can retrieve data of the parcels declared, along with results derived by the RS component, for use in other applications.

[7] The platform uses an open licence (GNU General Public License version 3; info available at: https://opensource.org/licenses/GPL-3.0). It is not intended to entail a cost for farmers. Certain costs relating to customisation or adaptations may be incurred by the paying agencies and other interested authorities. Operational costs are to be covered by the paying agencies.

The platform source code is available at: https://zenodo.org/record/1451796#.XOuNXYj7RPY

[8] These requirements are: Greening 1—Crop Diversification; Greening 2—Permanent Grassland; GAEC1—Buffer Strips; GAEC 4—Minimum Soil Cover; GAEC 5—Minimising Soil Erosion; SMR 1—Reducing water pollution in Nitrate Vulnerable Zones (VNZs) and GAEC 6—Maintaining the level of organic matter in soil (sources: https://ec.europa.eu/agriculture/direct-support/cross-compliance_en and https://ec.europa.eu/agriculture/direct-support/greening_en, accessed August 2018).

[9] The first iteration used data from June 2018, right after the completion of farmers' applications; and refers to the classification performed using satellite imagery until late June 2018. The second iteration was in late August 2018; and refers to the classification performed incorporating additional imagery (new Sentinel-2 acquisitions) that was acquired throughout the summer.

[10] For further details about the accuracy assessment, contact the case study participants.

[11] "Green light" signifies an almost completely trustworthy decision, yellow a less reliable but still usable decision, and red and unreliable being decisions of low confidence (these should be used with caution).

[12] The classification is performed for crop types (i.e. soft wheat, barley, oats), crop clusters/families (i.e. cereals, legumes, maize, etc.) and crop season (i.e. summer, winter, permanent). All three levels of crop classification are provided to the PAs. According to the Greek Paying Agency, most of cross compliance rules are decided based on the crop cluster (family), with the exception of Greening requirements that require the lowest level of crop type differentiation.

[13] Case study participants reported that initially, RECAP was aiming to develop a platform with a common interface and features for the delivery of public services. However, based on the results derived from the users' needs analysis and co-production of services in all pilot countries, the technical team designed and developed five different interfaces/workflows customised to the

specific needs of each of the five countries' users. (*Source*: Personal Communication. Case study participant, Dimitrios Petalios (CREVIS), June 2018)

[14] See https://ec.europa.eu/agriculture/glossary/acquis-communautaire_en_en, accessed August 2018.

[15] See https://www.recap-h2020.eu/inspire_2018_conference/, accessed August 2018.

[16] In theory, geo-tagged photos could also be used by farmers in support of an appeal. However, the use of geo-tagged photos to make an appeal may require changes to the existing EU CAP administrative and legislative frameworks. Consideration of such changes are beyond the scope of this case study.

[17] Note that the RECAP platform does not ensure that administrations will not ask farmers to provide information already obtained, but the principle is that information provided into the RECAP platform will be available; i.e. the platform allows for, but does not intrinsically ensure, that the "once only" principle is implemented.

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Chapter 10.

Case Study 5. Digital technologies applied by USEPA to achieve innovative compliance

The objective of this case study is to provide a practical example of how digital technologies and data transparency tools can be used as part of a broader strategy to improve the flexibility and robustness of regulatory environmental programmes.

Context: The policy environment

The United States Environmental Protection Agency (USEPA) implements national environmental law by writing and enforcing regulations, setting national standards that US states and tribes enforce, and assisting regulated entities to understand the requirements (USEPA, date na). As such, USEPA (together with the United States Department of Agriculture (USDA)) is one of the key national bodies tasked with implementing US agri-environmental policy. USEPA administers a range of US federal legislation relevant to agriculture, which has both regulatory and non-regulatory components (see additional description below).

Use of digital technologies to support

The problems

Evaluation of compliance and enforcement programmes is an important activity for any regulator. During 2010-2013, USEPA self-identified a range of issues or areas for applying innovative compliance approaches, including: "gaps in information about the compliance status of regulated entities, unacceptably high rates of noncompliance, deficiencies in state enforcement of delegated programmes, and substantial shortcomings in managing (collecting and transmitting) compliance-related information" (Markell and Glicksman, 2015[1]).

These problems are not unique to USEPA, and relate to fundamental challenges caused by *transactions costs*, *information gaps*, *information asymmetries*, and *incentive misalignment* between the regulator and the regulated community.[1]

The solutions

To address these gaps in the existing compliance and enforcement approach and improve the cost-effectiveness of USEPA's compliance programme, USEPA began systematically exploring innovative compliance tools in 2012 and activities such as the use of optical gas imaging cameras, electronic reporting, and working to improve the effectiveness of regulations and permits, have become more commonplace. Types of tools are:

- *Advanced monitoring and information technologies*:[2] real-time continuous monitoring generates actual measurements (as opposed to estimates), which reduces information gaps and information asymmetries between the regulator and the regulated entities (see Box 10.1 for additional explanation).
- *Electronic reporting*: e-reporting saves time, reduces error, enables automatic checks & triaging to help target monitoring and enforcement activities, reducing transaction costs of compliance and enforcement activities. The use of two-way digital communication between regulator and regulated entity could allow the regulator to provide targeted compliance assistance.
- *Transparency—public disclosure requirements*: increased public disclosure provides incentive for entities to improve their environmental performance via reputation effects. Examples include USEPA's ECHO database[3] and EnviroAtlas,[4] developed collaboratively by USEPA, United States Geological Survey (USGS), United States Department of Agriculture (USDA) and LandScope America (USEPA, 2017[2]). However, care must be taken to ensure no privacy interests are compromised.

- *Rule and permit design—"Compliance-ready" technology and rules with "compliance built in"*: recognising that enforcement action alone will not produce full compliance in every instance, this component entails promoting the use of technology, transparency, and other tools. Similarly, rules can be designed to require use of certain technology or processes by upstream manufacturing rather than attempting to regulate the use of technology by end users, e.g. auto manufacturers are required to install pollution control devices rather than requiring automobile buyers to do so (Giles, 2013[3]).

Box 10.1. Potential uses and use tiers of advanced monitoring data

(Performance and quality requirements for these uses may vary)

Directly Support Regulatory Programmes

- *Permitting*: Part of record for issuance of rules or permits.
- *Regulation and Compliance*: Identification of nonattainment areas/impaired waters; removal of designations when conditions improve; self-monitoring pursuant to a permit or an applicable rule.
- *Enforcement*: Evidence in an enforcement action.

Aid or Supplement Regulatory Action

- *Action Prioritisation:* Targeting, development, and prioritisation of enforcement actions.
- *Problem Identification:* Hot-spot identification and characterisation, or analysis for programme planning purposes or future regulatory action.
- *Additional Data:* Supplement current regulatory monitoring for planning.
- *Emergency Response:* Pollutant identification, characterisation of conditions and risks, response action planning, and status assessment following a response.
- *Temporary Source Monitoring*: Temporary monitoring (e.g. construction sites).

Educate/Inform the Public

- *Programme Evaluation:* Evaluation of research, programmes, and other policy outside of regulatory actions.
- *Transparency:* General information made available to the public about their environment.

Other Uses

- *Facility Self-Monitoring:* Use to inform operational control by facilities (e.g. drinking water systems).
- *Personal Health:* Personal exposure monitoring and crowdsourced networks.
- *Education*: Use of technology as a teaching tool (e.g. Science, Technology, Engineering, and Math [STEM] education).
- *Research:* Use by universities and others for research purposes.
- *Hazard Alert Systems:* Alert building occupants of a problem.

Note: While all of these uses of advanced monitoring data can be applied to the agri-environmental context, discussion in the original article was not sector specific.
Source: Reproduced from Hindin et al. (2016[4]), Table 1, p.3.

How does innovative compliance apply to agriculture in the United States?

Use of innovative compliance tools for agri-environmental policy implementation can broadly be separated into applications in regulatory (permit) and non-regulatory (voluntary) contexts. These are discussed in turn below, with primary emphasis given to the regulatory context.

Permitted agricultural operators and chemical input suppliers

In the US agriculture sector, some concentrated animal feeding operations (CAFOs[5]) such as certain feedlots, dairies and poultry houses are "regulated by EPA under the *Clean Water Act* in both the 2003 and 2008 versions of the 'CAFO rule'" (40-CFR) (NRCS, date NA). These regulations underpin a permitting system known as the National Pollutant Discharge Elimination System (NPDES). Innovative compliance tools are applied for NPDES permittees[6] via several avenues:

- *Electronic reporting*: in September 2015, USEPA introduced electronic reporting for NPDES permittees (USEPA, date na). This is being implemented in two phases, the first of which became operational in December 2016 (40 CFR § 122.41(l)(4)(i)). Permittees are required to submit certain documentation via an online portal known as NetDMR.[7] Data reported electronically is made available to the public via the USEPA's ECHO website.[8]
- *Innovative compliance components in permitting*: permits (e.g. NPDES permits) generally operate on a five-year cycle.[9] As permits are renewed, innovative compliance elements such as data reporting requirements or use of new technologies could be introduced into the permit. Innovative compliance elements have been introduced for certain non-agricultural permittees. Law or regulatory changes may be required to facilitate broader adoption of innovative compliance approaches in permits.
- *Innovative compliance tools used in rule-making*: innovative compliance components could be introduced into rules applying to regulated agricultural enterprises (e.g. NPDES-permitted CAFOs), for example by updating rules to allow or require regulated businesses to make use of state-of-the art technology, to require more transparency via public reporting, or to design new compliance pathways. However, USEPA's Office of Water (USEPA OW), who administers the CAFO-related rules under the Clean Water Act, has no CAFO-related rulemaking underway at this time, and hence an opportunity to consider the application of innovative compliance principles in this arena has yet to arise.

Agricultural operators participating in voluntary programmes and initiatives

Agricultural enterprises that are not required to obtain a permit may nevertheless choose to participate in a range of voluntary agri-environmental programmes, such as cost-share programmes administered by the USDA Natural Resource Conservation Service (NRCS), water quality trading programmes, and other federal, state or local programmes which aim to incentivise production of environmental goods on working agricultural lands and/or the conversion (or "retirement") of agricultural to other land uses such as forest or wetland.

In this voluntary context, when a producer enters into a voluntary contract for provision of environmental goods, innovative compliance tools can be used in much the same manner as in a regulatory context, with compliance with the terms of the contract taking the place of compliance with a permit. Certification programmes (e.g. organic labelling) can also implement innovative compliance tools as part of the certification process. Programme administrators and producers can also make use of some of the innovative compliance tools—particularly electronic reporting in conjunction with transparency—to foster public support for entirely voluntary environmental efforts (i.e. even those which do not use contracts or any other form of legal enforcement mechanism).

Beyond this, USEPA is also active in a range of initiatives to advance technologies which reduce environmental impacts from agriculture. Examples include:

- USEPA's Office of Water is involved in a voluntary partnership effort with USDA and animal agriculture industry to find innovative solutions to recycling nutrients.[10]
- USEPA is assisting the Nebraska Department of Environmental Quality and Kansas Department of Health and Environment on the initiative "Use of Next-Generation Molecular Tools for Harmful Algal Blooms and Microbial Source Tracking to Support Watershed Restoration in Kansas and Nebraska". This initiative aims to improve microbial source tracking and harmful algal bloom assessments using the PhyloChip, an innovative monitoring technology.[11]

Lessons learned for the application of innovative compliance tools in agri-environmental contexts

Lesson 1. Design principles for EPA's innovative compliance

The first lesson comprises key design principles on which the innovative compliance initiative was based, such as:

- Be sure regulated entities, the public, and the government can easily identify who is regulated and what they need to do to comply with the requirements. Where possible, use physical design, feedback technology, and/or self-implementing consequences to make compliance easier than non-compliance.
- Require regulated entities to monitor factors that affect compliance and take steps to prevent noncompliance.
- Provide the public and government agencies with real-time information on regulated entities' emissions, discharges and key factors that affect compliance and outcomes, leveraging accountability and transparency.
- Use market forces, benefits of demonstrated compliance, and other incentives to promote compliance.

For more information, see Hindin and Silberman (2016[5]).

Lesson 2. Good regulatory practices can be transferrable across different kinds of regulations

Case study participants noted that one of the earliest activities in the innovative compliance initiative was to consider what kinds of innovations in enforcement and compliance techniques were being pursued by other regulators, both within the US and internationally. Case study participants commented that the innovative compliance effort reviewed academic literature and engaged directly with many regulators, but that judgement was needed to identify which tools could be adapted to the USEPA context.

For example, the research identified that the use of third party reporting by the United States Internal Revenue Service (IRS) to improve compliance with US taxation law is a tool that can be also used by USEPA in the context of enhancing compliance with environmental law. They also drew on MIT research in Gujarat India which found that third party auditors must be independent and have results checked to produce reliable audits (Duflo et al., 2013[6]).

Lesson 3. Technological change offers new possibilities for improved monitoring and compliance. However, there needs to be clear and fit-for-purpose processes for demonstrating suitability of advanced monitoring tools for regulatory purposes, which may differ from existing processes. This may be challenging to achieve in a context of fast-paced technological change

Technology requirements, whether the technology is used to address or monitor pollution, are not a new feature of environmental regulation. Recent technological innovations are delivering new technologies for monitoring regulated entities' environmental performance and compliance with regulatory requirements. New monitoring devices are often smaller and more portable technologies, and are declining in cost. Further, the real innovation is that these technologies can be linked to information communications technology (ICT) that delivers data in real time, and can allow for the automating of alerts (e.g. via mobile telephones) that can help a facility fix problems before noncompliance occurs.

Regulations can shape the uptake of technologies in several ways, including by mandating use of a particular technology in a certain context (technology mandate) or setting standards that technologies are required to meet (technology performance standards). It is acknowledged that some USEPA programmes generally now use performance standards that technologies must meet, rather than mandating use of specific technologies.[12] Technological requirements, or standards that technologies must meet (in a regulatory context), are generally specified via USEPA rules and in manuals (e.g. the NPDES permit writers' manual[13]). Rule-making processes can be lengthy and costly.

Interest in using new technologies for monitoring the environmental performance of agriculture, particularly continuous monitoring systems, is rising, not only in the United States but elsewhere. For example, the EU Commission recently introduced regulations to permit use of remote sensing technologies to supplement (or eventually substitute for) on-the-spot-checks of environmental and other conditions under the Common Agricultural Policy.[14]

Given this interest, and the rapid pace of technological change of relevant technologies, existing processes for vetting new technologies for regulatory purposes, particularly ones which take several years to complete, need to become more agile. Environmental regulators and policy administrators could better engage with the regulated community, the private sector and researchers to develop "testbed" environments for assessing the potential of technological advances in regulated contexts. Further, processes for vetting new technologies should be clear for all participants and allow for unanticipated technological change (e.g. new types of sensors currently un-envisaged).

Regulators could also consider providing incentives for the regulated community to voluntarily participate in testing and adoption of new technology for both monitoring and reducing environmental impacts.

Lesson 4. Take a holistic approach: use of digital technologies complements non-digital, and regulatory efforts can work alongside voluntary efforts

As detailed above, USEPA's efforts to improve regulatory compliance are being complemented by efforts to support agriculture to improve its environmental impact outside the regulatory context. While this particular approach reflects the legislative and policy environment specific to the United States—particularly the fact that, to a large extent, agriculture is exempted from a range of environmental regulatory requirements that are placed on other industries (Breggin and Myers, 2013[7])—having a coherent approach across regulatory and non-regulatory contexts can have a wide range of benefits (OECD, 2008[8]). These include ensuring that voluntary approaches such as emissions or water quality trading are not stymied by rigid regulatory requirements (see (Stephenson and Shabman, 2017[9]) for a discussion), and allowing sharing of enforcement experience and expertise between regulators and voluntary programme administrators (who may, for example, need to enforce conservation contracts in agri-environmental payment schemes or verify credit creation in trading schemes).

Also, advances in digital technologies (e.g. the PhyloChip technology) are being pursued alongside other technologies which may have no digital component. It is important to recognise that in many cases digital tools are a way to encourage farmers and others to take environmentally beneficial non-digital actions. That is, better measurement, especially when connected to IT communication tools, can help focus attention and actions where they will be most effective. As such, investment in digital tools should be seen as a complement to, not a substitute for, non-digital technologies or other non-technological innovations which directly improve environmental outcomes.

Notes

[1] While this case study focuses on USEPA's activities in the regulated context, it is worth noting that many elements discussed here are relevant to non-regulatory contexts. For example, to improve the efficiency and effectiveness of voluntary programmes.

[2] See (Hindin et al., 2016[4]).

[3] See https://echo.epa.gov/, accessed August 2018. The Enforcement and Compliance History Online (ECHO) database provides "integrated compliance and enforcement information for over 900 000 regulated facilities nationwide. Its features range from simple to advanced, catering to users who want to conduct broad analyses as well as those who need to perform complex searches." Specifically, ECHO allows users to find and download information on specific facilities; find EPA enforcement cases; analyse compliance and enforcement data; access data services and inform EPA.

[4] See https://www.epa.gov/enviroatlas, accessed August 2018. EnviroAtlas is an interactive online platform comprising "tools [that] allow users to discover, analyse, and download data and maps related to ecosystem services, or the benefits people receive from nature."

[5] USEPA's regulatory definition of "CAFO" is found in the federal regulations at 40 CFR § 122.23. See https://www.gpo.gov/fdsys/granule/CFR-2011-title40-vol22/CFR-2011-title40-vol22-sec122-23, https://www.epa.gov/npdes/animal-feeding-operations-afos and https://www.epa.gov/sites/production/files/2015-08/documents/sector_table.pdf, accessed September 2018.

[6] Note that NPDES applies to more than CAFOs, however this case study focusses on the agriculture sector.

[7] See https://cdxnodengn.epa.gov/oeca-netdmr-web/action/login, accessed August 2018.

[8] See https://echo.epa.gov/, accessed August 2018.

[9] Source: https://www.epa.gov/npdes/npdes-permit-basics, accessed August 2018.

[10] See https://www.challenge.gov/challenge/nutrient-recycling-challenge, accessed August 2018.

[11] See https://www.epa.gov/newsreleases/epa-announces-innovative-research-across-country-address-state-environmental-issues, accessed August 2018.

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[14] EU Regulation 2018/746. See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018R0746, accessed August 2018.

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Chapter 11.

Case Study 6. Digital innovations to facilitate farm level data analysis while preserving data confidentiality

The case study objective is to show how recent innovations such as "confidential computing" can improve access to farm-level data for agricultural and agri-environmental policy or research, while appropriately maintaining data confidentiality and security. While recognising that there are many relevant innovations around the globe, this case study provides examples drawn from the experience of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), a world leader in these emerging technologies.

Context: Farm-level data is crucial for policy analysis, but high confidentiality requirements limit the ability to use it

Micro-level agricultural data (for example, farm level or field level data) is needed for evaluating the effectiveness and efficiency of agricultural and agri-environmental policies. They also allow understanding of how policy impacts differ across dimensions such as location, production practices, industry or sector, socio-economic status.

Agricultural censuses and surveys conducted by or on behalf of government agencies have long been a key source of such data. Most countries, including OECD countries, have a long history of gathering such data and using it to underpin policy decisions. However, in general, authorising legislation or regulation which enable this data collection also impose strict confidentiality requirements on the public release of records which could (whether intrinsically or when combined with other data) identify individuals or individual businesses (farms).

In addition to such datasets, administrative data,[1] usually gathered and held by government agencies, is an important source of information relevant for policy-making. Berg and Li (2015[1]) identify the following sources of administrative data for agriculture: soils information; crop insurance and subsidiary programmes; land registration and cadastral records; government regulations and monitoring programmes; private and non-governmental organizations and sources of operations; reporting systems (e.g. periodic crop condition reporting); and taxation data. Access to administrative data is often even more limited than access to farm level survey or census data.

Data confidentiality requirements are often cited in the literature as a limiting factor in micro-level agricultural and agri-environmental analysis (Martínez-Blanco et al., 2014[2]) (Tukker and Dietzenbacher, 2013[3]) (VanderZaag et al., 2013[4]). Further, researchers and analysts often need to be able to *link* different datasets in order to conduct policy-relevant analysis. In the agriculture context, one crucial type of linking is to tie data on *physical* characteristics (e.g. location-specific data on soil type, precipitation, temperature, proximity to water bodies, etc.) with data on *economic* characteristics (e.g. farm performance attributes such as farm profit, farm costs; subsidies received; input use, etc.). This linkage generally needs to occur at the farm or field level in order to evaluate policy microeconomic and environmental impacts (Jones et al., 2017[5]; Petsakos and Jayet, 2010[6]). Woodard (2016, p. 385[7]) sums up the situation: "Some work cannot be feasibly accomplished without being able to link together different databases at low levels of aggregation." While confidentiality requirements for individual organisations or individual datasets are often the reason that desired linkages across datasets cannot be made, a range of other factors also contribute, including: the absence of common linking variables (which enable record matching) (Lubulwa et al., 2010[8]); high costs or lack of resources or expertise needed to perform the linkages (Hand, 2018[9]); and lack of interoperability between datasets (e.g. different definitions with no rule to "translate" definitions in one dataset to match up with another) (Hand, 2018[9]).

Use of digital technologies to overcome the impasse

The problems

Efforts to increase the accessibility and reusability of agricultural micro data, and to link different sources of agricultural micro data, seek to address issues arising from *information gaps* and *information asymmetries*.[2] However, in doing so, they create new issues. At a conceptual level, ethical and practical[3] questions about the appropriate level of confidentiality or privacy protection for farmers (and other entities to which data refer) must be considered.[4] This then presents additional technical issues about:

- how to appropriately protect farmers from the *misuse of data* that pertains to them (a question with both competitiveness (economic) and ethical dimensions);
- how to ensure farmers are able to exercise their *right to privacy or confidentiality*;
- how to make datasets *interoperable*.

Researchers from the USDA's ERS succinctly define the challenge:

> *In essence, the trade-offs involve the desire to get the highest return possible for substantial data collection costs and respondent burden to gather information necessary to produce official statistics and support economic research on one hand and the requirement to uphold the pledge of confidentiality and ensure the future participation of respondents. (Towe and Morehart, n.d., p. 2[10])*

Digital solutions[5]

Existing approaches to improving data access and reuse while preserving confidentiality

Technology solutions have been developed over many years to enable more data to be available for use, such as anonymisation and data obfuscation techniques, and this activity continues today, with many exciting technologies for improved data availability on the horizon. Existing methods for protecting data include simple methods such as aggregation and suppression, such as only releasing data at postcode level and only with a sufficient number of counts. These methods can be augmented with perturbation methods,[6] which protect tables released from unit level census data from re-identification attacks.[7]

There are a large number of proposed approaches to confidentialisation to facilitate data sharing for research while protecting privacy. All of these have been used in successful, large scale implementations in Australia and internationally (O'Keefe and Rubin, 2015[11]; Reiter and Kohnen, 2005[12]). Relevant arrangements include:

- De-identified open data access – the analyst downloads the data directly (e.g. datasets accessible via the GODAN initiative[8]).
- User agreements for offsite use (licensing), in which users are required to register with a custodian agency, and sign a user agreement, before receiving data to be analysed offsite.
- Remote analysis systems, in which the analyst submits statistical queries through an interface, analyses are carried out on the original data in a secure environment and the user then receives the (confidentialised) results of the analyses.
- Virtual Data Centres (VDCs), which are similar to remote analysis systems, except that the user has full access to the data, and are similar to on-site data centres, except that access is over a secure link on the internet from the researcher's institution. (e.g. the USDA-ERS data enclave platform provided by NORC,[9] Australian Bureau of Statistics DataLab[10]). VDCs may also make use of *containerisation*, where the analyst can access the data in a limited way, on a secure platform through a containerised application (e.g. the SURE platform used by the Sax Institute[11]).

- Secure, on-site data centres, in which researchers access confidential data in secure, on-site research data centres (e.g. the Secure Access Data Center, France[12]).

Each arrangement makes data available at a specified level of detail, where sensitive detail can be reduced by methods including:

- Removal of identifying information.
- Confidentialisation of the data by one of a range of methods, including aggregation, suppression or the addition of random "noise".
- Replacement of sensitive variables or data with synthetic ("made-up") data.

Unfortunately, with the exception of the open data approach, these mechanisms greatly restrict the number of people that can access the data, and the convenience of that access. Also, some techniques may reduce the value of data for policy analysis, for example by reducing the level of granularity, introducing bias into the dataset, or reducing the ability to link individual records in different datasets.

Recent technological advances: Confidential Computing, Multi-party Computation and Synthetic Data Release

The Commonwealth Scientific and Industrial Research Organisation (CSIRO), a corporate entity of the Australian Government, is currently leading research into several innovative techniques for allowing researchers to make use of confidential data such as farm level records, without actually being able to see or access the raw data. These innovations rely on advances in digital encryption to preserve confidentiality.

Confidential computing and multi-party computation

CSIRO has expertise in homomorphic encryption, which enables calculations to be done on data while the data is encrypted; and secure multi party computation, which allows data to be shared between and computed on by multiple parties, but none of the parties have sufficient information to reconstruct the data itself. Both of these approaches are considered very promising as a long-term solution to the data protection problem, however "fully homomorphic encryption", which is a recently discovered capability, is not yet practical for large-scale data analysis problems.

As part of its "confidential computing" platform, CSIRO Data61 is developing a combination of "partial homomorphic encryption" (which is more limited but more efficient than fully Homomorphic encryption), distributed computing and machine learning. This platform enables the provision of services that allows individual organisations (both public and private) to do joint analysis of data without exposing their own data to any other party. These methods are being applied to federal government data within the Australian Government National Innovation and Science Agenda[13] (NISA) framework as a proof of concept.

The "Confidential Computing" platform allows access to a prescribed set of analytics functions that are performed over encrypted data that is not disclosed to the data scientist or analyst. As of September 2018, analytics functions that are available through this approach include aggregation and other simple statistical functions, simple supervised and unsupervised machine learning approaches, but currently exclude methods such as Random Forests and Deep Learning due to their incompatibility with the reduced set of operations available from the underlying cryptographic representation of the data. Confidential

Computing enables a new, low friction, method of doing exploratory linkage and analysis of datasets. This approach may allow the discovery of new connections between datasets or attributes and insights without the overhead of the training, authorisation and provision of current approaches, while still maintaining the confidentiality of the data. More expensive access to the data directly can still be obtained through current methods, particular if justified through exploratory analysis over encrypted data. This capability is equally relevant to intra-government data collaboration, government-private data collaboration, and private-private data collaboration.

Synthetic data release

There is a recent advance in privacy technology known as Differential Privacy, introduced by Dr Cynthia Dwork at Microsoft. Differential Privacy is a quantifiable measure of the privacy of certain data analytics techniques that involve random perturbation of either the data being analysed or the analysis itself. CSIRO Data61 is working on a variety of differentially private mechanisms to allow the release of synthetic unit record datasets that contain statistically similar data to the original data, but can guarantee that the released data cannot be re-identified. Data61 is undertaking investigation of these methods within the NISA framework to potentially allow the release of government datasets with fewer restrictions than are currently needed to ensure confidentiality. These techniques involve adding noise to the data, and so have some impact on the utility of the data for analytics.

Lessons learned for the use of innovative digital technologies to improve access to and reusability of farm level data for policy-relevant analysis

Lesson 1. Agricultural micro data, and the ability to "tie" farm level financial data to physical data, including location-specific attributes, are crucial for developing more efficient, spatially-targeted policies

Given the weight of evidence from existing economic analyses that untargeted agricultural policies are inefficient (see, for example, (Arbuckle, 2013[13]; Lankoski, 2016[14]; OECD, 2008[15]; OECD, 2012[16]; Rabotyagov et al., 2014[17]; Weersink and Pannell, 2017[18]; Whittaker et al., 2017[19]), the usefulness of micro-data for effective and efficient policy design, implementation and evaluation will only increase.

Governments need to recognise that access to agricultural micro data, including the ability to link different agricultural micro datasets (as well as other relevant data such as environmental data) is a crucial source of value-added, and is needed to produce robust and targeted policy analysis and advice.

Lesson 2. Even though governments may be moving towards more open data approaches, access to farm level data collected by public agencies is generally limited by enabling legislation and is underpinned by trust

Many governments have decided to pursue more "open data" approaches or enact general data privacy regulations which will shape governance on the use of agricultural micro data. Many have also committed to the principle that published data should confirm to FAIR standards[14] of being *findable*, *accessible, interoperable* and *re-useable*.[15] However, it is important to appreciate that government organisations are often legally required to maintain confidentiality in relation to raw data (particularly, in the agriculture context, where the raw data pertains to individuals or individual farms), and hence that commitments to open data or FAIR principles may not be considered relevant for access to farm-level data.

Moreover, most agricultural data is collected via trust-based relationships between farmers and government agencies or researchers. In a voluntary context, there is a clear link between trust in the data collector's commitment and ability to preserve confidentiality and the willingness to participate. In a mandatory context, while arguably participation could be more easily regulated, provision of complete, correct data may nevertheless be difficult to ensure.

The fact that government agencies' (and researchers') ability to collect farm-level data is based on trust and on often longstanding legislative commitments to maintaining confidentiality has several implications:

- Government may have limited ability to lessen these legislated confidentiality guarantees, especially in relation to existing datasets. This suggests that an open data approach for agricultural micro data may not be an achievable or desirable end goal.
- Government should consider how collection of data via new methods which do not require direct participation from farmers (e.g. collection of data via remote sensing, or automated collection of data from "smart" agricultural machinery or infrastructure) impacts on the existing trusted relationships with farmers. Interactions may not be straightforward – for example, increased use of remote sensing may induce farmers to become more relaxed about (certain aspects) of confidentiality because data is available to all; conversely, it could engender a more wary approach and resistance to what could be perceived as government overreach.

Lesson 3. By facilitating analysis of the data without the analyst being able to see the data, confidential computing can solve the confidentiality-reuse dilemma

CSIRO's N1 confidential computing platform provides an example of how technology can be used to bypass the traditional dilemma between the benefits of allowing access to highly disaggregated "true" data (including individual records) and the need to aggregate or perturb the data in order to preserve confidentiality. However, these technologies are still new and have yet to be applied a context involving agricultural data.

Lesson 4. Improving access to agricultural micro data needs a coherent, tiered data dissemination strategy

Existing arrangements for access to agricultural micro data for policy-related research and analysis is cumbersome and often fails to adequately provide researchers and analysts with the data they need. This results in duplication of effort (e.g. universities conducting their own surveys because they cannot access farm-level data collected by government statistical agencies) and limits the ability for researchers to provide targeted, dis-aggregated policy analysis and advice.

As demonstrated in this case study, there are a range of institutional and technological solutions which can facilitate access to agricultural micro data while preserving individual respondent confidentiality. It is not clear that one particular solution is superior; rather, government agencies (and other organisations who collect agricultural micro data) can take a graduated approach which takes into account both the benefits of allowing access to specific data for specific purposes and the potential harm caused if confidentiality is breached. Data dissemination strategies should explicitly recognise the trade-offs of different data access options.

It is suggested that governments take a tiered approach, as follows:

- Start from the position of open data and take a “Why not?” approach: that is, reasons why data cannot be openly provided should be clearly articulated. Pre-existing legislative requirements to protect confidentiality should be able to be periodically transparently reviewed.[16]
- Invest in data services such as providing linked datasets to increase the usefulness of government data collections. One important aspect of this is to link farm financial datasets with physical data such as soils, precipitation, and other climate variables.
- Increase use of secure remote access mechanisms to reduce transactions costs of allowing trusted researchers to access micro data.
- Explore greater use of new technologies such as confidential computing that avoid the traditional confidentiality-accessibility dilemma.

Organisations who collect or house data should work together with data providers (e.g. farmers in the context of traditional agricultural surveys) and data users to establish a clear framework governing data access.

Finally, while this case study has not considered broader issues about data ownership, data use rights and requirements to obtain consent to use and reuse data, it is important to emphasise that frameworks governing access to agricultural micro data should be coherent with broader policies governing such issues, as well as with underlying legislation authorising government agencies to collect agricultural data. For example, if a government were to take an approach that gives farmers ownership of agricultural data which pertains to them, data dissemination strategies of government agencies who collect, store or disseminate agricultural data needs to be consistent with this broader approach. Another example relates to consistency across jurisdictions: for example, organisations that are part of the Farm Accountancy Data Network (FADN)[17] should ensure their data dissemination strategies are as consistent as possible, to facilitate analysis across FADN countries.

Notes

[1] OECD (n.d.[20]) defines “administrative data” to have the following features:

- the agent that supplies the data to the statistical agency and the unit to which the data relate are usually different: in contrast to most statistical surveys;
- the data were originally collected for a definite non-statistical purpose that might affect the treatment of the source unit;
- complete coverage of the target population is the aim;
- control of the methods by which the administrative data are collected and processed rests with the administrative agency.

[2] McCaa and Esteve (in Eurostat (2006[21]) citing Julia Lane, 2003) highlight “five classes of benefits which accrue from broader access to microdata: address more complex questions, calculate marginal effects, replicate findings, assess data quality and build new constituencies or stakeholders. Replication is extremely important because there is an overwhelming temptation for scientists to misrepresent results when the data are unlikely to be available to others.”

[3] "Beyond law and ethics, there are also practical reasons for statistical agencies and data collectors to invest in this topic: if individual and corporate respondents feel their privacy guaranteed, they are likely to provide more accurate responses." (Domingo-Ferrer and Franconi, 2006[22])

[4] It is acknowledged that in some cases there may be little scope, at least in the short to medium term, to alter existing levels of protection provided confidentiality requirements already set in data collecting agencies' authorizing legislation. Nevertheless, as opportunities to review such legislation arise, the appropriate level of protection should be carefully considered and not take as a "given".

[5] The material in this section is taken from CSIRO's 2016 *Submission to the Australian Government Productivity Commission's Inquiry into Data Access and Use* (Chapman, 2016[23]), with minor editorial modifications and addition of examples that are relevant to the agri-environmental context. Changes have been approved by the original authors.

[6] *Perturbation methods* such as swapping, recoding, etc. make "exceedingly unlikely the identification of individuals, families or other entities in the data. Technical [perturbation] measures have the additional benefit that any assertion of absolute certainty in identifying anyone in the data is false." (Eurostat, 2006[21])

[7] *Re-identification attacks* are methods of analysing aggregated data to extract the details of a single individual or a group of individuals with a common characteristic. A notable example is the re-identification of the Netflix public dataset as performed by Narayanan and Shmatikov, https://www.cs.cornell.edu/~shmat/shmat_oak08netflix.pdf.

[8] The Global Open Data for Agriculture and Nutrition (GODAN) initiative promotes the "the proactive sharing of open data to make information about agriculture and nutrition available, accessible and usable". See https://www.godan.info/, accessed August 2018.

[9] "The [United States] Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS), in coordination with the Food and Nutrition Service (FNS) utilise the [university of Chicago's NORC] Data Enclave to provide authorised researchers secure remote access to data collected as part of the Agriculture Resource Management Survey (ARMS), the primary source of information to the US Department of Agriculture and the public on a broad range of issues about US agricultural resource use, costs, and farm sector financial conditions." See http://www.norc.org/Research/Projects/Pages/usda-ers-data-enclave.aspx, accessed August 2018.

[10] "The DataLab is the data analysis solution for high-end users who want to undertake interactive (real time) complex analysis of microdata. Within the DataLab, users can view and analyse unit record information using up to date analytical software with no code restrictions, while the files remain in the secure ABS environment. All analytical outputs are checked by the ABS before being provided to the researcher." See http://abs.gov.au/websitedbs/D3310114.nsf/home/CURF:+About+the+ABS+Data+Laboratory+%28ABSDL%29, accessed August 2018.

[11] SURE is "Australia's only remote-access data research laboratory for analysing routinely collected [health-related] data, allowing researchers to log in remotely and securely analyse data from sources such as hospitals, general practice and cancer registries." See https://www.saxinstitute.org.au/our-work/sure/design-and-functionality/, accessed August 2018.

[12] See https://www.casd.eu/en/, accessed September 2018. This is the channel for accessing agricultural micro-level data in France, including FADN data, but also surveys of farm practices. The CASD has been in place since 2012 and contains various types of sensitive data (e.g. health, taxation, business surveys, and administrative data such as agri-environmental measures).

[13] See https://www.industry.gov.au/strategies-for-the-future/boosting-innovation-and-science, accessed August 2018.

[14] See https://www.force11.org/group/fairgroup/fairprinciples, accessed August 2018.

[15] In the Australian context, the Australian Government released in 2015 the *Australian Government Public Data Policy Statement*. The Policy Statement states: "The Australian Government commits to optimise the use and reuse of public data; to release *non sensitive* data as open by default; and to collaborate with the private and research sectors to extend the value of public data for the benefit of the Australian public. Public data includes all data collected by government entities for any purposes including; government administration, research or service delivery. Non-sensitive data is anonymised data that does not identify an individual or breach privacy or security requirements." (emphasis added).

See https://www.pmc.gov.au/sites/default/files/publications/aust_govt_public_data_policy_statement_1.pdf, accessed August 2018. See also the Policy Statement on F.A.I.R. Access to Australia's Research Outputs, at https://www.fair-access.net.au/, accessed August 2018.

[16] Note that this recommendation does not presume that an open data approach will be appropriate in all cases. Rather, it is recommended as a useful conceptual starting point so that the case for confidentiality requirements can be re-evaluated and transparently made.

[17] See http://ec.europa.eu/agriculture/rica/, accessed August 2018.

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Chapter 12.

Case Study 7. Data transparency, digital technologies and California's water quality coalitions

The objective of this case study is to give a practical example of how data regulations and coalition-based water quality monitoring regimes can be used to underpin collective governance mechanisms to address nonpoint source environmental impacts from agriculture. These mechanisms strike a balance between lessening information asymmetries and gaps on the one hand, and protecting sensitive information and reducing regulatory burden on the other.

Context: The policy environment

California agriculture is extremely diverse, producing more than 400 commodities and spanning a wide array of growing conditions from northern to southern California. The state produces nearly half of US-grown fruits, nuts and vegetables, as well as exporting many agricultural products to markets worldwide. However, water discharges from agricultural operations (including irrigation runoff, flows from tile drains, and storm water runoff) can affect water quality by transporting pollutants, including pesticides, sediment, nutrients, salts (e.g. selenium and boron), pathogens, and heavy metals, from cultivated fields into surface waters. Many surface water bodies are impaired because of pollutants from agricultural sources. Groundwater bodies have suffered pesticide, nitrate, and salt contamination.

To prevent agricultural discharges from impairing receiving waters, the Californian Irrigated Lands Regulatory Program (ILRP) regulates nonpoint source discharges from irrigated agricultural lands. This is done by issuing waste discharge requirements (WDRs) or conditional waivers of WDRs (Conditional Waivers) to growers or groups of growers called Coalitions. Both WDRs and Conditional Waivers contain conditions requiring water quality monitoring of receiving waters and corrective actions when impairments are found. Further conditions require monitoring of agricultural runoff and impose reporting requirements – for example reporting on management practice implementation and nutrient application data (California Water Board, 2018). Enrolment in the ILRP is around 40 000 growers, or 6 million acres of agricultural working lands.[1]

Sections 13263 and 13241 of the Californian Water Code state that "economic considerations" is one of the factors a regional water board must take into account in issuing waste discharge requirements. Additionally, section 13267 requires the regional water board to ensure that "the burden, including costs, of [monitoring] reports shall bear a reasonable relationship to the need for the report and the benefits to be obtained from the reports." (State Water Board, 2018, p. 10[1])

Refining data transparency requirements and use of digital technologies to deliver better outcomes for agricultural producers and water quality

The problems

The California State Water Resources Control Board's (State Water Board) Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program[2] (Nonpoint Source Policy) directs that any nonpoint source programme incorporate monitoring and reporting. The Nonpoint Source Policy "does not require any particular framework for monitoring and does not necessarily even require comprehensive ambient monitoring. But the nonpoint source implementation programme must 'include sufficient feedback mechanisms so that the [regional water board], dischargers, and the public can determine whether the programme is achieving its stated purpose(s), or whether additional or different [management practices] or other actions are required".

This requirement to undertake monitoring of agricultural runoff and receiving water bodies and reporting constitutes an effort to reduce *information gaps* about the quality of these waters, as well as the impact of agriculture on water quality. This data is crucial for the California Water Boards to achieve their mission "to preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and to ensure proper water resource allocation and efficient use, for the benefit of present and future generations" (State Water Board, n.d.[2]).

However, these requirements are controversial to the agricultural community because they are *costly to comply with* and result in lessening of *information asymmetries* that producers may have incentive to maintain. Such incentive may occur for several reasons. One reason is that certain high-risk operations are subject to more rigorous management practices to minimise pollutants found in agricultural runoff and percolating water are required to address toxicity in receiving waters and nitrate associated with the over-application of fertilisers that has contaminated drinking water; since these additional requirements are costly, a producer may wish to avoid being identified as one of these high-risk operations. Another reason is that reporting on management practices risks disclosure of information that producers consider to be commercially sensitive. Finally, producers may be concerned that improved data on agricultural water quality impacts could be used to tighten regulations in future, resulting in increased regulatory burden and potentially negatively impacting the viability of agriculture in the region.

Therefore, the challenge for California Water Boards, who acknowledge the "critical importance" of agriculture in the region (Karkoski, 2012[3]), is to balance "the need for transparency and measurable benchmarks" and maintaining acceptable regulatory outcomes on the one hand with ensuring regulatory burden is minimised and respecting "the need for the agricultural community to protect trade secrets and other sensitive information" on the other (State Water Board, 2018[1]). This challenge is not unique to this context; it arises from the characteristics of existing agricultural production, which uses agricultural inputs (e.g. fertiliser and pesticides) and commercially sensitive information (e.g. fertiliser application regimes) to produce valuable outputs, but which also produce environmental externalities that are costly to address.

The solutions

The Water Boards have devised a monitoring and reporting regime which aims to provide data for the required "sufficient feedback mechanisms", while minimising regulatory burden and risks for producers related to information disclosure. This case study uses the example of the monitoring and reporting regime of the Central Valley Water Board, one of nine regional water quality control boards. The regional water boards operate semi-autonomously and are divided by watershed. The State Water Board works with the regional water boards and sets state-wide standards and policies. The jurisdiction of the Central Valley Water Board covers over seven million acres of irrigated agricultural land (Wadhwani, 2018[4]). The Central Valley Water Board's regime comprises:[3]

- The use of *water quality coalitions to act as intermediaries* between growers and the regulator (in this case, the East San Joaquin Water Quality Coalition[4]).
- *Data transparency requirements* which incentivise growers to participate in the coalitions.[5]
- A *representative approach* to water quality monitoring (Box 13.1).
- Mandated and voluntary use of *digital tools*, including e-reporting and publicly-accessible data repositories,[6] to *minimise costs* of data collection and reporting requirements.

Box 12.1. The representative approach to water quality monitoring in Eastern San Joaquin

The Eastern San Joaquin Agricultural General WDRs do not require water quality monitoring of discharges coming off the farms, but require monitoring in the receiving waters. The watershed is divided into six zones. Two "core" sites and several "represented" sites are designated in each zone. According to the General WDRs, the represented sites are sites with characteris

tics similar to the core sites such that a water quality issue detected at the core site may be an indication of a similar issue at a represented site. The two core sites are continuously monitored on an alternating basis. An exceedance at a core site triggers the requirement to monitor at the represented sites within the same zone…

[The State Water Board] presented the question of the appropriate surface water quality monitoring framework to the Agricultural Expert Panel. The Agricultural Expert Panel agreed [in its final report, released in 2014] that monitoring of surface water discharges from individual fields or farms is costly and complicated, as well as subject to serious challenges in identifying the appropriate timing for periodic sampling and coordinating with shifting field crew operations, pesticide applications, and sediment runoff events, and with schedules for lab operations…[The State Water Board] continue[s] to believe that receiving water monitoring is generally preferable to field-specific surface water discharge monitoring in irrigated lands regulatory programmes for the reasons articulated by us in Order WQ-2013-0101 and by the Agricultural Expert Panel. Receiving water monitoring is a reliable and effective methodology for identifying water quality issues without resorting to more costly end-of-field measurements.

Source: State Water Board (2018, pp. 53-57[1]).

Recent review of monitoring and reporting regime

In February 2018, the State Water Board adopted Order WQ 2018-0002, which amends and updates the Waste Discharge Requirements (WDRs) General Order No. R5-2012-0116, the WDR for growers within the Eastern San Joaquin River Watershed that are Members of a Third-Party Group. The final Order was the result of an extensive consultation process that commenced with the release of a first draft for consultation in February 2016.

Order WQ 2018-0002 "directs a number of revisions, primarily to add greater specificity and transparency in reporting of management practice implementation, to require reporting of certain nitrogen application-related data needed for management of excess nitrogen use, and to expand the surface water and groundwater quality monitoring programmes of the General WDRs (State Water Board, 2018, p. 1[1]).

The review process covered many complex and specific concerns raised by stakeholders and State Water Board staff. However, at the heart of the review is the broad question whether the existing regime strikes the appropriate balance between providing sufficient data to evaluate the ILRP and ensuring that the burden of monitoring regime for growers satisfies the test of bearing a reasonable relationship to the need for and benefit of monitoring.

In theory, various institutional, legal or technological factors could contribute to a decision to change the existing regime, for example:

- Evaluation of existing data provided by monitoring may lead to the conclusion that the *existing monitoring regime is inadequate* in some respect(s), thereby motivating change to ensure provision of sufficient information to effectively evaluate the programme.
- Changes in the cost of the monitoring regime due to *technological innovation* (e.g. lower cost water quality sensors, new digital technologies for recording, sharing or analysing data) could reduce the regulatory burden of monitoring for growers, leading to a re-balancing of monitoring requirements.
- *Methodological innovations* (i.e. innovation in approaches to measuring nitrate losses from agriculture) could lead to a change in the monitoring approach towards using new and improved methods.
- Evaluation of the existing third party-based mechanism may reveal *unintended consequences* that need to be addressed.

In practice, all four of the above factors are present in the State Water Board's explanation of the changes embodied in Order WQ 2018-0002, albeit in differing degrees.

Methodological innovation was perhaps the most important factor underpinning changes directed in the Order. In particular, the Order implements a recommendation from the Agriculture Expert Panel (Box 12.1) to introduce a new indicator for monitoring potential nitrate impacts from agriculture: the *AR metric* (Box 12.2). This metric is considered scientifically robust and less prone to misinterpretation; both key factors underpinning the decision to require de-identified field-level reporting of AR data.

In response to concerns expressed by some stakeholders (the "Environmental Petitioners") that the existing monitoring regime is inadequate,[7] the State Water Board directed several revisions to data reporting requirements, in particular:

- To require more granular, anonymous field-level reporting of growers' land management practices and nitrogen application (related to the AR metric) to the Central Valley Water Board.
- Expansion of the requirements currently imposed only on Members in high vulnerability groundwater areas on all Members, with some limited exceptions.

Box 12.2. The AR metric

Wadhwani (2018, pp. 245, 249-251[4]) *provides an overview of the AR metric and its anticipated benefits*

A comparison of the nitrogen-applied [A] with the nitrogen-removed [R] for each field provides a reasonable estimate, even if not precise indicator, of the nitrogen left in the soil that has the potential to percolate to groundwater in the form of nitrates. Minimizing that difference—which can be measured as a ratio (nitrogen applied over nitrogen removed or A/R) or a subtraction (nitrogen applied minus nitrogen removed or A-R)—also minimises the nitrogen left in the soil and consequently the nitrate that may reach drinking water…The A/R and A-R metrics [are referred to] collectively as the "AR metric" and the underlying data as the "AR data"…

The AR metric is an indicator of the amount of nitrogen in the soil that could potentially reach groundwater as nitrate. Over the next several years, as the regional water boards gather the field-level AR data, the data will be analysed to determine ranges of the AR metric for each crop that represent acceptable values to support crop growth, but minimise nitrogen left in the soil. The AR metric ranges will be crop-specific and measured over multiple crop cycles and may be further refined over township-level data.

Ultimately, the availability of field-level AR data means that the regulatory agencies, research institutions, growers, and public can begin to evaluate what levels of nitrogen application are compatible with safe drinking water and translate that knowledge into improved management practices for particular time for different conditions such as irrigation methods and soil types. Given the challenges of groundwater quality monitoring for evaluating the effectiveness of nitrogen application practices, development of the AR metric ranges currently represents the most promising methodology for fair and even-handed evaluation of efforts to minimise the potential for nitrates to reach groundwater. Significantly, development of the AR metric ranges requires access to the database of field-level data, including field-level values for nitrogen applied, nitrogen removed, and crop type, but not the names and locations associated with that data…

…While AR metric ranges must be based on several years of data, the field-level AR data also supports immediate efforts to reduce the potential for nitrates to reach groundwater. Each grower will have information on how his/her nitrogen application compares to other growers planting the same crops. For any given year, the regional water boards will be able to work with the coalition to identify a set of outliers for each crop and require the coalition (which will have identifying grower name and location information for each field) to follow up with those growers…

… With the requirement for submission of field-level AR data, the Agricultural Order also ensures that…township-level analyses will be fortified by the ability of the more granular field-level data to identify and address over-application of nitrogen in "hot spots" that might otherwise be obfuscated by the averaging effect of growers or categories of growers.

Despite concerns raised by some stakeholders, the State Water Board continued to support the representative monitoring approach in principle, considering monitoring farm discharge points as "impractical, prohibitively costly, and often ineffective method for compliance determination". Changes in the cost of alternative monitoring regimes due to technological innovation were not a major factor evident in the State Water Board's explanations for the directed changes to the monitoring regime, although the changes in regulatory burden (transaction costs) associated with these changes was considered. Thus, despite suggestions in the relevant literature that the cost of wireless water quality sensor networks has declined sufficiently in recent years to make monitoring water quality on-farm a potentially feasible option (or, at least, for high-density network of nodes throughout a catchment—see, for example (Ruiz-Garcia et al., 2009[5]; Zia et al., 2013[6])),[8] at least in this context this does not yet appear to be the case. Nevertheless, the State Water Board directed the Central Valley Water Board to "implement a public external expert review process to evaluate the existing monitoring and assessment framework and make recommendations for improvements or corrections if needed". This evaluation could explore whether the changes in the costs of different monitoring approaches due to technological innovation are or foreseeably will be sufficient to motivate a shift away from the representative monitoring approach in future; however, given the introduction of the *A/R metric* as the key indicator for potential nitrate impacts from particular fields, it seems unlikely that a shift towards use of *on-farm* wireless water quality sensors is imminent.

As stated previously, the State Water Board continues to support the third party (coalition-based) approach. However, it recognises that "concerns with privacy and protection of proprietary information may create strong incentives in support of a framework where the third party retains most information on farm-level management practice and water quality performance rather than submitting that information to the regional water board and, by extension, making it available to the public" (State Water Board, 2018, p. 21[1]). This finding suggests several possible unintended or undesirable consequences of supporting the third party mechanism. First, this support could be seen as legitimising the view that growers have some kind of "right" to confidentiality. Second, the third party may encounter a conflict of interest in that, on the one hand, it needs to report "sufficient" detail to the regulator (which may include farm-level data and even potentially data which identifies individuals), but on the other hand, its members favour reporting of aggregated data only. While the State Water Board has been careful to clarify that it does not recognise any right to privacy in relation to field level data,[9] grower submissions during the consultation process cited an expectation of confidentiality for growers participating in coalitions (Agricultural Council of California et al., 2017[7]), and thus the regulator needs to be continually attentive to these issues and ensure that there is appropriate regulatory oversight of the third party.

Lessons learned

Lesson 1. Well-constructed data transparency requirements can provide incentive for farmers to participate in collective mechanisms to improve water quality

In the case study context, if growers do not opt to join a coalition, individual data reporting requirements apply. Thus, this regulatory mechanism leverages growers' preferences to maintain privacy to incentivise participation in collective governance mechanisms (in this case, the coalitions). This incentive can be reinforced by the use of digital tools customised for the coalition's use to further lower the transaction costs of reporting data via the coalition.[10] However, regulators seeking to use this approach need to be mindful of (perhaps tacitly or inadvertently) supporting or creating expectations of maintaining confidentiality of farm-level data. Regulators should make clear the circumstances under which anonymised and identified farm level or individual data will be reported to the regulator or made available to the public, and provide for adequate regulatory oversight of the collective entity.

Lesson 2. Digital tools are only one part of a broader approach, and the approach shapes which digital tools are needed

This case study makes clear that data reporting and transparency requirements are the main tool via which compliance with legal requirements, and programme evaluation, are undertaken. However, the fact that data is required to be reported in digital format and (in some cases) using digital tools such as geographic information systems (GIS) means that digital technologies actually underpin the data reporting system. The choice of the representative monitoring system by the State Water Board, together with the new A/R requirements, influence which types of digital tools are needed: in particular, this system relies on digital platforms into which data is entered manually by Coalition employees or is gathered automatically from Coalition administrative systems, and from which data can be made publicly available. There is less focus on the use of digital technologies to *gather* primary data (see also Lesson 3).

Lesson 3. Even with the declining cost of sensors, the "representative monitoring" approach is currently considered the most cost-effective

As noted above, throughout the review process the State Water Board continued to support the representative monitoring approach in favour of what it considers to be a prohibitively costly on-farm monitoring alternative. It remains to be seen whether, during the independent evaluation of the monitoring system, innovative technologies such as low cost wireless sensor networks are considered to be a cost-effective option in this context. While the introduction of the AR metric may preclude demand for use of digital technologies to estimate edge-of-farm nutrient loads, digital technologies including remote sensing technologies and ambient water quality sensor networks may yet prove to be worthwhile additions to the monitoring framework.

Notes

[1] Adapted from: https://www.waterboards.ca.gov/water_issues/programs/agriculture/, accessed August 2018.

[2] See http://www.waterboards.ca.gov/water_issues/programs/nps/docs/plans_policies/nps_iepolicy.pdf (accessed August 2018, AR 36138-36157).

[3] In this case, the State Water Board adopted precedential components with direction for the programme, but the Regional Water Boards must adopt those requirements into their own orders for the growers in their Regions before the growers must comply with those requirements.

[4] See https://www.esjcoalition.org/home.asp, accessed August 2018.

[5] "On 22 June 2006 the Central Valley Regional Water Quality Control Board adopted a Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands for Individual Dischargers, which took effect on 1 July 2006. The waiver for Individual Dischargers, amended order number R5-2006-0054, sets forth the requirements for individual dischargers participating in the Irrigated Lands Regulatory Program. Dischargers enrolled under the Conditional Waiver for individuals must also comply with Monitoring and Reporting Program Order No. R5-2003-0827". This regime requires Individual Discharges to report directly to the regulator (Central Valley Regional Water Quality Control Board, n.d.[8]).

However, "[t]o take advantage of local knowledge and resources, leverage limited regulatory resources, and minimise costs, the Central Valley Water Board allowed growers to form *discharger coalitions*, with a third-party representative responsible for grower outreach and education and for implementation of a number of the requirements of the regulatory programme, including representative monitoring" (State Water Board, 2018, p. 21[1]) (emphasis added)

[6] The Eastern San Joaquin Agricultural General WDRs require entry of surface water quality data collected under the General WDRs into CEDEN and groundwater quality data collected into GeoTracker. CEDEN is the State Water Board's data system for surface water quality in California.

GeoTracker is a state-wide database and geographic information system that provides online access to environmental data (State Water Board, 2018, p. 21[1]).

[7] The environmental petitioners considered that the existing regime is deficient in two respects: (i) "there is insufficient disclosure and transparency with regard to the management practices being implemented on the ground by the Members [growers] because only limited, aggregated data must be reported regarding such practices"; and (ii) "the representative and regional monitoring programme does not produce specific enough data to determine if any of the implemented management practices are in fact leading to meeting water quality requirements" (State Water Board, 2018, p. 22[57]).

[8] For example, Ruiz-Garcia et al. (2009[5]) state that Wireless Sensor Networks have "become an important issue in environmental monitoring. The relatively low cost of the devices allow the installation of a dense population of nodes that can adequately represent the variability present in the environment."

[9] The Order states "[t]o the extent we recognise the incentive privacy provides growers to join coalitions, nothing in this order should be construed as recognizing any right to privacy of the specific field-level data and regional water boards retain flexibility provided by this order." (State Water Board, 2018, p. 22[1]). The State Water Board also stated that "we believe and emphasise that third parties serve an extensive set of functions for growers beyond the maintenance of confidentiality, and we are not persuaded that the maintenance of confidentiality, in and of itself, is a legitimate goal of a regulatory programme that must have transparency and accountability to the public" (State Water Board, 2018, p. 47[1]).

[10] While of course it is possible to design digital tools for individual reporting, the point here is that exploitation of synergies between data reporting rules and use of digital tools can *create* incentives for individuals to participate in the collective mechanism.

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Chapter 13.

Case Study 8: Estonia e-government and the creation of a comprehensive data infrastructure for public services and agriculture policies implementation

The case study objective is to give a practical example of how a government can build data infrastructure for the provision of public services, including the registration and payment of subsidies in the agriculture sector. The case of Estonia is of particular interest as 99% of their public services are accessible online via a one-time login gateway.

Review of the e-Estonia initiative and its use for agriculture policy implementation

The following is based on interviews with Oliver Väärtnõu, CEO of Cybernetica, a private company which has been developing the data infrastructure for the Estonian Government, and Mr Ahti Bleive, Deputy Director, Estonian Agricultural Registers and Information Board (ARIB – Estonian Paying Agency) Estonia, and responsible for the project SATIKAS that will enable to verify whether the grasslands have been mowed by using satellite data. Along with processing applications for aid, one of ARIB's duties is to maintain national registers – the register of farm animals and the register of agricultural support and land parcels. The study has benefited from on-line information about the e-Estonia initiative.[1]

The creation of a digital infrastructure in Estonia

The development of the Estonian e-Government is based on the Principles of the Estonian Information Policy, adopted by the Estonian Parliament in 1998. Through this, the government initiated a digital transformation to increase efficiency of its processes as well as how efficiently it delivers public services. In addition to a full coverage for digital mobile phone networks in the country[2] and ensuring a secure data exchange environment, the Estonian government made two critical technology choices, which supported this digital transformation and referred to as *interoperability enablers*.

The first was the choice to create, early on, a digital identity (ID-card). This ID-card was made compulsory and was considered as a way to recognise individuals in the digital world, being the key allowing the real world to match the digital. The card is issued by the government and was made a mandatory document. The adoption was also facilitated by Estonian banks, which heavily invested in e-Banking and were using the e-ID card as a way to access their services. The system is based on cryptographic keys, with a personal key, which used as the primary key in the majority of databases containing personal information. In particular, it can be used in the *public key infrastructure (PKI),* for authentication and signatures identification. The state undertakes to assure the existence and functioning of the public key infrastructure.

- The Police and Border Guard Board is issuing personal (digital) identity documents enabling secure electronic authentication and digital signing (ID-card or another smart card).
- The Ministry of the Interior drafts legislation that determines the types and requirements for the digital identity documents.
- The Information System Authority (RIA) develop software applications necessary for using the PKI (ID-card middleware including drivers, utility and client software).
- Ministry of Economic Affairs and Communications (Department of State Information Systems): determines the quality.

eID-cards can also be stored on smartphones using a special SIM card enabling the use of a mobile ID. In Estonia, a digital signature has similar juridical power than a written one.

The second choice was to develop the X-Road, the data management infrastructure. In the name of efficiency, data management is often centralised, meaning putting all the data together in a single digital facility. Such option has the advantage to facilitate access to data and to be cheaper. This is the reason why small countries usually decide to adopt such systems. However, it also create vulnerabilities and increases the risks: hackers would only have to attack one facility to access all data, making it a potentially lucrative exercise.

Estonia innovated in choosing a decentralised system. However, such systems are usually confronted by issues of inter-systems connectivity, resulting in duplication of data storage or harvest when sharing is not possible, ultimately resulting in higher costs. To solve and avoid those constraints, the Estonian government innovated, in a decentralised *linked* government data infrastructure, the XRoad. To make sure that government bodies would all adopt this strategy, a law was passed stipulating that the same information should not be asked twice. Agencies looking for some information should go directly to the agency holding the data.[3] This access is secured by cryptography and information about the exchanges is referenced.

The proof of concept was tested in 2004 and then they started building the ecosystem. The first application was internet voting in 2005. The uptake slowly increased. In 2015, 19.6% of the eligible voters voted on-line, representing 30.5% of the participating voters. In March 2019, the numbers were 27.9% and 43.9%, respectively.[4] Also, votes can now be made from anywhere in the world. In 2015, votes were received from 116 countries. In 2019, it reached 143 countries.

Box 13.1. Some figures about costs and benefits of digitalisation in Estonia

Digital transformation is an overarching process. It started in Estonia with first applications early 2000 and Estonia's administration applies a principle of digital-by-default. It is therefore difficult to extract some distinct comparative figures about the cost benefit of this process. However, a few indicators are available: 99% of Estonia's public services are online, 98% of Estonian nationals use eID-s, which are used to produce more than 10 million digital signatures per year. The use of the data exchange layer, X-Road, saved Estonian administration 804 working years compared to previous calendar years and it is estimated that using the electronic signature saves 2% of the Estonian GDP each year. The ICT sector forms about 7% of Estonia's GDP.

On the cost side, Estonia spends approximately 1.1% to 1.3% of the state budget on digitalisation. The actual need is around 1.5%. In comparison, the same number in Finland is 1.4% but in Denmark is 2.4%.

Source: https://www.x-tee.ee/factsheets/EE/#eng.

Application in the case of agriculture policy and regulations

The Estonian paying agency has been using satellite imaging and remote sensing since 2005. Controls were then increasingly automatised from 2011, before Sentinel data arrived and provided more detailed images. Access to data from Sentinel allowed further automation of processes. Automation of processes is mostly for mowing requirements, specifying that mowing has occurred before or after certain dates. While more flexibility might be provided to this requirement to match environmental realities better (see case study on meadow birds' supervision) mowing data is a requirement that is often violated. Accordingly to EC requirements EU-wide, only 5% of fields are physically checked on site by controllers. With remote sensing and automation of processes, this percentage reaches 100%, meaning that all the monitoring can now be done remotely, by detecting the changes in biomass. Information is based on GIS data, entered by the farmers and checked by the agency availing it to all farmers registered.

Beyond this example a broader range of digital services are now available to farmers, including digital registers. For instance, farmers can provide information about birth of an animal, whether they are moving their pack, etc. In other words, all types of information that previously had to be recorded on paper can now be recorded on line.

Table 13.1. Uptake of the animal register e-services since 2006

	Documents		Events	
Year	% E-service	% Paper based	% E-service	% Paper based
2006	0.42	99.58	2.37	97.63
2007	7.00	93.00	19.23	80.77
2008	13.50	86.50	31.13	68.87
2009	21.36	78.64	42.03	57.97
2010	28.53	71.47	53.17	46.83
2011	36.10	63.90	60.74	39.26
2012	40.96	59.04	66.74	33.26
2013	44.52	55.48	69.39	30.61
2014	48.40	51.60	73.29	26.71
2015	51.74	48.26	76.85	23.15
2016	55.44	44.56	80.60	19.40
2017	60.36	39.64	85.68	14.32
(12.08.) 2018	64.35	35.65	88.85	11.15

Note: Documents can be birth or veterinary certificates. Events can be the movement of the pack to another location, etc.
Source: Communication from the Estonian Agricultural Registers and Information Board.

In order to support the shift from paper to digital, the government launched different advertising campaigns to communicate its advantages to farmers, including a more rapid identification and treatment of errors. Advice services explaining how to fill documents on line are free and was very welcomed by farmers. The system relieved farmers from some administrative burden and from the potential time previously needed to rectify errors in the documentation when occurring. In addition, as administrative processes are managed faster, payments are more rapidly transferred to farmers.

The LPIS (land parcel identification system) and animal data are also used by statistical offices and for the cadastre system as well as by the environment agency, allowing conducting cross checks with different agencies. For example, in the case of investment measures, it is possible to check whether the applicant is in debt or has taxation problems. In general, this system is well accepted as most of the time, its purpose is to provide support. In the case of the environment ministry, the administration can get access to useful information on livestock systems, and in particular on manure.

Ministry of Rural Affairs has initiated a feasibility study for development of agricultural big data system. The aim is to create a central electronic system to link and integrate existing data with analytical models and practical applications. Data linked in this system must be harmonised, compatible, updated, linked to spatial data, transferable from the producer to the system and from the system to the producer enabling access to potential models/applications.

The system will provide useful practical information flow for the farm management decisions (e.g. machine-readable data for the precision farming machinery). The system will also enable to collect more precise farm data with less effort. This improves the quality of statistical data and enables more comprehensive analyses.

The study includes the assessment of the needs and roles of stakeholders, assessment of data storage systems and evaluation of existing data quality. The proposed concept of the big data system will include the technical, legal and economical analyse and the roadmap for implementation of such system. The project includes trainings for the farmers to explain the potential of the use of big data for farm management decisions, to introduce the practical applications and models for that purpose and to demonstrate the technologies for precision farming.

This one-year duration project started in September 2018. The next phase will be the implementation of the system based on the results of the feasibility study.

Lessons learned from the development of a government data infrastructure and use in agriculture

Efficiency gains for both citizens and the government is the objective of the digitalisation of government services in Estonia. This infrastructure was not implemented in a piece meal manner, and rather was built as a comprehensive, open but secured and flexible way. The lessons learned in this case study are more about the questioning and elements to consider when creating such infrastructure. The implementation was successful, but was nevertheless confronted by challenges, which can serve as learning material for other OECD countries.

Lesson 1. The implementation of Estonia data infrastructure required the government to rethink the way it was operating, as well as its role and what problems the previous government administration organisation was facing

One of the first questions was about the way to create interoperability between government agencies, previously operating in silos and with their own system. It was important to ensure the protection of government data and who had access to it. Estonia dealt with such problems using a decentralised system and cryptography, but also by using the blockchain. All information about any request for information is registered on the blockchain and citizens are able to check who, and when, accesses their data.

The other question was how to make government data more useful to citizens and in the case explored here, to farmers. If the role of the government is to gather relevant information for the use of policy implementation, is it also the role of the government to expand their database to information that is not directly of use to the government but can be for farmers when combined with government data? Enabling private sector access to government data brings the questions of data ownership. However, in practice, the question is more about data use and what data will be used for then about data ownership. It is envisaged that in Estonia, the data management system could be based on an agreement per data type by farmers. The data infrastructure created by Estonia, clearly identifying who accessed data could enable the creation of such system.

Lesson 2. The creation of a data infrastructure requires creating a setting and a regulatory environment guaranteeing trust in the new system

Data security is taken very seriously in Estonia and is considered to be the most important feature allowing the Estonian digital society to function. Anyone with a social security code can look up their information online, see who has accessed their data and when. It is also possible to ask about any single query, which allows for a higher trust in the services. The rare occurrence of data privacy violation have been treated as important offences to serve as a deterrent.

- Legislation including a range of acts created the core principles of the development of the Estonian e-government. Some were adopted by the Estonian parliament as early as in 1998, then reviewed and updated in 2006 in the course of preparing the Estonian Information Society Strategy 2013 Public Information Act
- Digital Signatures Act
- Archives Act
- Population Register Act
- Identity Documents Act
- Personal Data Protection Act
- Information Society Services Act
- Electronic Communications Act
- Public Procurement Act
- State Secrets and Foreign Classified Information Act

One of the core principles is that the public sector is leading the way for the development of what is more broadly referred to as the *information society*, but developments are in co-operation between the public, private and third sector. Therefore, and in order to reassure the Estonian society about the use of their data, a range of acts have been passed to ensure the protection of fundamental freedoms and rights, personal data and identity. In particular, individuals are the owners of their personal data and they have an opportunity to control how their personal data are used.

Lesson 3. Providing the right incentives with flexibility to implement change and avoid barriers to adoption, both within the government and between the government and citizens

In Estonia, the regulatory environment has been used to set the incentive for the implementation and use of the e-government by government agencies, by centralising policy development, letting the Ministry of Economic Affairs and Communication develop the principles of information policies and supportive legislation, also taking responsibility for supervision of relevant state organisations starting from 1993. Then the implementation was decentralised, with e-Government developments done mainly by responsible ministries and state agencies. Accordingly, every government department, ministry or business, gets to choose its own technology, based on commonly agreed principles.

It appears that in the case of Estonia, there have been few barriers to adoption, whether from the institutional side or from the users. Various reasons explain this, including the population size making implementation more straightforward and communication about initiatives more efficient. On the agriculture side, the fact that data provided by farmers is used to provide support, and not only, like in other countries, to verify that farmers comply with regulations, had an important role in the level of adoption. But so did the support to farmers in getting to know the platforms and the additional on-line services compared to paper-based communication (revision of documents, etc.) provided by government bodies.

Notes

[1] E-Governance in practice, https://ega.ee/wp-content/uploads/2016/06/e-Estonia-e-Governance-in-Practice.pdf

[2] 100% advanced 3G mobile broadband coverage.

[3] This is a principle that also applied in the European Commission: the “once only” principle.

[4] https://www.valimised.ee/en/archive/statistics-about-internet-voting-estonia

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Chapter 14.

Case Study 9: Connecting the dots to create a data infrastructure: The US National Soil Moisture Network

The objective of this case study is to provide the example of the National Soil Moisture Network (NSMN) initiative in the United-States, which intends to address the fragmentation and heterogeneity of data coverage for the tracking of soil moisture. Its intent is to combine data from satellites with the data captured from state level in situ networks, to build a national inventory that can inform policy management and decisions.

Context: Disconnect between different layers of data about soil moisture in the United States prevents their reuse for comprehensive water policies

Soil moisture matters to inform policy makers

Soil moisture is an important element for the assessment of water use and water demand. Soil moisture data are critical for assessing:

- Drought conditions and operational drought monitoring
- Flood forecasting
- Land surface modelling (Component in weather and climate models, to simulate the exchange of surface water and energy fluxes at the soil–atmosphere interface.)
- Crop yield estimation
- Water supply forecasting
- Operational hydrologic models
- Weather forecasting

Mesoscale in situ meteorological observations provide the data used for weather and climate forecasting and decision-making.[1] The data they create are essential to a large range of stakeholder communities. These include state environmental and emergency management agencies, water managers, farmers, energy producers and distributors, the transportation sector, the commercial sector, media, and the general public (Mahmood et al., 2017[1]).

The history of the development of soil monitoring in the United States

Two types of technologies are used for the monitoring of soils water content in the United States. The first system relies on direct in situ instruments; the second relies on remote sensing. Each approach has strengths and weaknesses, and each was designed and has evolved to meet specific purposes and goals.

The in-situ monitoring of surface soil moisture in the United States is not new. The first surface weather observations began on the East Coast in the late seventeenth century (Fiebrich, 2009[2]). Those sparse initiatives were then organised into a network of volunteer weather observers by the Smithsonian Institution, following the Surgeon General, army, and General Land Office request for regular observations at widespread locations.[2] From the 1970s, technological improvement allowed the process of automation of weather data collection with the development of sensors and multiple-function data processors at remote sites. Cellular and satellite communication systems also allowed for a more rapid transfer of information. Developments ultimately lead to the creation of automated weather networks, continuously providing data, such as soil moisture and temperature enabling near-real-time decisions. Those systems rely on sensors which provide instantaneous estimates of soil moisture at discrete depths, but also can provide event detection, event ID, location sensing, and local control of actuators (devise responding to a digital signal, for instance a valve in an irrigation system). As technology continues to progress, the concept of micro-sensing and wireless connection of these nodes promise many new application areas, including the monitoring of environmental conditions and precision agriculture.

Most data used by researchers are still mostly at the 30 km scale. Those mesoscale networks, also called mesonets, were principally resulting from initiatives at the State level.

Their coverage across the United States is different in intensity, but also in nature and were developed for specific diverse purposes. In addition, some of those networks operate on a fee basis to fund themselves in part or in whole.

Table 14.1. Statewide mesonet

State	Network	Total number of real-time stations
Alabama	North Alabama Climate Network	22
Alabama	University of South Alabama Mesonet (CHILI)	25
Arizona	Arizona Meteorological Network	21
Arkansas	Arkansas State Plant Board Weather Network	50
California	California Irrigation Management Information System	152
Colorado	Colorado Agricultural Meteorological Network	75
Delaware	Delaware Environmental Observing System	57
Florida	Florida Automated Weather Network	42
Georgia	Georgia Automated Weather Network	82
Illinois	Illinois Climate Network	19
Iowa	Iowa Environmental Mesonet	17
Kansas	Kansas Mesonet	51
Kentucky	Kentucky Mesonet	66
Louisiana	Lousiana Agroclimatic Information System	9
Michigan	Enviroweather	82
Minnesota	Minnesota Mesonet	8
Missouri	Missouri Mesonet	24
Nebraska	Nebraska Mesonet	68
New Jersey	New Jersey Weather and Climate Network	61
New Mexico	New Mexico Climate Network	6
New York	New York Mesonet	101
North Carolina	North Carolina ECONet	40
North Dakota	North Dakota Agricultural Weather Network	90
Oklahoma	Oklahoma Mesonet	120
South Dakota	South Dakota Mesonet	25
Texas	West Texas Mesonet	98
Utah	Utah Agricultural Weather Network	32
Washington	Washington AgWeatherNet	176
Total		**1 619**

Source: Mahood et al (2016).

While those networks are useful for some of applications, the understanding of a range of natural phenomenon requires a broader coverage, national if not beyond borders. In addition, the understanding of the dynamics of soil moisture requires more information than soil moisture data point estimates. It requires knowledge about soil characteristics, not only surface composition, but also composition across multiple soil depths, weather patterns, and land use information. These data layers are available but in disparate data networks and from different sources.

More recently, capacities have increased, in particular in the context of the development of new data storage, processing and aggregation capacities (big data). Today, sensors networks are more than networks creating data. Their use relies on algorithms and communication protocols. Data layers captured by sensors networks are compiled with other data to make predictions and support decision making of a range of stakeholders, from farmers to policy makers. For example, a range of environmental conditions, including information about soil moisture and nutrients, can be combined by an algorithm to estimate crop health and production quality over time. The more precise networks, such as wireless sensors networks (WSN), providing data at the farm level, can be integrated into decision systems for precision agriculture or water management. For example, a sensor can measure levels of humidity and be linked to an actuator responsible for opening an irrigation valve.

The other technology available is remote sensing, which presents the advantage of allowing contiguous data coverage across the United States.

The use of digital technologies to improve the coordination and use of soil moisture data

The problem

While a large amount of data exists and could support researchers and policy makers, it is not used to its full potential.

Sensors networks developed at the farm level are the only one providing information at a level of granularity fine enough for farmers to use for decision making, analysis and monitoring of soil moisture on farm. However, those are often private and systems are proprietary. In addition, the data is considered[3] as belonging to either the farmers or the company providing the service and therefore not easily accessible by other stakeholders, including researchers and the government.[4]

At the level of mesonets (States), many in-situ sensors networks have been developed in the United States, but they are distributed unevenly, with some geographic areas being more densely covered than others. In addition, they are not always publically accessible and protected by paywalls. Finally, remote sensing data is gaining in popularity now that multiple high quality platforms are providing near daily products. However, data provided is still at a coarse resolution. Models can also be used to provide better spatial coverage, but they are limited by input data layers (primarily precipitation) and have water budget closure issues. Indeed, many factors influence how soil moisture varies, including soil properties, topography, vegetation, land cover or land use and climate.

The production of an accurate representation of soil moisture at an informative scale enabling policy management and monitoring and with regular coverage and comparative data on conterminous United States the 48 adjoining States plus Washington, DC on the continent of North America (CONUS) has been a challenge. This was the result of a lack of technical capacity (data processing and management) but also of the existence of parallel independent and non-coordinated developments of networks across the United States. Consequently, soil moisture observations have been poorly integrated into assessments of vulnerability, for instance early warning systems for droughts and floods.

The central issue is the traditional investment behaviour conflicts in infrastructure in networks industries (fixed networks to deliver services based on lumpy initial investments and presenting elements of natural monopoly), which calls for role of the public sector as a provider of public services. In the case of the United States, this is also a problem linked to devolution and differences in investment priorities among States. The realisation of this issue and of the opportunity cost of the lack of coordination for policy management triggered an effort to promote the better integration of soil moisture data across the United States, spawning the National Soil Moisture Network (NSMN) initiative.

Overview of the National Soil Moisture Network (NSMN) initiative[5]

In 2013, the National Integrated Drought Information System (NIDIS) initiated discussion for the development of a Coordinated National Soil Moisture Network. This network is intended to be based on Federal and State in situ monitoring networks, satellite remote sensing missions, and numerical modelling and draw on the experiences of the soil moisture community. Such a platform would aim to improve knowledge of soil moisture status across multiple spatial and temporal scales and over multiple soil depths.

The initiative brought together experts from the USDA Natural Resources Conservation Service's Soil Climate Analysis Network (SCAN) and Snow Telemetry (SNOTEL) in situ instrument networks (Schaefer, Cosh and Jackson, 2007[3]); the NOAA Climate Reference Network (Diamond et al., 2013[4]); state in-situ networks; remote sensing and modelling experts from NASA, NOAA, and USDA; and soil moisture database managers from academia and federal and state governments.

The first workshop held in 2013 highlighted a range of issues in relation to soil moisture data. At the conclusion of the workshop launching the initiative (McNutt, Verdin and Darby, 2013[5]), the need was identified for improving metadata and calibration and validation of soil moisture data as well as data integration, leading to the creation of the initiative for the development of the National Soil Moisture Network (NSMN). The original objective was to develop a high-resolution gridded soil moisture resource, accessible to the public through a web portal. Therefore, the project brought together in situ measurements of soil moisture from the federal networks, in combination with a range of other databases, including the NRCS SSURGO, which provides a unique gridded database of soil properties and satellite (PRISM) data.

As a result of the first workshop, NIDIS funded a pilot project operated by the North American Soil Moisture Database at Texas A&M University, focusing on the southern plains networks of the U.S. to demonstrate the feasibility of the process. Challenges included data transfer protocols, storage, and data gaps from intermittent connectivity to stations.

Additional NSMN workshops were held in 2016, 2017 and 2018, with the last meeting held in Lincoln Nebraska at the National Drought Mitigation Center. As a result of this workshop, an Executive Committee was formed and a charter was drafted to provide more structure to the effort.

Rationale and lessons learned from the development of a National Soil Moisture Network[6]

According to the type of public services required, to the institutional environment and initial conditions of the network, enabling the development of a data infrastructure might require different types of actions and role for the government, whether as a central planner, as a regulator setting interoperability standards or to directly develop the data infrastructure and create markets for usage rights. The role of the government is likely to change according to how advanced those networks are, whether the service provided can be marketable and whether the costs of providing the services are higher than the benefits.[7]

Lesson 1. There is path dependency from previous policy-making and infrastructure development on the data infrastructure and governance

In the case of the NSMN, issues result from path dependency from the devolution of investments decisions to sub-national scales, investments that were taken rationally according to priorities in each particular State. While there was a logic in this devolution, today, this lack of coordination and alignment of objectives creates inefficiencies in terms of data creation, management, potentially spiralling down into poor water policies and managements in a context of information gap.

A lot of data is already being produced which could be better exploited by cutting across administrative borders. A maintenance updating of the current mesonet infrastructure and the creation of an enabling environment for data sharing might be enough for the creation of an efficient data infrastructure. Both the public and private sectors – Farmers, policy makers and the community – would benefit from better preparation and resilience to drought.

The NSMN initiative acted as a catalyser, bringing together institutions and creating awareness about the specificity of soil moisture monitoring, highly variable in space, depth and time.

Lesson 2. There could be a role for the government to support the development of infrastructure

A traditional question for network infrastructure is where the role of government stops and where the role of private sector starts. There might be cases requiring broader government support to the financing of network infrastructure, including in less economically important areas.

In addition, questions about the sharing of data according to the status, definition and value (economic and social) provided to the different users of data produced by private systems is still to be discussed. Discussions at the Global Forum for Agriculture held at the OECD in May 2018[8] highlighted a range of diverging views in relation to data ownership, and the issue of privacy. In particular, asking the question of which types of information and derived conclusions can be left with the private sector and which need to be managed (governed) by public authorities.

The NSMN is in the process of using existing networks, but most current networks were created with spatially restricted objectives (states, watersheds, etc.) and the concluding report of the workshop, which launched the creation of the NSMN in 2013 (McNutt, Verdin and Darby, 2013[5]) mentioned that an increase in the number of monitoring sites would be the most important improvement in the overall depiction of soil moisture. Indeed, drought risk and water flows do not end at regional borders nor are they only an issue within one land cover group, and more specifically highly productive areas: water management, policies and drought risk require a comprehensive understanding of soil water dynamics at a high resolution across all landscapes.

To be considered too is that new sources of data will likely become available in the future with the digital transformation of agriculture. Although the sharing of data between stakeholders is not a given, the private sector might have incentives to develop infrastructure when it holds promises of profitability. For instance, WSN can be developed to support decision systems, more likely to be sold to farmers. Consequently, WSN would produce a lot of information, in specific areas, such as high density farming areas, to which services can be provided to make investment profitable. However, there might still be constraints to the sharing of such data. In addition, the quality and veracity of data obtained via private application of new digital technologies to support policy-making would need to be ensured.

Finally, the creation of a network of sensors and of information needed to monitor soil moisture in ways that allow the provision of public services such as drought early warning systems, and to inform water policy and management, requires coverage of all geographic areas, whether cultivated or not. Such cases identify a clear role for the government as it might not be economically viable for the private sector to develop infrastructure in some areas, which are nevertheless important for the understanding of ecosystems dynamics and forecasting. In addition, myopic views of hydrologic concerns have major impacts downstream.

Lesson 3. There might be a role for some regulatory oversight or central planners when there is a collective gain to coordination but no returns or private incentives

This leads to the second issue highlighted by this case study, which is interoperability standards. Any network or platform, whether public or private is developed to answer specific questions, achieve certain purposes, explaining their difference of approach to data creation, management and codification. As a consequence, the data produced might not be "fit for purpose" and create biases if used in modelling and analytics that depart from the initial goals. While there can be collective gains to coordination, there might not necessarily be private or return incentives. In such cases, networks lend themselves to some form of regulatory oversight or a central planner.[9]

With the creation of the NSMN, an important need was for the data produced to be usable for a diversity of objectives and by a diversity of end users. The first step of the NSMN was the coordination of existing networks, bringing together current entities in a common format. As such, the NSMN also acted as a standards marker: effectively leveraging the full variety of existing networks and modelling efforts first relied on consistent calibration and validation practices and metadata characterisation.

Notes

[1] Roughly spanning a 30 km radius or grid box around a given location

[2] The foundation for today's National Weather Service Cooperative Observing Program (COOP).

[3] See section discussing data ownership and the example of the Privacy and Security Principles for Farm Data in the United States in main report.

[4] See main report for a discussion about data ownership. In the United-States, farmers are reluctant to share data about their production system.

[5] Information about the development of the NSMN was taken from sources available on the website of the National Integrated Drought Information System, https://www.drought.gov/drought/sites/drought.gov.drought/.

[6] Or worldwide but this would go further than the premises of this document which is focusing on domestic policies. Initiatives at the G20 are aiming to develop such knowledge sharing international networks. See G20 Meeting of Agriculture Ministers declaration, 27-28 July 2018, Buenos Aires, Argentina: "*We highlight the importance of enhancing the quantity and quality of soil data and information and support the sharing of knowledge and technology to measure, restore, rejuvenate and maintain soil health.*"

[7] Although cost-benefit analysis are often difficult to implement for issues in relation to the environment and disaster risk reduction.

[8] Global Forum on Agriculture (GFA), 14-15 May 2018, Digital technologies in food and agriculture: Reaping the benefits. http://www.oecd.org/agriculture/events/oecd-global-forum-on-agriculture/.

[9] WMO is in the process of developing standards for soil moisture network development.

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Chapter 15.

Case Study 10. Data infrastructure and the potential role of the government supporting the data infrastructure – example of the *Akkerweb* in the Netherlands

The Akkerweb is an open platform for digital services for precision farming. This case study provides a practical example of how public-private partnership on an open data infrastructure can facilitate the creation and uptake of value adding services by the private sector, supporting productivity growth and sustainability improvement in agriculture. As such, the Akkerweb is a new way for the government to support access to advise services to farmers. Akkerweb is a foundation, founded by both Wageningen University and Research and a farmers' association, Agrifirm.

Context: Fostering capacities, good use of public data and support private sector services development in precision agriculture

The problem

Farmers have been using guidance systems, yield monitoring, variable rate application,[1] long-distance transmission of computerised information (telematics) and data management for a long time (OECD, 2016[1]). The use of digital tools on-farm has been developing over time and a farmer can end up having to manage a multitude of unrelated systems giving various information (e.g. about yield variation, production assets characteristics) but rarely connecting the different elements to explore correlations and causations. Most data points make more sense when provided with the context and put in relation with benchmarks, trends, or causal references, applying and testing knowledge obtained from experience, either on farm but also though innovation and research.

One of the key reasons data has not been used to its full potential to date is that farmers often lack the tools and skills to analyse jointly those multiple sources of data and fully exploit them. The inability to link data across systems, each focussed on a specific task, prevented both insights into the relationship between certain management practices and within the farm system, at least in the absence of costly manual data synthesis.[2]

This fragmentation of data created a data gap that not only prevents its efficient use on-farm, but also its reuse for research and deeper analysis. While on farm, a large amount of data is acquired but cannot be combined to produce knowledge beyond the initial intended purpose; on the research side (relying on some public data such as remote sensing data), data is often only available at in an aggregated form. The use of this data for the production of knowledge at the level of the individual animal, field or farm is then limited, and, where it does occur, is often costly and cumbersome.

The Akkerweb brings together public and private data to support precision agriculture

Akkerweb is an initiative of both Wageningen University and Research (WUR) and farmers' association Agrifirm. In this joint venture, both scientific knowledge and a practical approach to farmers' problems is combined. The *Akkerweb* was thought as an open platform for precision farming, enabling to bring all farm data together and in addition, proposing a variety of agriculture related applications usable by farmers, using this data, to support their decision making process in order to optimise their production objectives.

In in particular, WUR currently provides free satellite data, which require specific analytics capacity to interpret and translates them into in vegetation indices. Those vegetation indices are complex mathematical combination or transformation of spectral bands that accentuates the spectral properties (how leaves react to ultraviolet, visible, and infrared frequencies) of green plants so that they appear distinct from other image features. Such indices usually provide indication of the amount of vegetation, meaning the percent cover or the biomass, and they also distinguish between soil and vegetation. The tech start-up Bioscope combines a mix of public and commercial satellite data and drones data to provide a guaranteed data stream essential for precision farming.

This data is then combined with other data from the private sector and farmers, for a range of advice services. Some applications have been built in by the WUR research team, others are added by the private sectors, and require payment.

The platform compiles information made available by farmers in one “geo-platform”, where the geo-spatial location is a key connection between activities, data sets and analyses. For arable farmers a ‘crop rotation application’ is the entry point to explore the data and serves as the foundation for all the functionalities that provide added value to farms operations (e.g. for fertilisation or crop protection).

Farmers can freely open an account and add information that is securely managed. In *Akkerweb*, the farmer can combine his farm specific data with data from public sources (e.g. satellites, soil maps, weather data, parcel maps from the Netherlands Enterprise Agency (RVO)), but also proprietary data sources such as sampling bodies (laboratories and certification), other parties in the value chain, farm management systems, own sensors etc. Active links are available with the data store of the national Paying Agency (RVO) and with other farm management systems, to prevent double entry of data. Only the farmer has access to his own data but he can grant access to others on his own discretion. In this way, he can give access to his advisor to help him monitor the crops or interpret a soil analysis.

Farmers are therefore free to share enriched data with advisers and other users on the platform, to obtain practical recommendations (or actionable insights) to optimise crop production. The system itself provides interoperability of data. Any data provider can upload their data (e.g. soil laboratories) and make them available to farmers. Different private sector companies have their own “app” on the platform for farmers to use at their discretion. *Akkerweb* is in the first place a digital repository and work bench. Applications are built on top of this data repository either by the public or the private sector, ranging from visualisation to analytics and decision support.

It is generally accepted by the user community that farmers are the controllers of their data and the platform was built as GDPR (European Union, General Data Protection Regulation) compliant.

Lessons learned

Lesson 1. To be adopted and successful, digital technologies have to be designed based on expressed user needs

Commercial GIS software, in use by many professionals, failed to gain traction in farming because of their price and complexity. The GIS functionality in *Akkerweb* is designed based on expressed user needs. In that sense, *Akkerweb* filled a need. Moreover, the ability for third parties to develop applications is a strong advantage over some of the other platforms.

Lesson 2. The success of the platform relies on the integration of all public and private sector stakeholders of precision agriculture

Other technical platforms offer similar technology, but a success of *Akkerweb* is the strong interaction between stakeholders, which provides both scientific backstopping to models and algorithms, and practical approach concerning functionality. Public bodies are participating in the data repository construction by linking their agriculture policy data (for example LPIS) to the platform as well as supporting the pre-processing of satellite data.

Notes

[1] In precision agriculture, Variable Rate Application (VRA) refers to the application of a material, such that the rate of application is based on the precise location, or qualities of the area that the material is being applied to. Variable Rate Application can be Map Based or Sensor Based.

[2] See for instance: *Scientists to create dairy-farm 'brain'*, Bob Mitchell for UW-Madison Department of Dairy Science, 29 August, 2017, accessible at: http://www.agriview.com/news/dairy/scientists-to-create-dairy-farm-brain/article_e56e7e80-9c89-53ab-9639-c4eaac835ec1.html

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Annex A.

Agri-environmental policy components and policy mechanisms

The policy cycle shown in conceptual framework for analysing use of digital technologies for better agricultural and agri-environmental policies (Figure 2.1 of the main report) is a stylised representation of the broad components undertaken to design, successfully implement, and evaluate an agri-environmental policy. In that figure, the components are set out linearly; it is acknowledged that the particular components and ordering of components for a particular policy will depend on context – the emphasis here is on considering the usefulness of digital technologies for each component. The components, drawn from the literature on agri-environmental policy design (see for example, OECD (2008[1]) and OECD (2010[2]), are:

- ***Policy design:*** identification of policy issues and definition of policy objectives. Specific operational objectives or targets which will achieve the broad objectives are then identified. Having defined the objective(s), the next step is the selection and specification of a particular policy mechanism (or suite of mechanisms) to achieve the objective(s).
- ***Initial outreach and enrolment in policy mechanism*** is the preliminary step for implementation. It is the process of raising awareness of the policy mechanism with potential participants, soliciting (voluntary) or requiring (regulatory) participation, gathering baseline data and checking eligibility criteria are met (if applicable) and enrolling participants. Depending on mechanism design, this may consist of informing the regulated community of requirements; registering programme participants in a database; gathering baseline information; performing preliminary eligibility checks; setting up a process to accept tenders or auctions, etc.
- ***Implementing policy mechanism***: This entails the practical implementation of the policy mechanism. Depending on mechanism choice, this could involve, for example, administering payments provided to eligible farmers; executing contracts; administering tradeable permit programmes.
- ***Monitoring and enforcement (if relevant) of participation in policy mechanism*** in order to be able to assess whether they are in compliance (examples include: auditing for regulatory compliance in a mandatory scheme; in a voluntary pay-for-practice programme, verifying whether contracted best management practices (BMPs) have been implemented and are being maintained as per the terms of the contract). Further, if non-compliance is identified, carrying out enforcement protocols (e.g. requiring remedial action, fines, legal action).
- ***Policy evaluation*** involves monitoring the achievements of the policy mechanism, relative to its objective (effectiveness) and also in terms of the costs of implementing the policy mechanism (efficiency), including transaction costs.[1]

- ***Communication with broader public about policy*** involves sharing information about the policy mechanism, including progress toward achieving the objectives and the results of evaluations, with the broader public. Further, feedback from interested stakeholders is sought. This 'component' could be performed throughout the policy cycle - e.g. initial consultation during the policy design component; ongoing communication and consultation about implementation progress; participation of stakeholders in policy evaluation.

This report notes that digital technologies are useful for a range of different agri-environmental policy mechanisms. Table A A.1 provides an overview of such mechanisms: this was used in the OECD questionnaire conducted to support this work (Annex B).

Table A A.1. Agri-environmental policy mechanism classifications

Category	Instrument	Examples
Regulatory instruments	Environmental standards	Chemical bans
		Agricultural input standards
		Performance (output) standards (e.g. agricultural waste management standards)
		Technology standards
	Activity prohibitions	Permanent outright bans on undertaking an environmentally damaging activity in an agricultural area
		Temporary outright bans on undertaking an environmentally damaging activity in an agricultural area
	Environmental property rights	Regulations to assign minimum environmental flow
		Purchase of water rights from agricultural enterprises, with purchased rights being allocated to the environment
Economic Instruments	Environmental taxes	Performance or emissions taxes
		Input taxes (e.g. fertiliser taxes)
	Environmental subsidies (Agri-environmental payment schemes)	Cost share programmes
		Payments for ecosystem services
		Subsidies for agri-environmental technology innovation or public investment in structural adjustment towards “greener” agricultural systems
	Extension services	Mandatory training requirements
		Voluntary training programmes
	Tradeable allowances	Emissions trading schemes and pollution reduction credit trading
		Tradeable offset schemes
		In lieu fee programmes
Hybrid instruments	Environmental “cross-compliance” requirements	Cross-compliance mechanisms; baseline eligibility requirements

Source: Adapted from OECD (2010[2]) and Hardelin and Lankoski (2018[3]).

Note

[1] OECD (2010[2]) defines the "environmental effectiveness" of policies as their success (or otherwise) in achieving their stated environmental objectives, and "cost-effectiveness" as the degree to which the policy instrument achieves its objective at minimum cost.

References

Hardelin, J. and J. Lankoski (2018), "Land use and ecosystem services"*, OECD Food, Agriculture and Fisheries Papers*, No. 114, OECD Publishing, Paris, https://dx.doi.org/10.1787/c7ec938e-en. [3]

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Annex B.

OECD Questionnaire on use of digital technologies by agri-environmental policy administrators

In order to gather information about OECD member governments' current experiences with digital technologies, the Secretariat constructed a questionnaire. The questionnaire provided information on the current and expected use (within the next three years) of digital technologies to support the implementation, monitoring and evaluation of agri-environmental policies in OECD countries. In particular, it focuses on better understanding:

- which types of data are currently used and how they are gathered
- the extent to which agri-environmental policymakers and programme managers make use of particular digital technologies in carrying out their functions as they relate to the agricultural sector, including for policy design, policy implementation, monitoring and compliance, policy evaluation, and communication
- the extent to which use of digital technologies differs across agri-environmental policy areas
- strategies or management policies organisations are putting in place maximise their beneficial use of digital technologies
- organisations' experiences with digital technologies and future plans.

Four members volunteered to participate in the testing of the questionnaire: Canada, Chile, New Zealand and the Netherlands. The test questionnaire was sent to participants on 18 January 2018, for return on 23 February 2018.

The questionnaire received 46 responses covering 67 institutions (some responses consolidated data from several institutions) from 16 OECD member countries, plus the European Commission' Directorate-General for Agriculture (Table A B.1). These responses provided data on 108 policies and programmes, as well as respondents' experiences with and views on use of digital technologies by their organisation. This dataset provides a wealth of information on how digital technologies are currently being used by reporting organisations.

The Questionnaire data is available on the OECD website as a digital annex, or can be obtained by contacting the OECD. For enquiries relating to this data, please contact the OECD Trade and Agriculture Directorate (tad.contact@oecd.org).

Table A B.1. OECD questionnaire respondent list

Country	Institution	Acronym	Individual national organisation	Individual sub-national organisation	Consolidated response collated by lead agency
Australia	Department of Agriculture and Water Resources (Australia)	AUS-DAWR	Y		
	Department of the Environment and Energy (Australia)	AUS-DoEE	Y		
Austria	Federal Ministry of Sustainable Development and Tourism (Austria)	AUT-FMSDT			Y
Canada	Agriculture and Agri-Food Canada (AAFC)	CAN-AAFC	Y		
	Manitoba Agriculture, Government of Manitoba (Canada)	CAN-Manitoba		Y	
	Department of Fisheries and Land Resources, Government of Newfoundland and Labrador (Canada)	CAN-Newfoundland and Labrador		Y	
	Department of Agriculture, Government of Nova Scotia (Canada)	CAN-Nova Scotia		Y	
	Ontario Ministry of Agriculture, Food and Rural Affairs; Government of Ontario (Canada)	CAN-Ontario		Y	
	Department of Agriculture and Fisheries, Government of Prince Edward Island (Canada)	CAN-PEI		Y	
	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (Canada)	CAN-Quebec		Y	
	Saskatchewan Ministry of Agriculture, Government of Saskatchewan (Canada)	CAN-Saskatchewan		Y	
Chile	Ministry of Agriculture (Chile)	CHL-Ministry of Agriculture	Y		
	Bureau of Agricultural Studies and Policies (ODEPA), Ministry of Agriculture (Chile)	CHL-ODEPA	Y		
	Agriculture and Livestock Service (SAG), Ministry of Agriculture (Chile)	CHL-SAG	Y		
	National Irrigation Commission (CNR), Ministry of Agriculture (Chile)	CHL-CNR	Y		
	Institute of Agricultural Development (INDAP), Ministry of Agriculture (Chile)	CHL-INDAP	Y		
	Institute of Agricultural Research (INIA), Ministry of Agriculture (Chile)	CHL-INIA	Y		
	Forest Institute (INFOR), Ministry of Agriculture (Chile)	CHL-INFOR	Y		
	National Forestry Corporation (CONAF), Ministry of Agriculture (Chile)	CHL-CONAF	Y		
	Section of Emergencies and Management of Agricultural Risks (SEGRA), Ministry of Agriculture (Chile)	CHL-SEGRA	Y		
	Agency for sustainability and climate change (ASCC), Ministry of Economy (Chile)	CHL-ASCC	Y		
Czech Republic	Nature Conservation Agency of the Czech Republic (Agentura ochrany přírody a krajiny České republiky)	CZE-AOPK	Y		
	Ministry of Agriculture, Department of the Environmental Support of the Rural Development Programme (Czech Republic)	CZE-Cons.			Y
	State Agricultural Intervention Fund (Czech Republic)	CZE-Cons.			Y
	Administration of National Parks (Czech Republic)	CZE-Cons.			Y
	Nature Conservation Agency of the Czech Republic	CZE-Cons.			Y
	Regional authority (Czech Republic)	CZE-Cons.			Y
	Military regions (Czech Republic)	CZE-Cons.			Y
Denmark	Ministry of Environment and Food of Denmark	DNK-MEF	Y		

Country	Institution	Acronym	Individual national organisation	Individual sub-national organisation	Consolidated response collated by lead agency
France	Direction générale de la performance économique et environnementale des entreprises (DGPE), Ministère de l'Agriculture et de l'alimentation (France)	FRA-Cons.			Y
	Direction générale de l'Alimentation (DGAL), ministère de l'Agriculture et de l'alimentation (France)	FRA-Cons.			Y
Estonia	Estonian Agricultural Registers and Information Board	EST-Ag Reg & Info	Y		
	Estonian Agricultural Research Centre	EST-Ag Research Centre	Y		
	Estonian Ministry of the Environment	EST-Min. of Env.	Y		
	Ministry of Rural Affairs of the Republic of Estonia	EST-Min. of Rural Affairs	Y		
Italy	Ministry of agriculture, food, and forestry (Ministero delle politiche agricole, alimentari e forestali, MIPAAF ministry / department) (Italy)	ITA-Min. of Ag	Y		
Japan	Ministry of Agriculture, Forestry and Fisheries (Japan)	JPN-MAFF	Y		
Korea	Korea Agency of Education, Promotion and Information Service in Food, Agriculture, Forestry and Fisheries (EPIS)	KOR-EPIS	Y		
	Korea Rural Community Corporation (KRC) (Korea)	KOR-KRC		Y	
	Ministry of Agriculture, Food and Rural Affairs (MAFRA) (Korea)	KOR-MAFRA	Y		
	Rural Development Administration (RDA) (Korea)	KOR-RDA	Y		
	Gyeong-gi province (Korea)	KOR-Gyeong-gi		Y	
Netherlands	Ministry of Agriculture, Nature and Food Quality (Netherlands)	NLD-Cons.			Y
	Netherlands Enterprise Agency	NLD-Cons.			Y
Norway	Ministry of Agriculture and Food (Norway)	NOR-Cons.			Y
	Norwegian Ministry of Climate and Environment	NOR-Cons.			Y
	Norwegian Agriculture Agency	NOR-Cons.			Y
	Norwegian Environment Agency	NOR-Cons.			Y
	Norwegian Institute of Bioeconomy Research	NOR-Cons.			Y
Portugal	DGADR Directorate-General for Agriculture and Rural Development / Direção-Geral de Agricultura e Desenvolvimento Rural (Portugal)	POR-DGADR	Y		
	IFAP – Institute of financing for agriculture and fisheries – PT paying agency (IFAP - Instituto de Financiamento da Agricultura e Pescas, I. P.) (Portugal)	POR-IFAP	Y		
	Office for Planning, Policies and Administration (GPP Gabinete de Planaeamento e Políticas) / Ministry of Agriculture, Forestry and Rural Development (MAFDR Ministério da Agricultura, Florestas e Desenvolvimento Rural) (Portugal)	POR-GPP	Y		
	AG PDR 2020 Managing Authority of the Rural Development Programme for Mainland Portugal / Autoridade de Gestão do Plano de Desenvolvimento Rural (Continente) (Portugal)	POR-PDR2020		Y	

Country	Institution	Acronym	Individual national organisation	Individual sub-national organisation	Consolidated response collated by lead agency
	AG PRODERAM 2020 Managing Authority of the Rural Development Programme for the Autonomous Region of Madeira / Autoridade de Gestão do Plano de Desenvolvimento Rural da Região Autónoma da Madeira (Portugal)	POR-PRODERAM		Y	
	AG PRORURAL+ Managing Authority of the Rural Development Programme for the Autonomous Region of the Azores / Autoridade de Gestão do Programa de Desenvolvimento Rural da Região Autónoma dos Açores (Portugal)	POR-PRORURAL		Y	
Sweden	Swedish Board of Agriculture	SWE-BOA	Y		
Switzerland	Federal Department of Economic Affairs, Education and Research (EAER), Federal Office for Agriculture (FOAG) (Switzerland)	CHE-FOAG	Y		
United States	USDA FSA (United States)	USA-USDA FSA	Y		
	USDA NRCS (United States)	USA-USDA NRCS	Y		
EU Commission	European Union Directorate General for Agriculture	EC-DG AGRI			

Note: Cons. = Consolidated response.
Source: OECD Questionnaire.

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