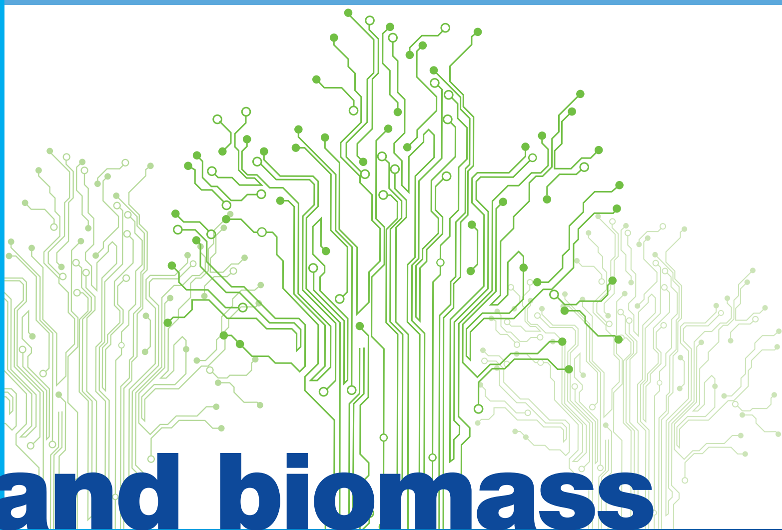

Bits and biomass

A roadmap to the digitalisation-empowered bioeconomy

VISIONS • SCIENCE • TECHNOLOGY • RESEARCH HIGHLIGHTS
12

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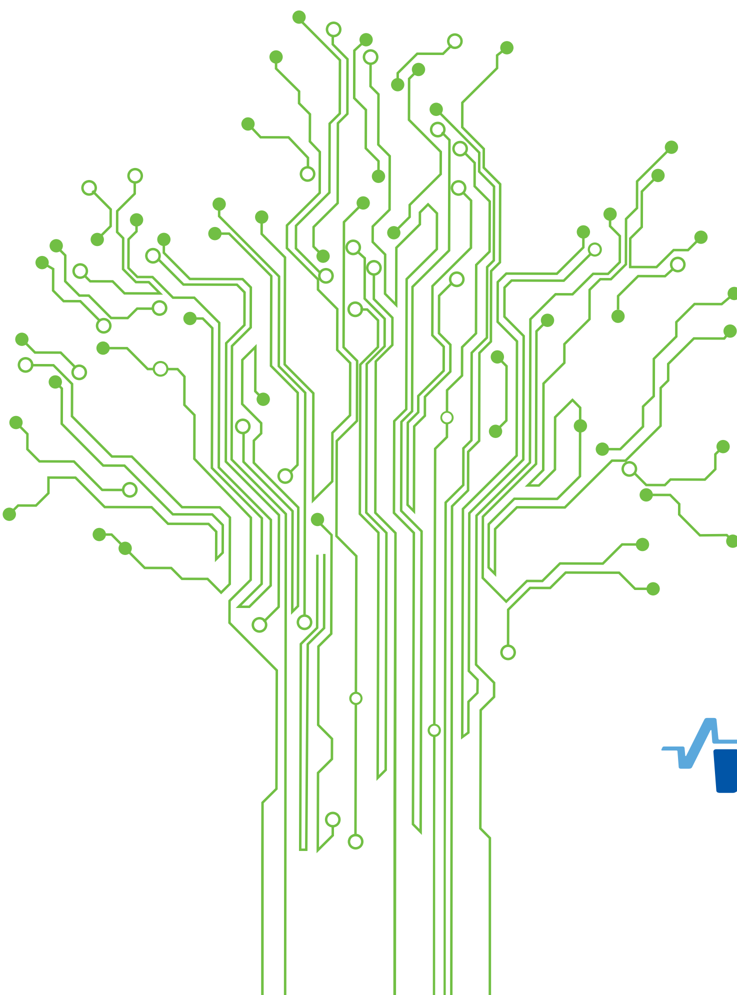

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Preface

The digital revolution and transition from the fossil economy to the bioeconomy are in the process of fundamentally transforming the economic environment. The Digitalisation-Driven Bioeconomy roadmap study examines how the transition to the smart utilisation of biomass flows and immaterial ecosystem services can be achieved in a manner that simultaneously promotes the sustainable use of natural resources and creates potential for new primary production and processing business in agriculture and forestry.

The Digitalisation-Driven Bioeconomy roadmap has been drawn up in cooperation by VTT Technical Research Centre of Finland Ltd (VTT) and Natural Resources Institute Finland (Luke). Luke and VTT have the profound bioeconomy expertise in Finland. Luke has a solid foundation of expertise in primary production, which forms the basis of the bioeconomy, while VTT possesses special expertise in the processing of natural resources and providing digital solutions.

The roadmap you are reading continues the work of both organisations in creating visions based on new, bio-based products and ecosystem services. Examples of this work include the Food Economy 4.0 roadmap published by VTT in 2017, the Policy Brief on the circular economy published in 2016, the review of the current state and development trends of the bioeconomy drawn up by Luke in 2016, the Roadmap to the digitalisation of plant production systems published in 2015 and the Roadmap for improving the protein self-sufficiency of Finland, produced in cooperation by VTT and Luke in the same year.

The Digitalisation-Driven Bioeconomy roadmap was drawn up as part of VTT's Bioeconomy Transformation spearhead programme and

Luke's Boreal Green Bioeconomy programme. The roadmap is based on the cooperation of VTT's and Luke's experts in two workshops (5 April 2016 and 28 October 2016) and the independent work of thematic working groups in the interval between the workshops. The work focused on the biomass flows of agriculture and forestry, which is why the blue bioeconomy is not discussed in this roadmap. The transition paths and sample applications presented have been created from the material produced by the working groups.

The printed publication is supplemented by online materials including applied examples of the digitalisation of the bioeconomy (see *http://www.vtt.fi/inf/pdf/visions/2017/V11.pdf*). The supplemental report was written by VTT scientists Mikko Arvas, Tuomas Häme, Pekka Isto, Kristiina Kruus, Raija Lantto, Anna Leinonen, Emilia Nordlund, Juha-Pekka Pitkänen, Anu Seisto and Mikko Utriainen, and Luke scientists Jari Ala-Ilomäki, Antti Asikainen, Juha Backman, Jarkko Hantula, Katja Holmala, Annika Kangas, Timo Muhonen, Kaisa Nieminen, Matti Pastell, Rainer Peltola, Liisa Pesonen, Tuula Piri, Jyrki Pusenius, Pasi Suomi, Heli Viiri and Kari Väätäinen.

We thank all of the experts who took part in drawing up the roadmap for their contribution and new, innovative ideas.

Espoo, Tampere and Joensuu, 1 March 2017

Editors
Anna Leinonen (ed.), VTT; Maria Åkerman (ed.), VTT; Kristiina Kruus, VTT; Antti Asikainen, Luke; Timo Muhonen, Luke and Johanna Kohl, VTT

1. Towards a smart bioeconomy

The Finnish Bioeconomy Strategy [1] aims to make Finland a global pioneer in the bioeconomy, capable of offering solutions to the pressures exerted on the global economy by declining natural resources, climate change and population growth.

According to population growth forecasts, the global food production requirement will grow by 60% by 2050. Responding to this need will require changes to food systems and a shift to a more vegetable-based diet. The development of new, biological products and services and the diverse utilisation of immaterial ecosystem services are also essential to the advancement of the bioeconomy.

At the heart of the bioeconomy lies the transition from the fossil economy to the use of renewable energy and materials and chemicals relying on renewable natural resources.

In 2014, Finland's bioeconomy output was EUR 63 billion, and the industry employed more than 330,000 personnel [2]. The functions of the bioeconomy comprised 12% of Finland's GDP, and the sector's products and services accounted for slightly more than one fifth of Finnish exports. The bioeconomy accounted for 16% of our national economic output (Figure 1). The majority of this output consists of the production of timber products and energy from wood. The employment impact of the bioeconomy was most significant in agriculture, construction, forestry and food industry

Therefore, the functions of the bioeconomy already have solid foundations in Finland. However, the transition to an economic system relying on renewable raw materials instead of fossil fuel and non-renewable natural resources represents a more radical change than simply expanding the existing bioeconomy sector. It is not limited to the enhancement of production based on biomass flows and ecosystem services, but represents a fundamental economic reorganisation, which requires cooperation between sectors and an open-minded search for new value creation potential. Until now, few operators in the field of bioeconomy have succeeded in breaching the walls between sectors [3].

The transition to the bioeconomy will not happen overnight. Building new types of expertise and cooperation networks and developing innovations based on them will require long-term strategy work.

There are high hopes for new business opportunities in the bioeconomy, particularly in the shape of more extensive and diverse product and service offerings and in the circular economy that makes use of the side streams of the processing industry. New types of bioeconomy business are in fact being created in Finland:

- ST1 is in the process of building a bioethanol plant in Kajaani, which will use industrial waste streams, i.e. sawdust and sludge as a raw material.
- Metsä Fibre is building a multi-purpose bioproduct mill in Äänekoski. In addition to pulp, the facility will produce a diverse selection of other bioproducts, such as pine oil, turpentine, biocomposites and biogas, product gas and sulphuric acid.
- UPM is refining tall oil into traffic fuel.
- At its factories in Sunila, Stora Enso has adopted LignoBoost technology for the extraction of Kraft lignin.
- Lumene uses extracts and components obtained from Finnish berries for cosmetics.

The field has also spawned start-ups, such as the VTT spin-off Paptic, which manufactures substitutes for plastic bags from cellulose.

There have been attempts to promote the development of the bioeconomy through various policy measures, such as a renewal of waste legislation, subsidies for product and service development, investment subsidies and investments into research in the field. These objectives have also received significant support from a number of government key programmes: Towards carbon-free, clean and renewable energy in a cost-efficient way, Wood on the move and new products from forests, Economically viable food production in Finland, balanced trade and thriving blue bioeconomy, Breakthrough to a circular economy and adoption of clean solutions,

The industrial revolution of the bioeconomy sector and its servitisation on the basis of customer-centered business have only just begun and are still taking shape.

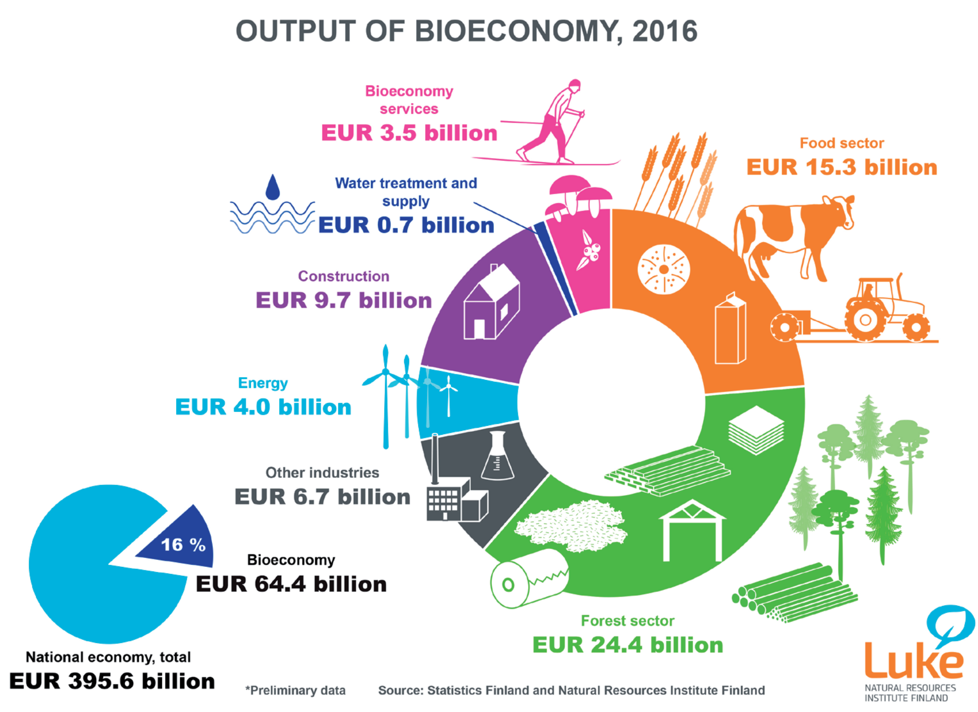


Figure 1. Share of the bioeconomy's functions and services in Finland's national economic output in 2014 [4].

Nature policy based on trust and fair means [5]. In addition, the Ministry of Employment and the Economy organised an international Biorefinery Competition in 2014 in order to support and boost promising bioeconomy companies [6].

At the same time as and in spite of these bioeconomy promotion measures and the development of new and promising business models for the bioeconomy, the foundations of the bioeconomy, agriculture and forestry and the refining industry, are nevertheless suffering from profitability problems. This also has an impact on the investment willingness of producers and the attractiveness of the industry as a future work environment.

On the other hand, there is a strong investment trend in the forest industry, due to which the use of roundwood is projected to increase by 10–15 million cubic metres per year in Finland. The sawmill industry has also experienced a revival, and its exports set a new record in 2016 (Figure 2). Thus, material such as wood-processing side streams will be available in greater quantities as raw material for the bioeconomy.

Even though the industry's new development possibilities, biorefineries, clean tech exports and new natural resource services are much talked about, the operations of the bioeconomy still largely revolve around the traditional raw materials production of agriculture and forestry and the processes of the forestry and food industries. At the heart of the bioeconomy lies the transition from the fossil economy to the use of renewable energy and materials and chemicals relying on renewable natural resources. The industrial revolution of the bioeconomy sector and its servitisation on the basis of customer-centered business have only just begun and are still taking shape.

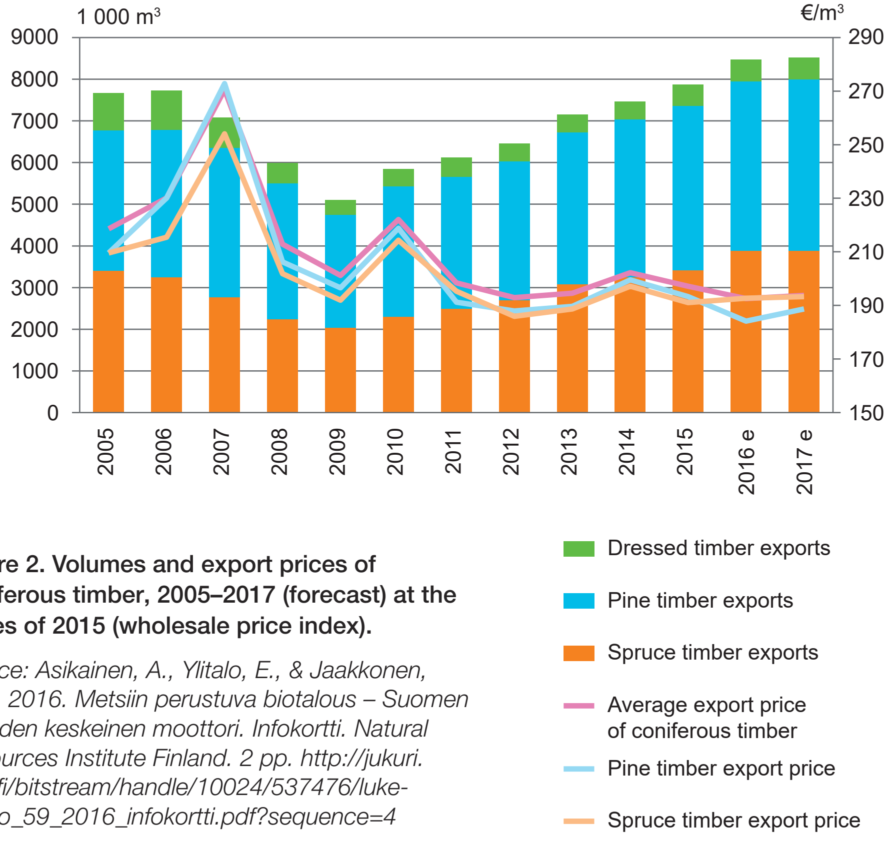


Figure 2. Volumes and export prices of coniferous timber, 2005–2017 (forecast) at the prices of 2015 (wholesale price index).

Source: Asikainen, A., Ylitalo, E., & Jaakkonen, A.-K. 2016. Metsiin perustuva biotalous – Suomen talouden keskeinen moottori. Infokortti. Natural Resources Institute Finland. 2 pp. http://jukuri.luke.fi/bitstream/handle/10024/537476/luke-luobio_59_2016_infokortti.pdf?sequence=4

2. Digitalisation as a trailblazer

While Finland is looking for ways to promote the transition to a bioeconomy, digitalisation is also transforming the economic environment in many ways. Digitalisation refers to the use of information technology so that ICT tech is increasingly merged into the everyday lives and work of individuals and companies[7]. We are in the midst of a period of change in which new operating models are being shaped and tested.

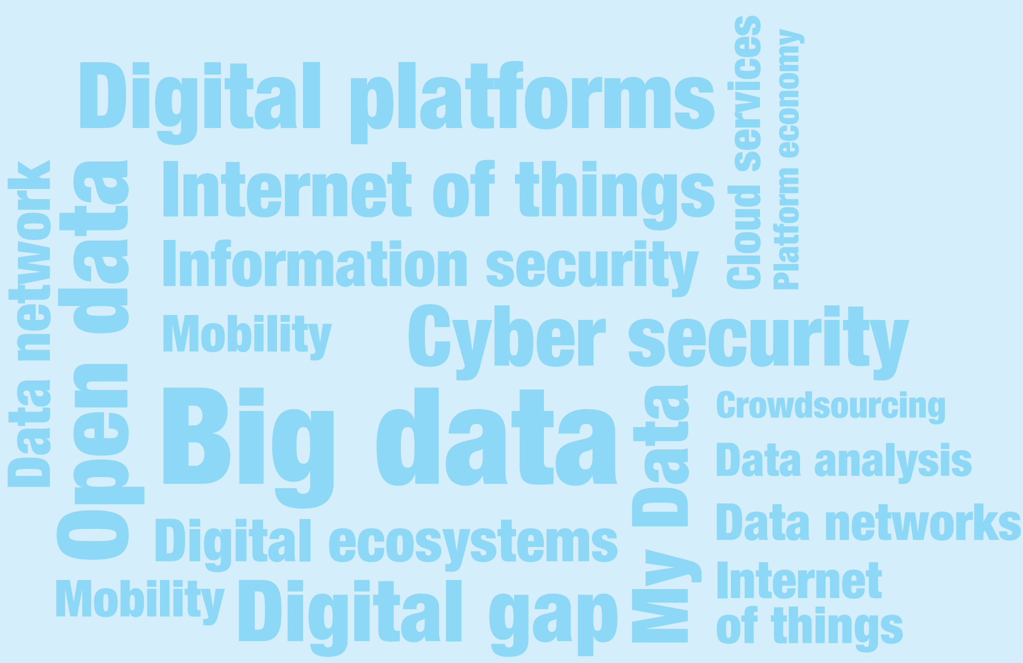
Digitalisation is based on simultaneous advances in several fields of information and communication technology. The amount of available computing power has increased and, simultaneously, sensors and radio devices have become smaller and cheaper. Global information networks are faster and more stable than before, and mobile and WLAN networks have improved. Data centres and the cloud services offered by them have enabled the quick and effortless scaling of services, and the productivity of software development has improved. New operating models for business, public administration and civic activities can be built on the foundation of this technological development. The digital revolution will entail fundamental changes in the activities of people, companies, public organisations and civic society.

The digital revolution will entail fundamental changes in the activities of people, companies, public organisations and civic society.

A glossary of digitalisation [8]

- ***Big data and data analysis:*** *Big data refers to the foundation of digitalisation, the enormous amount of data that can be gathered from advanced sensors and networked devices. The utilisation of existing data requires data analysis, which is made possible by increasing computing power and the improvement of programming skills, among other things.*
- ***Mobility:*** *The proliferation of portable, powerful and network-ready smart devices will create a new kind of operating environment characterised by mobility. The importance of time and place will decrease as people are able to access services through smart devices. Mobility also helps with the adoption of novel methods of communication and organising work.*
- ***Cloud services and information networks:*** *Cloud services are related to the infrastructure solutions of the digital world. They transfer data storage and management from local servers to large data centres. The benefits of cloud services arise from the rapid implementation and scalability of services: expansion will no longer require slow and costly IT investments.*
- ***The Internet of Things (IoT):*** *The decrease of total data management costs will enable the connection of everyday items to information networks. The Internet of Things refers to a scenario in which increasing numbers of devices are connected to an information network and can communicate with each other. The latter scenario is also described by the term M2M (machine to machine), by way of differentiation from communication between or conveyed by humans.*
- ***Open data and My Data:*** *Because data is a central commodity of digitalisation, it also has financial value. The idea of open data is to open data gathered with public funds to public use, potentially creating new, commercial services benefiting society and citizens. My Data, on the other hand, describes the principle that every individual should have ownership of the data concerning them and their behaviour.*
- ***Digital ecosystems:*** *Digital ecosystems are networks in which companies collaborate in various roles and can improve their special areas of expertise. Digital ecosystems can change and evolve extremely quickly, and the roles of actors can change over time. They are global by nature. In the past, similar phenomena have been referred to with the terms 'value network' and 'cluster'.*

- ***Digital platforms and the platform economy [9]:*** *Digital platforms are IT systems that various actors (users, providers and other stakeholders irrespective of organisation) can use to implement activities that generate added value. In addition to the technical solution, the platforms include common principles according to which the various actors create, offer and maintain mutually complementary products and services. In the platform economy, business relying on digital platforms has achieved a significant or dominant market position.*
- ***Crowdsourcing:*** *Crowdsourcing refers to a method of operations enabled by the internet and mobile devices, in which a task, data gathering or collecting funding can be shared across a large group of people. In crowdsourcing, traditional monetary wages are not paid for work; rather, the participants are motivated either by the appreciation won in the community or the possibility to obtain benefits later, for example, in the form of better services.*
- ***Digital gap:*** *The flip side of digitalisation is that a digital gap can open between groups of people, separating them according to their digital skills and the technologies they have access to. The digital gap can also impede digitalisation if new operating models are not adopted because the old structures cannot be given up without compromising the equality of citizens.*
- ***Cyber security, information security [10]****: A digitalised world also involves vulnerabilities and threats. When systems vital to the functioning of society, such as the distribution of water and electricity or monetary transactions depend on information networks, they are easy to paralyse by attacking those networks. Cyber security refers to securing the systems that are critical to the functioning of society. Information security has a more specific meaning, referring to the secure storage and transfer of information.*



The discussion on digitalisation cannot be restricted to technological change. Digitalisation is changing the role of information as an enabler of economic activity. It entails a fundamental change in operating methods, in which digital solutions are used comprehensively in the activities of individuals and functions of organisations and society [11]. In this roadmap, we approach digitalisation's potential for promoting the bioeconomy through the digitalisation wheel presented on page 14.

As depicted in Figure 3, the technological basis of digitalisation rests on advances in sensor and measurement technologies, information networks and computing capacity. These enable the gathering of measurement data also from objects that were previously impossible to monitor technologically. With regard to the utilisation of data, it is also essential to develop cloud services that enable the storage of data and combination of data sources.

Data in itself will not create new added value, however. Through analysis, data becomes information that enables diverse activities, which is why the progress of digitalisation is also dependent on the advancement of analysis solutions and application development. The efficient utilisation of data analysis requires data of sufficient quality

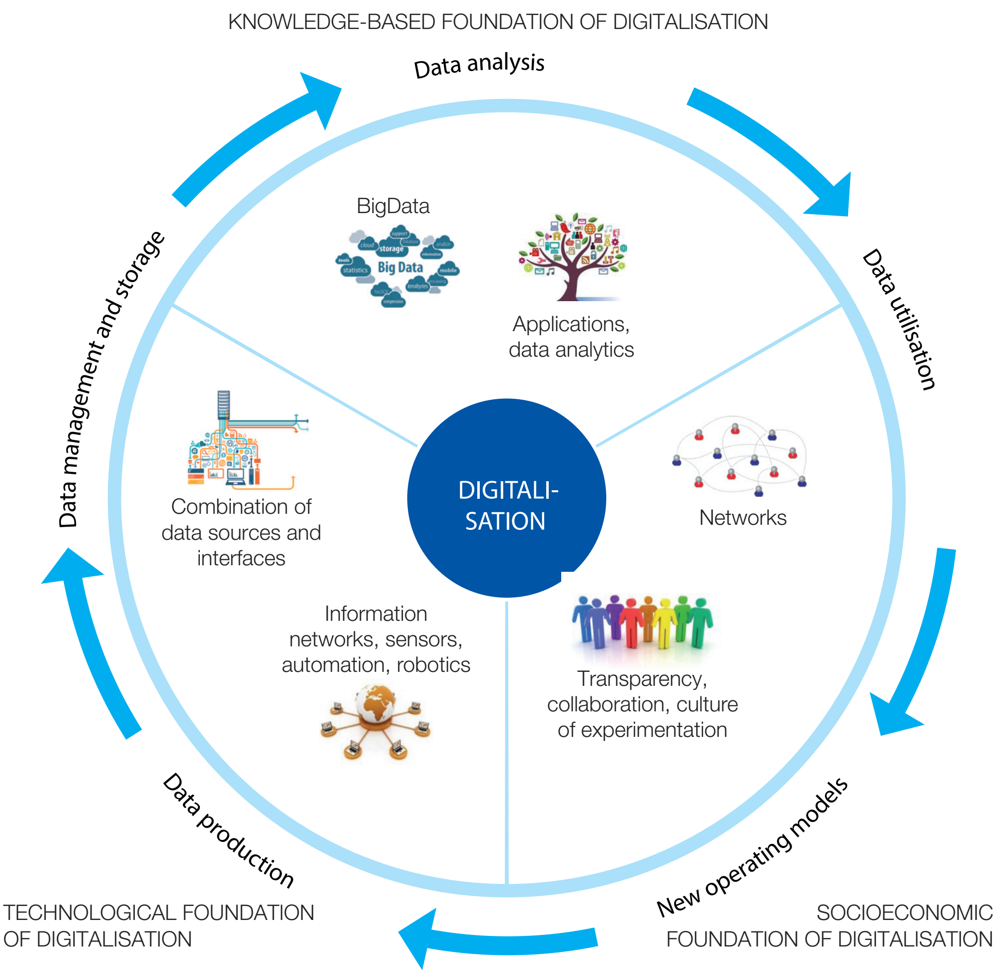


Figure 3. The wheel of digitalisation: technological advances enable new operating models, which require new technological and organisational solutions.

and accuracy. We refer to these matters that require special expertise as the knowledge-based foundation of digitalisation.

The digitalisation of the bio-economy thus requires a clarification and open public discussion of the ethical rules governing it.

Finally, there is the field of data utilisation, which requires – or enables – the development and adoption of novel operating models. Examples of such changes in operating models can include various networks or collaborative operating models, along with increased transparency or the promotion of a culture of experimentation. These changes in operating models are part of the socioeconomic foundation of digitalisation.

Digitalisation as a driver of the bioeconomy

How is digitalisation, understood as a constantly revolving circle of technological development and new operating models, and related to the bioeconomy? The optimal utilisation of digitalisation in the bioeconomy does not mean simply enhancing current processes and reducing manual phases with digital tools, but the customer-oriented design of new types of bioeconomy services for both business and public administration.

In addition, networked operating models may change the conventional roles of producers and consumers when consumers will be able to take part in the production or tailoring of products through new technologies. This combined role of consumer and producer is sometimes referred to the concept of prosumer. We will present examples of new practices in connection with the transition paths described in Chapter 3.

In addition to customer and citizen-oriented operating models, the digital revolution of the bioeconomy also includes a disruption of the established value chains. Cheaper sensors, cloud services, M2M, advanced analysis techniques and machine learning will provide an opportunity for the precise utilisation of more comprehensive information flows. Various innovation and service platforms will also enable new types of cross-sector partnerships and networked business models. Such models will break the customary value chains of production, since they reduce the need for, e.g., intermediaries that deliver products to the market.

When speaking of the digitalisation of the bioeconomy, it is essential to understand that the digital revolution and transition to a bioeconomy are simultaneously ongoing processes of change, which may radically transform economic structures and the relationships of societal actors. As is typical for systemic changes, the revolution will produce both winners and losers.

In addition to technological solutions, digitalisation will create new types of expectations on bioeconomy actors. Companies will have to be better prepared to fulfil customers' expectations concerning the ethics, environmental and welfare impact of production. The increased amount of information and proliferation of surveillance technology in everyday life will increase the pressure for transparent production processes. In addition, the growing amount of information will increase the risk of abuse and raise concerns related to the protection of privacy and ownership of information.

The basic idea of the digitalisation wheel presented in Figure 3 is that the change towards digitalisation can originate at any point on the circle. We identified such potential for change and drivers of digitalisation development in the course of drawing up this roadmap. Next, we will present three examples in which the different foundations of digitalisation – technological, knowledge-based and socioeconomic – can be seen behind the developments.

Technological advancement as a driver of change: Digitalised farming

Agriculture is undergoing a period of change driven by the development of digitalisation [12]. The number of sensors on machines is constantly increasing, farming IT systems advance and different systems are being integrated with each other. This development enables new solutions with which a part of the farmer's decisions – and tasks in the future – can be delegated to machines.

Knowledge-based advancement as a driver of change: Genomic big data

The development of gene technology, originating in the 1980s, in combination with the simultaneous growth of computing power opened dazzling opportunities for the digitalisation of gene data and increasing the amount of genetic data available. In the future, the growth of knowledge and development of hardware will move the generation of genetic data out of the laboratories and within the reach of ordinary people. These developments will generate genomic big data and the internet of living things [14].

Socioeconomic changes as a driver of change: Crowdsourcing of natural resource information management

State organisations, such as the Finnish Food Safety Authority, Natural Resources Institute Finland, Finnish Environment Institute and Centres for Economic Development, Transport and the Environment have cut resources spent on practical monitoring and field research and made reductions in personnel. As a result of these cuts, tasks such as the observation of invasive species and forest damage cannot be performed efficiently enough with the organisations' own resources. This has created a need for digital systems that enable citizens to participate in the compilation of observation data.

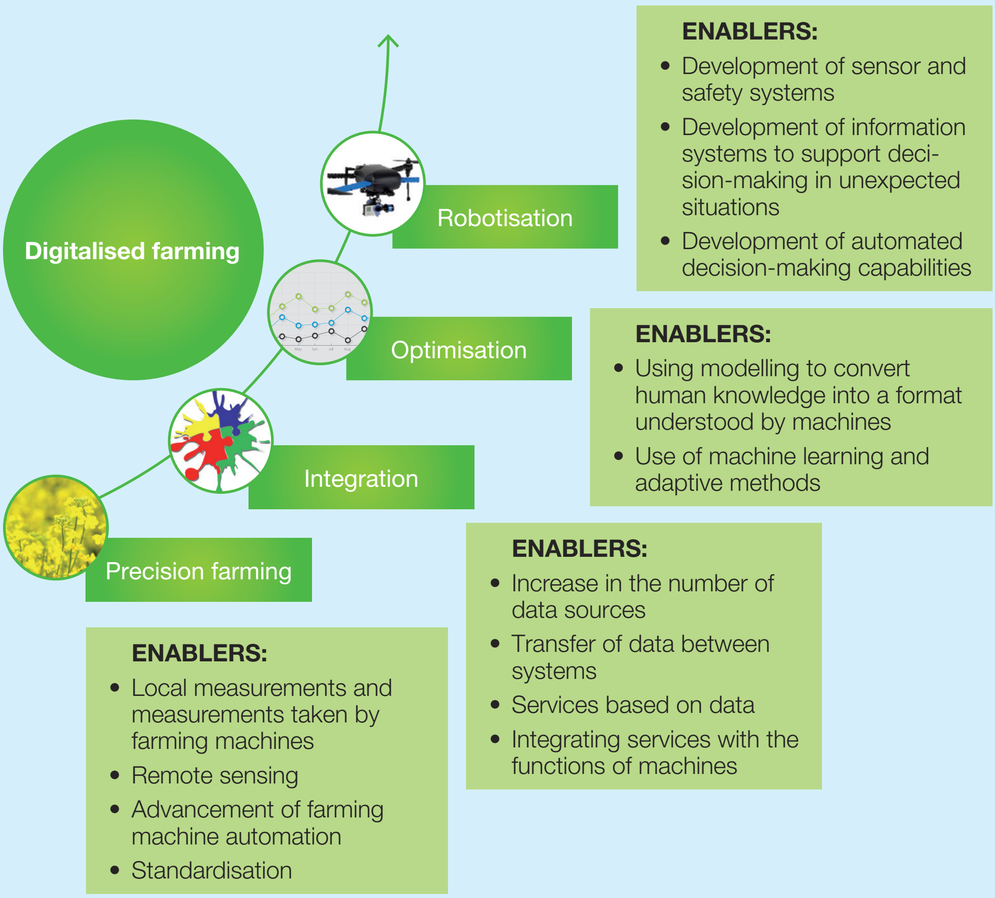
Digitalisation and crowdsourcing create new opportunities for implementing services related to natural resource management and active monitoring. However, the value created by crowdsourcing and the services suitable for the method must be analysed on a case-by-case basis before their full utilisation. Such change would require retuning the entire system to a new mode of operation [20].

Case: Digitalised farming

In the agriculture of the future, a part of the work in the fields could be performed without physical human presence. Robotic tractors will receive their tasks from information systems, and the farmer will supervise the activities of the robot, either from another tractor or on a device such as a tablet while doing other work. Various manufacturers have already generated concept-level studies of such semi-autonomous farms.

Digitalisation must not become an end in itself, however. Instead of just making current production methods more efficient with the technology available, the farming process should be developed into a more environmentally friendly and sustainable direction. The increased amount of data enables the modelling of different phenomena and processes, which increases knowledge. In the end, the new knowledge can be used to steer and automate farming operations [13] .

The development of technology and processes is not a linear activity; rather, it takes place in a networked and gradual fashion in different sectors. Below, we present the steps required for the development of digitalised farming. The standardisation of technology plays a major role in all of the development phases presented below, since the systems and machines of different manufacturers need to work together. In this regard, the future looks promising, since the standardisation process has already begun.



Phase 1: Precision farming

The first phase will be precision farming, in which the use of substances such as fertilizer and pesticides can be adjusted precisely according to needs. This method is already possible thanks to site-specific crop management plans. The plans are based on measurements taken by machines, remote sensing data and manual measurements and analyses. The automation of farming machinery has also advanced to the point where plans can be implemented without manual adjustments.

At present, the precision maps are still mostly created manually, however. It is not yet possible to create prescription maps directly from measurement data. Human knowledge needs to be converted into a form understood by machines, and we need to learn from different farming strategies in different conditions.

Phase 2: Integration

The integration of various systems will enable the increased automation of precision farming and more extensive production control across multiple functions. Planning, quality and measurement data will be transferred between systems before any physical materials are moved. Similarly, data will flow out of the farm with the material streams and enable a greater degree of traceability and processing control. On the other hand, farmers will also receive data from consumers, which will help them develop their operations in the right direction.

The technical development and decline in prices of sensors will enable their wider use in farming. More and more precise information will be obtained on the various parts of crops, their growth stages and the well-being of crops, which will increase the accuracy of modelling and forecasting and further facilitate automated decision-making. Cloud services will be integrated with the operation of machinery, and machines will be able to use data from surrounding data sources in real time.

Phase 3: Optimisation

The next step in the utilisation of the increased amount of data and knowledge will be optimisation. It means finding the best alternative and is always performed in relation to some desired criterion. In farming, this means optimising the entire farming process, not just the more efficient control of machinery. In the development of farming machinery, optimisation supports the utilisation of machine learning and adaptive methods. The functioning of farming machine systems can be optimised by adjusting the machine's parameters to suit the prevailing conditions. At the same time, some routine tasks will be transferred from the driver to the machine.

Phase 4: Robotisation

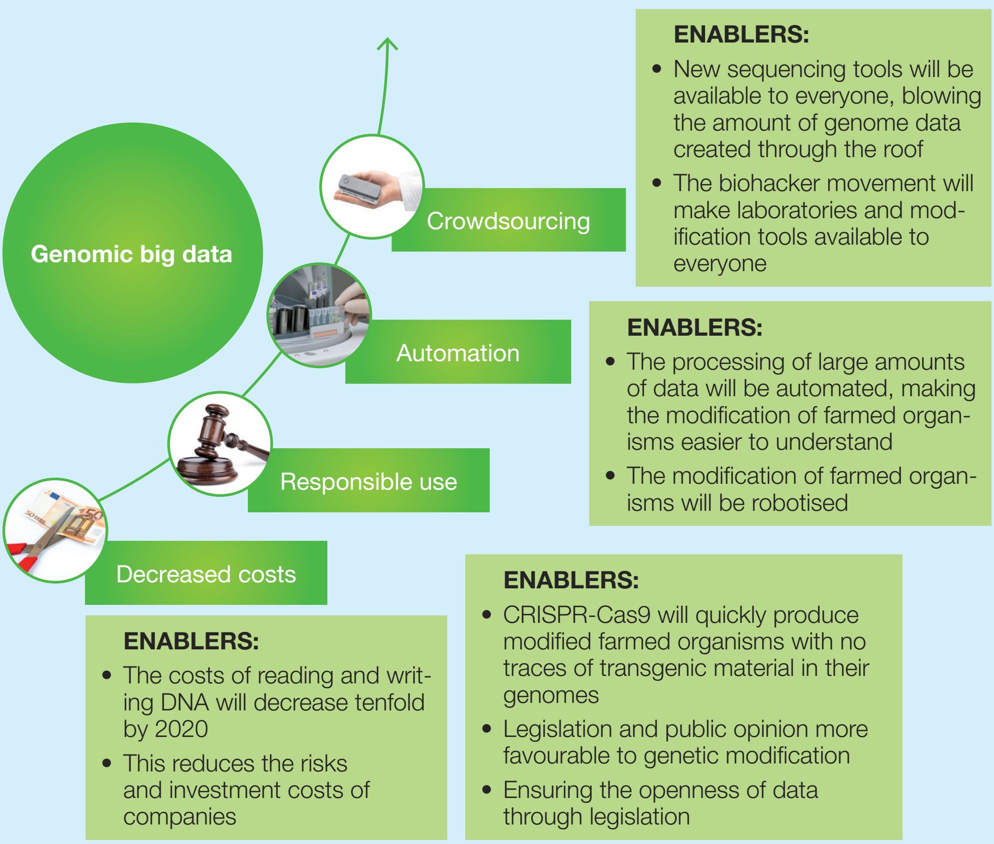
The final phase in the digitalisation of farming is robotisation. The difference between an automat and a robot is that an automat will always perform the same spefic task, but a robot's tasks can be varied. The technology that enables robotised operations is already available and used in farming. In current autosteer tractors, for example, humans are still needed to plan the route and prevent collisions. In the future, the autosteer systems will be able to optimise routes in advance and take into account the shape and crops of field plots, along with routes used previously, making the tractor truly robotic. To be able to handle unexpected situations, the robot will need support from various information systems that enable either independent decision-making or human intervention in the robot's operation.

Case: Genomic big data

Converting the genomes of organisms, such as microbes, plants or animals, into a format that can be processed by computers, i.e. digitalisation on a massive scale, will enable computer-assisted genome design. This can be used to improve the characteristics of farmed organisms and develop entirely new kinds of biological products. The use of digitally designed and saved genome changes will require the ability to convert the genome back into chemical form and inject it into a living cell.

The development of gene technology methods in the 1980s enabled processes such as the production of insulin with yeast and creation of bacterial strains capable of producing powerful industrial enzymes by adding new genes to the production organisms or modifying or deleting some of their existing genes. This type of genetic modification has also been performed on plants and animals for purposes such as improving the shelf life of plants and productivity of animals.

Genetically modified plants are used in food production, particularly in the United States and Brazil [15]. Genetically modified animals are coming to food production: a genetically modified and faster-growing population of salmon developed in the US has obtained the approval of the FDA (US Food and Drug Administration) and is



available on the market. [16] *As a rule, the development of farmed organisms is still based on traditional cross-breeding methods, which are more time-consuming and expensive. For this reason, the work has progressed mostly through trial and error.*

Reading the entirety of the massive genomic DNA, writing dozens of genes and synthetic biology will improve the efficiency of genetic modification. This will enable an entirely new type of genome modification: large synthetic DNA libraries can be designed from digital DNA databanks covering the entire biodiversity of the planet and used to modify the characteristics of farmed organisms or introduce entirely new characteristics on an unprecedented scale. At the same time, the advancement of synthetic biology will increase the quality and speed of genome modification techniques, i.e. the introduction of modified genes to farmed organisms.

The vision is for the entire planet's essential genome data to be digitalised and available for the digital design of new and improved farmed organisms. The digital design and creation of farmed organisms will be so fast and inexpensive that the process will also be available to SMEs.

Microbes are already being genetically modified everywhere in the world for instance in the development of industrial organisms. Advances in synthetic biology will enable the more diverse and efficient modification of microbes, such as for the production of biochemicals. This will enable the use of renewable raw materials to manufacture products that are able to compete with oil. As long as the process ensures that the modified microbes cannot be released into the environment, such production methods are generally approved around the world.

In the production use of genetically modified plants and animals, and food production in particular, the situation is wholly different. The European public opinion is strongly against the production use of genetically modified plants, whereas attitudes are more favourable in North and South America. China and India also produce genetically modified crops, cotton in particular. It is difficult to predict the direction attitudes will take.

Understandably, the public opinion is extremely critical of the genetic modification of animals. It has been demonstrated in laboratory conditions that relatively major modifications can be made to the genotypes of animals such as pigs [17]*. Genetically modified salmon has been approved by the US authorities after more than two decades of trials, which have demonstrated that the salmon in question do not impact their environment adversely and are as safe to use as traditionally bred salmon* [16] *.*

After a long wait, the salmon has received a marketing authorization, and its manufacturer announced in August 2017 that it has already sold 4.5 metric tons in Canada. In practice, the merchants and legislators are sounding out public opinion. Attitudes towards the genetic modification of animals would appear to be the most positive in Korea and China. In Korea, for example, a genetically modified breed of miniature pig is marketed as a pet [18]*. This is probably a way of testing how people will react to the subject.*

The following four development phases can be identified in the utilisation of genomic big data:

Phase 1: Decrease in the costs of reading and writing DNA

It has been estimated that the development of farmed organisms will become ten times as precise and fast by 2020. The change is based on advances in synthetic biology and improvements in the speed of reading and writing DNA. The amount of new, biotechnically produced products such as various chemicals will increase rapidly, because the required R&D investments and risks will decrease.

Phase 2: Responsible use of new gene editing methods for the modification of farmed organisms

New gene editing methods, such as CRISPR-Cas9, enable the production of genetically modified farmed organisms with no traces of transgenic material in their genomes. The *technology will also make the development cycle more than ten times faster. The widespread use of genetically modified farmed plants and, in particular, animals will require responsible practices and consideration of the public opinion.*

In one potential development path, digitalisation will enable the public display of the origin of food ingredients on food packages, making it possible for every consumer to see from where and with which organisms, whether modified genetically or with traditional methods, the food has been produced. As compensation for the maintenance of this open data, the producers could introduce food produced with genetically modified organisms to the market. The testing histories and environmental impact assessments of such organisms would then be openly available on the food package. In this scenario, the open data would maintain "traces" of the product's development path, even tough new gene editing methods do not leave traces on the product itself.

The major challenges threatening humankind, such as food sufficiency and the need to replace fossil-based raw materials, can potentially change attitudes on the use of gene technology. This, in turn, can lead to the amendment of legislation on the subject.

Phase 3: Automation in data processing and the creation of farmed organisms

The amount of data created by gene sequencing is enormous. Massive amounts of genome and phenotype data are laborious to store and process, requiring great computing power and storage capacity. The management of such data requires specialised expertise, such as the contribution of bioinformaticists, further improvements in data transfer speed and the automation of data processing.

Challenges central to the bioeconomy include the automation or robotisation of the modification of the genomes of farmed organisms, analysis and understanding of the effects of changes made to organisms and using the gathered data to develop design algorithms of sufficient quality to crash the price of farmed organism design. These advances will entail significant improvements to current entrepreneurial activities as well as generate entirely new areas of business.

Phase 4: Crowdsourcing of genome data reading

New technologies for reading or digitalising genomes can transfer the reading process from laboratories into the field. Oxford Nanopore Technologies has already introduced a prototype that can read part of an organism's genome in the field or even at home [19]. DNA isolation techniques that enable the reading and instant analysis of genotypes with, e.g. an auxiliary device connected to a smart phone are being developed around these new genome-reading technologies. The vision could thus be the creation of a new concept: the internet of living things, meaning the digitalisation of our living environment.

When citizens will be able to digitalise their own genotypes and genotypes from their environment in real time and save them into an information network with geographic and environmental data, this will open unprecedented potential for modelling ecosystems and predicting their operation, environmental and disease control and the monitoring of personal health. It will also make biodiversity more efficiently available for the design of industrial strains or modified plants and animals.

Case: Crowdsourcing of natural resource information management

Several examples of services in which the active engagement of citizens could complement, and partly compensate for, the decrease in professional observations can be identified in the field of natural resources governance. These include the electronic moose information system (Oma Riista), digital service for invasive alien species observations, forest damage monitoring service and wild berry and mushroom yield monitoring.

The earnings logic of each service must be examined and determined before development. For them to commit to the use and, possibly, development of a service, customers must obtain concrete benefits from its use. Those taking part in crowdsourced data generation may also have their own motives for participating, such as a desire to protect valuable natural sites. At its best, crowdsourcing can generate rich data on people's relationship with and appreciation of the environment, which is valuable to the bioeconomy.

Since there are many data collectors with varying degrees of competence, crowdsourcing involves a quality risk. Such quality issues must be identified and prepared for in advance. This is particularly vital in services in which the crowdsourced data is used for planning measures, such as preventing the spread of invasive species or forest damage.

When the provision and use of a service are based on crowdsourcing, it is impossible to manage the development of a digital service product like in traditional production processes. The management of the crowdsourcing process thus requires consideration:

- How to identify the groups of people with interest in and motivation (short- or long-term) for participating in and using crowdsourced services?
- What types of motivational factors can be identified in potential service users, how can they be used in service development and what impact will they have on the service's earnings logic?
- How to identify the cases and potential services in which crowdsourcing could be useful?
- What forms of crowdsourcing, crowdfunding included, would work in different scenarios?

Phase 1: Need surveys and trials

Discovering the optimal model for each service requires the collection of data from the various parties linked to the service, such as authorities, companies, land owners, clubs, associations and individual citizens. The new service concepts should also first be tested with different user groups before the start of development. A trial period should be reserved before the launch of a service in order to discover potential problems related to its use.

The attitudes of consumers and other parties towards the chosen business model and its functionality can also be charted at various stages of the process.An open culture of experimentation enables the agile testing of highly innovative service models with low costs if the services are developed iteratively and in close cooperation with the interested parties.

Phase 2: Mobile service implementation

In the crowdsourcing of natural resource data collection, it is crucial to consider what type of data should be collected (images, measurements, calculations or other observations), how the quality of the collected data can be ensured, where the collected data will be stored and maintained, and how the collectors of the data will benefit from it. It is also important to understand and develop the service's earnings logic. It should be possible to collect and, if necessary, validate natural resource data collected by anyone.

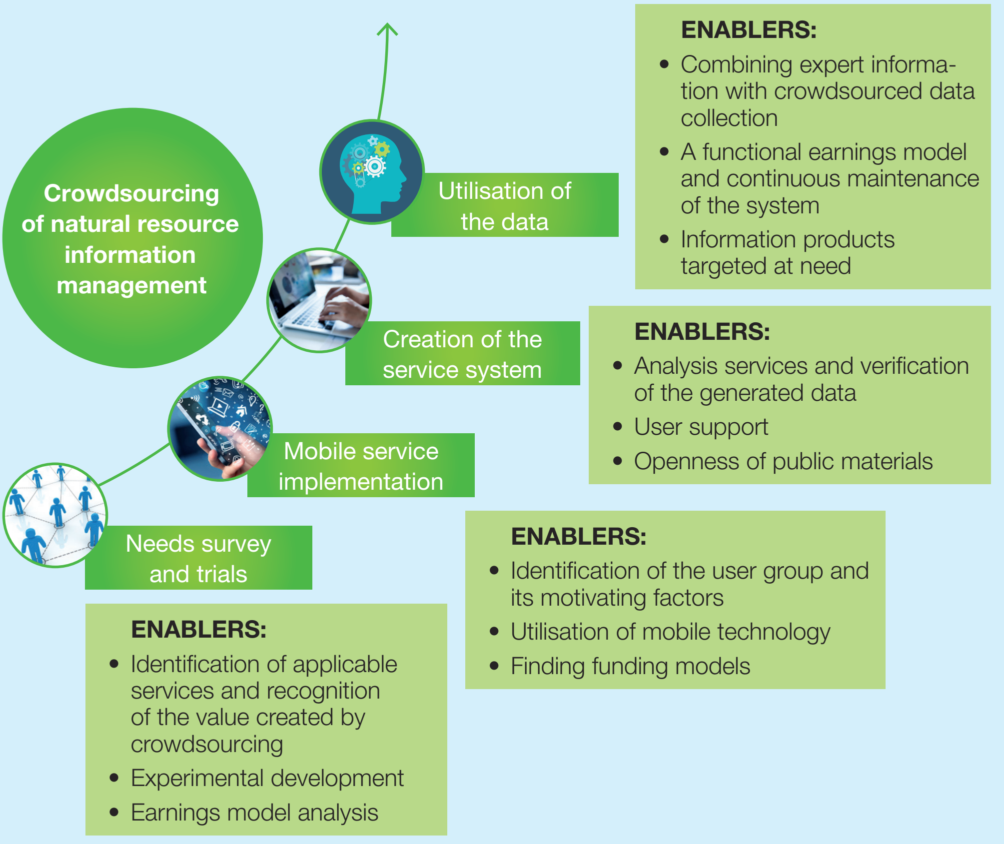
For it to work, use of the service should be rewarding. In some cases, the reward can consist of making the user's own activities easier (e.g. hunters knowing the movements of game, berry-pickers receiving yield forecasts), while in others it could be provided through gamified *elements (activity reward, progress in virtual levels or collecting points), but some services should offer monetary rewards. On the other hand, some services can be subject to a fee.*

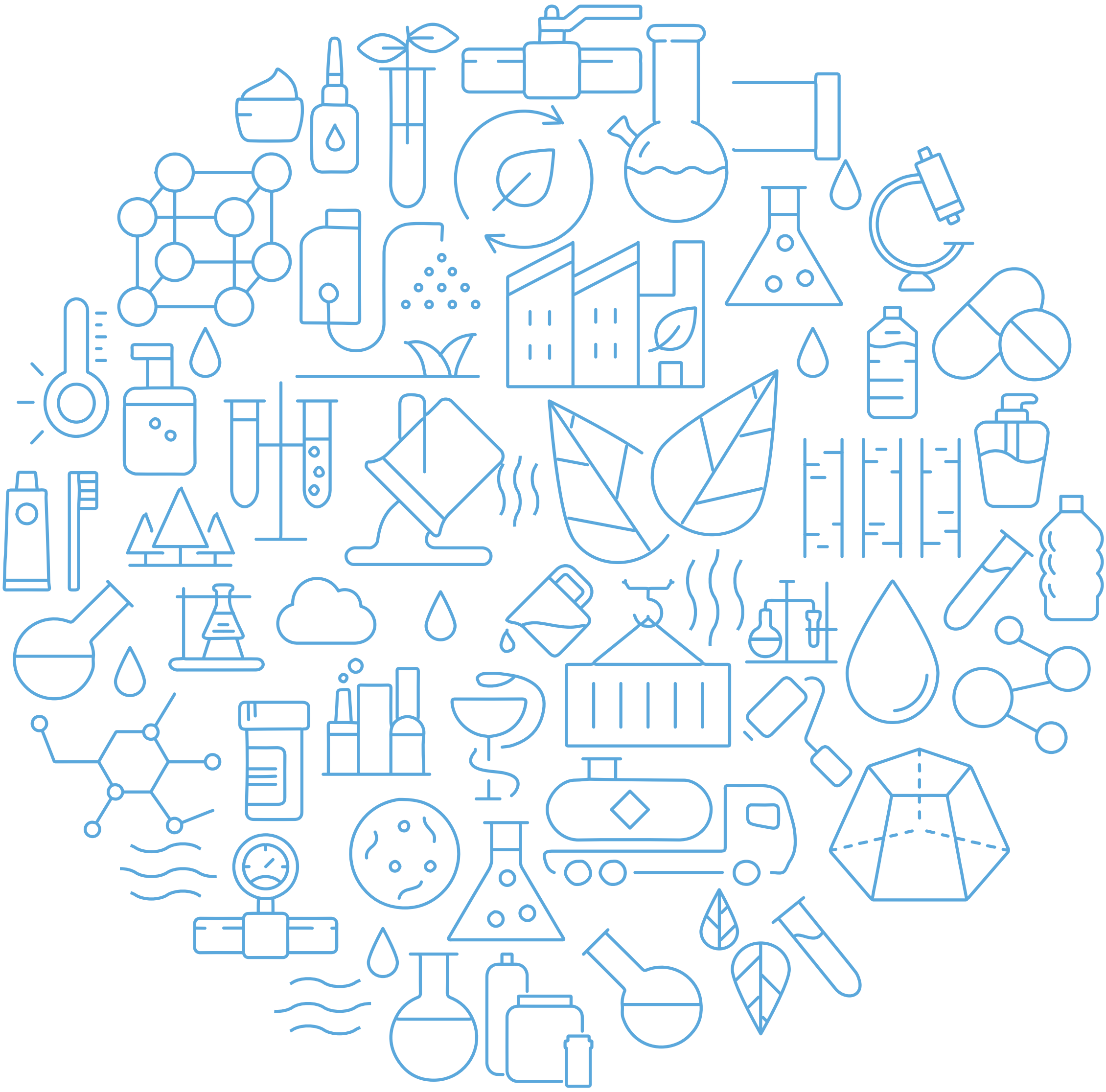
Phase 3: Creation of the service system

The basic idea of services is to enable the equal participation of citizens in data collection in different parts of Finland.However, analysing the results, launching potential measures and drawing up releases and maps always requires the competence of experts. Service development must therefore be viewed as part of the systemic change. The new system cannot be superimposed on existing practices, since ever scarcer resources will not permit the maintenance of parallel systems.

Phase 4: Utilisation of the data

The greatest shared problems in the development of natural resource data crowdsourcing systems are related to identifying the earnings logic of each case, particularly in the development of general, public services. The interests of the data collectors must also be identified, for example when designing predator or game population evaluation systems. On the other hand, the starting point of service development should be finding synergies between the activities of the public and private sectors. The combination of crowdsourced data and official action could create new information, which could in turn increase civic trust and benefit industry and commerce.





3. Transition paths and roadmap

Vision: An agile, networked and collaborative bioeconomy in 2030

Learning and predictive digital systems that support decision-making are part of the everyday operation of the bioeconomy. In the bioeconomy, business is customer-centered and a wide variety of bio-based products and services are available to the industry and consumers. Networks between citizens, producers and authorities increase cooperation and trust between actors and social acceptance for the bioeconomy.

Fossil fuels and raw materials based on non-renewable natural resources have been replaced with products refined from renewable natural resources. The side streams of agriculture and forestry are utilised extensively and raw materials are directed for optimal use by advanced monitoring and ERP systems.

Digitalisation can promote the realisation of this vision and development of the bioeconomy in several ways. In the roadmap, we have defined the bioeconomy's development targets for which information and communication technologies can offer potential solutions (see Figure 4). These are 1) smart biomass flow management; 2) a data-driven bioeconomy; and 3) a networked and collaborative natural resource economy.

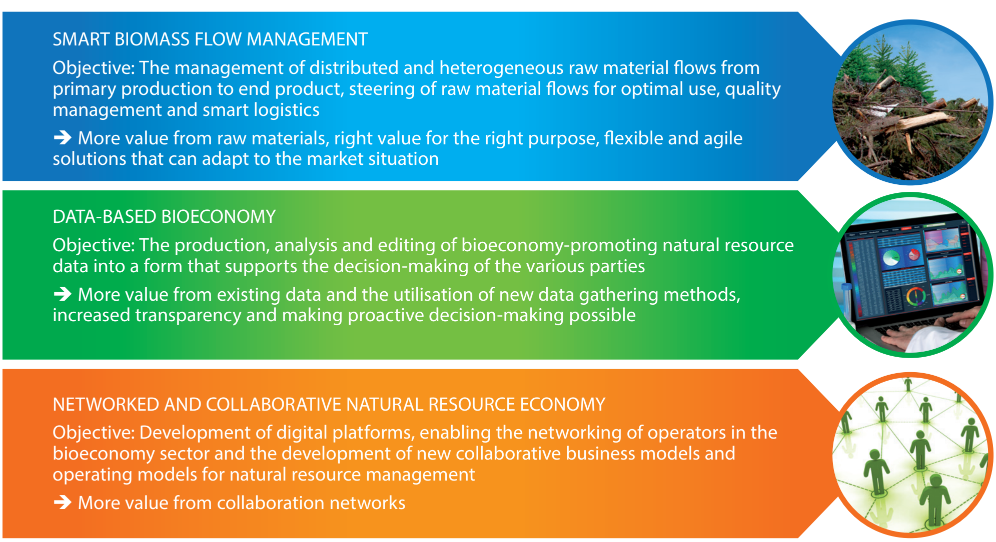


Figure 4. Goals for the transition paths of the smart bioeconomy.

TRANSITION PATH 1:
Smart biomass flow management

At present, the management of biomass flows is made problematic by the dispersed nature of primary production, quality differences in raw materials and waste caused by spoilage. The practical processes are managed by microenterprises or small companies. In 2014, there were a total of 80,629 agriculture, forestry and fishing enterprises in Finland, of which 22% operated in all three sectors. These companies employed 57,000 people and more than 63% of the companies were agricultural enterprises, of which 86% were family farms.

In the forest sector, forest management and harvesting is largely handled by contractors. The personal work contribution of forest owners is constantly decreasing as forests are inherited by new generations and the number of urban forest owners increases. For the most part, the natural resource entrepreneurs making use of the renewable material products and immaterial services of nature are also small-scale operations.

The side streams produced by the natural resource processing industry are highly centralised, but their further use is currently limited by the fact that the data concerning the amount and quality of side streams generated is not open. This is one factor hindering the growth of the side streams market.

In Figure 5, we illustrate how the operating environment, solutions, technologies and capabilities will change in a smart economy based on the efficient optimisation of biomass flows. The middle of the figure highlights development and change requirements that will facilitate the transition.

In the future, producers will be able to produce biological raw materials efficiently for a variety of purposes. Monitoring technologies will make it possible to separate batches of different quality raw materials better, in both primary production and manufacturing, and to deliver them for processing in a profitable and traceable manner. The side streams market will function smoothly.

On the right in Figure 5, the efficient utilisation of the side streams of agriculture and forestry has been emphasised as a key definer of the bioeconomic operating environment. The formation of agroecological complexes and industrial symbioses that utilise side streams in a diverse manner will further emphasise the need for biomass flow separation. These new bioeconomic value networks will produce fertilizer and soil conditioners for agriculture and forestry, along with more processed chemicals and new biological raw materials for the manufacturing industry [21]. The optimisation of the raw material flows of agriculture and forestry will also promote the production of new biological fuels and, thereby, the transition to fossil-free energy production.

Advances in precision farming methods will go hand in hand with the optimisation of raw material flows. The pressures for this originate from the cost-efficiency requirements created by global competition and the need to manage the nutrition load of agriculture. The need for automated quality control and monitoring will also be emphasised in domestic animal production, which will be subject to immense cost-efficiency pressures. The need for monitoring is also increased by the consumers' interest in the welfare of farmed animals and concern for food safety.

At present, valuable quality batches produced by agriculture and forestry either remain undiscovered or are so small that their separate processing and marketing is not profitable. A comprehensive data collection system for forest resources and fields will enable the smart management of biomass flows in the future. There is a wealth of regularly updated inventory and remote sensing material available on forest resources, such as aerial and satellite photographs [22], and forestry machines are already collecting site data from their environment while working. In agriculture, feeding automats and harvesting machines are also producing data on subjects such as nutrient flows. Monitoring will be further improved by the constantly dropping prices of sensor technology, including printed electronics and biodegradable sensors.

Developmental bottlenecks include combining different data sources and the development of ERP systems that could make use of the data. The automated separation and remote management of raw material flows will also require advances in the monitoring and identification infrastructure and guidance systems. Methods for quality measurement and control are currently in development for both agriculture and forestry and, in combination with IoT technologies, will enable the better optimisation of raw material flows.

Smart biomass flow management

	NOW	CHANGES	IN THE FUTURE
OPERATING ENVIRONMENT	The varying quality and dispersed primary production of the raw materials of the bioeconomy set special demands for raw materials management. Finland's agriculture is suffering from profitability problems and the dilemma of nutrient pollution remains unresolved.	• Increase of resource efficiency • Growth in farm size • Transformation of the forest industry into the biorefinery industry • Development of industrial and agroecological symbiose	The transition to a bioeconomy and circulation economy has progressed. There are new raw materials and biological products on the market. Energy production is moving from fossil-based to renewable energy sources. The efficient utilisation of side streams has become commonplace.
SOLUTIONS	The management of nutrient circulation in forests and on farms is based on data collected from different sources and compiled, in part manually. The growth of computing capacity and development of data transfer networks have nevertheless enabled the development of targeted applications for various data needs.	• Use of sensors and automated steering on farming machines • Development of flying robots used for imaging • Development of electronic quality assurance for meat production, farming and forestry • Development of predictive ERP systems	Automated steering making use of terrain and weather information has improved the efficiency of wood harvesting, and wood raw materials can be directed to optimal use. Digitalisation has brought advances to precision farming and the well-being of farmed animals and increased opportunities for remote-controlled and dispersed production.
ENABLERS	There is a great deal of remote sensing material and measurement data available on forest resources and fields, but the data is not being utilised fully. Finland has a strong foundation of expertise in the forestry and forest industry, as well as in information and communication technology.	• Decrease in the cost of sensor technology, biodegradable sensors • Advances in separation and identification technologies and development of the monitoring and identification infrastructure • Availability of more accurate weather data • System integration based on standardisation	Advances in closed-loop technologies and systems have created a strong sector consisting of the bioeconomy and supporting IT solutions. Integrated data sources and advanced calculation infrastructures create a solid foundation for development.

Figure 5. A roadmap to smart biomass flow management.

Case: Digital solutions for the more efficient utilisation of timber [23]

The seamless and efficient functioning of raw materials delivery chains is essential for the functioning of the bioeconomy. Cost-effective, on-time and quality-conscious deliveries of wood biomass from the forest to refineries are a vital part of both the industrial and energy wood delivery chains. Information such as refining plant operation forecasts, stock quantity and quality data and their forecasts, combined with geographic data and data on the condition of the road network open new vistas for digital solutions to optimising transport and improving the efficiency of the entire timber transport chain.

The figure illustrates how digital solutions can be used to improve the efficiency of the timber delivery chain. Everything is based on up-to-date information on forest resources, which can be compiled from several data sources. Digital solutions can support production control at biorefineries and the timely deliveries of timber.

Multisource, verified and up-to-date forest resource data

The sustainable utilisation of timber and other forest products is based on sufficiently accurate and up-to-date data on renewable natural

OBJECTIVE:
Multilayer forest resource data compiled from several data sources, including interpreted material as well as tools that enable further analysis

OBJECTIVE:
Information on the growing stock, terrain conditions and road trafficability are automaically updated using weather data and data provided by timber trucks.

OBJECTIVE:
The market and demand information of the product portfolio is used by biorefinery's production management. This information is seamlessly transferred to biomass sourcing to be used for steering of raw material supply.

ENABLERS

Development of digital technologies
- Generation of multisource growing stock and condition data, data analytics and distribution to users
- New sensors for sensing logging conditions and measuring the logging footprint
- Cloud technologies for data management
- Smart automation and robotics

Innovation activities
- Culture of experimentation
- Multi-actor projects, joint development

Development of delivery chain tools
- Unique electronic batch identifiers
- Precise positioning and communication between machines

Biorefinery interface
- Dynamically updated production forecast
- Interactive demand forecast and communication with the procurement chain
- Continuous quality feedback and measurement

resources. Remote sensing, such as satellite imaging and airborne laser scanning, has been used for charting the resources of large forest areas for some time now. For smaller forest areas, miniature UAVs are available for collecting data on growing stock, with either a digital camera or small laser scanner.

Remote sensing is supplemented with measurements taken on the ground. The latest methods include mobile applications for measuring the volume of growing stock, along with portable and vehicle-mounted laser scanners. Digital image interpretation and more efficient calculation methods have significantly improved the accuracy of data and cost-effectiveness of data collection. Precise forecasts on species-specific diameter and height distributions and, increasingly, quality make significant additional data available for timber procurement and trade.

Continuously updated harvesting condition, road network and stock data

Approximately 2,000 harvesters are in operation in Finland every day. The stand-specific data collected by these machines provides an enormous store of data, which can be used to improve the efficiency of forest exploitation through digitalisation.

The forest machines of the future will be partly automated and measure their own operation and the forest environment during work, which will improve the efficiency of forest management and wood harvesting (e.g. charting and modelling the accessibility of terrain, driver guidance systems, measurement of remaining growing stock and the collection of real-time rot data in connection with logging). The measured data is provided to the driver for guidance and delivered to the logging company and timber procurement organisation for improving the efficiency of machine use.

This development is promoted by improvements in the level of education, the scarcity of resources, increasing environmental consciousness, cheaper sensor technology and advances in wireless data transfer. According to current knowledge, fully automatic harvesters are still a long way off, as challenging conditions and variable terrain pose difficulties in the development of such solutions.

Similarly to forest machines, timber trucks also feature systems that facilitate the control and implementation of operations. Drivers are supported by map-based navigation systems, which show the locations of road-side landings, amounts of different timber types and locations of timber chosen for transport. Logistical control is based on the needs of mills and status of road-side landings, and daily transport plans are created on the basis of this data.

The adaptiveness of these systems is crucial. The timber trucks then reserve the transported timber type or types from the selected landings. Loaded timber types are also immediately updated into the system and become visible to other vehicles. Certain large mills have delivery windows for arriving timber, and these are also visible in the vehicles' information systems.

Predictive biorefinery control system

In their operations, biorefineries must manage heterogeneous and dispersed raw material flows. The biorefineries of the future may also produce several different products. From the perspective of economic viability, refineries may need to be able to control their production flexibly, taking account of the availability and price of raw materials and the demand forecasts and projected prices of their products. Seasonal variations in the availability and quality of raw materials, along with predictive consideration of maintenance needs, also have an impact on the profitability of the biorefinery. For these reasons, biorefinery control represents a complex decision-making scenario that could be supported by the development of systems that utilise a broad scope of data.

The development of biorefinery control systems that utilise big data and predictive models would require resolving several questions of data management. Firstly, it must be possible to combine different data sources, for example through a cloud service. The combination *of different services and data sources requires a common platform, which in turn requires functional information security and user rights management solutions. Providing a sufficient amount of required data to the system will also require changes to current practices. For example, the availability of electronic forest resource data should be ensured and timber trading would have to take place electronically. The providers of maintenance services would also need to be integrated into the system.*

In one potential future operating model, the device manufacturers would be responsible for production process condition monitoring and production-phase maintenance on the basis of operating data sent by the machines. The expansion of the device manufacturer's role into machine operation could blur the lines between producer and operator. Providing device manufacturers with access to operating data would enable the utilisation of the data in the further development of processes.

Case: Digitalisation of animal production[24]

According to forecasts, the global consumption of foods of animal origin will double during the next decade. We have to be able to produce meat and milk more efficiently and ecologically. Consumers are also placing more importance on the well-being of animals. In the future, producers should offer more stimuli to animals and will need more space per animal. The monitoring of the animals' health must be improved and health issues prevented through changes in production methods.

Traditional animal-based agriculture, or the production of meat, milk, eggs, fish and fur, can optimise its productivity through automation and new, data-oriented functions. The automatic monitoring of domestic animals with various sensors and other digital data sources has already been introduced to the production control of some farms.

As the amount of monitoring data increases in the future, the data-based optimisation of farm production can be based on the comprehensive control of the animals' nutrition and breeding along with the tracking of their growth and health, anticipation and prevention of problems, management of material flows or farm processes, automatic reporting and the management of logistical functions.

Healthier animals will generate more income for the producer. The utilisation of sensor data in the monitoring of the health and well-being of domestic animals will also enable more ethical production that is simultaneously more transparent to consumers. New measurement methods enable the automatic monitoring of the well-being of animals. There are several commercially available systems for applications such as indoor positioning, measurement of time spent lying down and monitoring activity. Such data would create new customer value for animal farms if it would be used, for example, as a pricing basis for products, and producers offering traceably good living conditions to their animals could charge extra for their products. The growth of consumer awareness of animal conditions and demand for ethically produced food could thus promote the adoption of new technologies.

Advanced sensors, devices, information networks and IoT platforms and data sources enable the generation of new, more precise data at less cost. Imaging technology is well-suited to the controlled environments typical in agricultural production. The monitoring of animal well-being could also make use of solutions originally developed for independent health monitoring.

Connecting a motion sensor to a wireless IoT device would be an example of such solutions. Crowdfunding and growing investor interest in agriculture increase opportunities for the development and productisation of solutions.

The figure below presents the potential of digitalisation in animal production, particularly through advances in information systems, sensor technology and imaging technology. As a fourth example, we examine the better utilisation of animal production side streams, especially manure. More extensive descriptions of the examples can be found in the electronic appendix to this report.

Digitalisation of animal production

Sensor technology in the monitoring of animal well-being

OBJECTIVE: An automatic system for monitoring animal well-being, replacing or complementing inspections

ENABLERS:
- Development of measuring devices
- Development of well-being models making use of measured data
- Standardised data transfer
- Development of a national information system and its integration with food industry processes

Imaging technologies in animal production processes

OBJECTIVE: Making use of imaging technology, for example in the weight and meat quality assessments of slaughter animals

ENABLERS:
- Collection of extensive development data
- Combination of imaging technology with other measurements, e.g. ultrasound measurement of external fat
- Creation and testing of the model
- Application development

Information systems

OBJECTIVE: Centralised data collection and enrichment, with the objective of a service business based on a digital platform

ENABLERS:
- Data analytics expertise (e.g. machine and deep learning)
- Data collection expertise (e.g. calibration, traceability, utilisation of context)
- Data transfer expertise (e.g. wireless data transfer, 5G)
- Standardisation, platform development
- Creation of a service business

Utilisation of the side streams of animal production

OBJECTIVE: More efficient use of manure in, e.g. fertilizer or energy production

ENABLERS:
- Process development (e.g. biogasification, pyrolysis, microbiological processes)
- Development of devices for the preliminary processing of manure
- Map-based availability data (e.g. a Biomass atlas)
- Piloting of commercial operations

TRANSITION PATH 2:
Data-driven bioeconomy

In a digitalised society, information is one of the most important production inputs. The bioeconomy is no exception in this regard. Various parties are generating increasing amounts of data on natural resources, and that data is used by consumers, producers and the authorities regulating and supervising the use of natural resources.

Factors related to the creation of a data-driven bioeconomy have been compiled into Figure 6. At present, the monitoring of climate change and biodiversity, along with the related contractual obligations, are increasing the need for data in Finland and abroad. Other key change trends that increase the need for data include increased consumer interest in the origin of products, sustainable friendliness of production, quality of raw materials and ethical questions related to production.

The current trend of moving from products to services is also steering us towards a bioeconomy based on the more intensive use of data. Natural resource data, such as the health benefits of intangible recreational services or nutritional values of food, will be an integral part of the service built around biological products. The proliferation of such services will be assisted by the increased use of consumer applications that track well-being, such as activity bracelets and various energy consumption calculators. The food-production impact of technologies that enable extensive tailoring of food production is discussed in more detail in the Food Economy 4.0 vision published by VTT [25].

The identification of benefits obtained from natural resources and customer needs related to information on such benefits will be required in order to effect the transition from a production-oriented to a consumer-oriented bioeconomy. In this regard, we will see more and more virtual and gamified ecosystem services, in which the well-being or recreational service has been detached from the physical natural resources it is based on.

Services that produce and enrich natural resource data for the strategic planning, monitoring and predictive decision-making needs of producers and authorities, as well as for natural resource services aimed at consumers, are a key area of the smart bioeconomy. These will enable, for example, more efficient forestry service offerings to forest owners, more transparent and efficient official processes, the minimisation of biological risks and the development of the natural resource information service business.

The prospects of an economy based on natural resource data are promising, since there is a great deal of data on forest resources and agricultural production already available. On the other hand, this same aspect will pose a development challenge to the data-driven bioeconomy. In the middle part of Figure 6, we have compiled steps required for the development of business based on the available data. There is much data available from different sources, but it is highly heterogeneous. In addition, the combination and further refinement of different data stores into a form usable in specific decision-making situations is currently difficult due to shortcomings in standards and analysis methods.

The fast and reliable movement of data in the value network is a key issue for the development of natural resource information service development. The development of standardised and certified data collection and transfer systems is of paramount importance for the creation of services that utilise natural resource data. The processing of enormous amounts of data also requires cheap and fast computing infrastructure. The development of open and uniform cloud services enables the use of extensive data stores by various actors and, at its best, the creation of a global market for natural resource information products.

Practices of data ownership and privacy protection can create a bottleneck for the data-based bioeconomy. The creation of new service business would benefit from the availability of comprehensive open or affordable, high-quality natural resource data. In order to promote the use of the data in the exploitation of forest resources, the Ministry of Agriculture and

Forestry has decided to open its natural resource data to the public. Indeed, the Metsään.fi forest resource information service is a key resource for the development of new information services. At the same time, it is eroding the foundations of the business of the forestry centres and forest service entrepreneurs, which was based on closed data.

The proliferation of free and more precise open data will thus force bioeconomy operators

Data-based bioeconomy

	NOW	CHANGES	IN THE FUTURE
OPERATING ENVIRONMENT	Forest planning and the system of agricultural subsidies create information needs concerning natural resources. The data collection required by climate treaties has also begun. Forest resource data is available from various organisations and services, which creates overlap and inefficiencies in data management.	• The servitisation of society also has an impact on the bioeconomy • The traceability requirements of raw materials will increase • The identification and utilisation of customer needs will be core development needs	The integration of different forms of production has progressed, which has emphasised the need for information. The importance of the environmental friendliness and sustainability of bioeconomy processes has increased. Immaterial ecosystem services have increased in significance in addition to financial benefits.
SOLUTIONS	The guidance systems of machines have improved, and the collection of data to improve the efficiency of farming practices would be possible, but the various systems are not communicating with each other yet.	• Information system standardisation and data integration • Development of data analysis methods • Development of business models • Utilisation of genome data: from the Internet of Things to the Internet of Living Things	A cloud-based forest resource data calculation and service system has been adopted. The timber trade has moved to electronic systems, and there are fully automatic machines and gamified virtual recreation services on the market. Genome data is used more extensively in plant and animal production.
ENABLERS	There is a wealth of imaging material and cartographic data on forest resources and fields. The development of the computing infrastructure will facilitate the use of this data. Finland's efforts to host data centres will improve data infrastructures even further.	• Opening closed data • Clarification of the practices of data ownership exchange and data protection • Advances in image analysis and machine intelligence • Availability of computing capacity • Decrease in the prices of writing and reading DNA and designing biological systems	Decision-support, learning and predictive systems and intelligent systems that monitor the work environment, machine and operator create a foundation for the operation of the data-based bioeconomy and improve the efficiency of human-machine interactions.

Figure 6. A roadmap to a data-driven bioeconomy

to rethink their earnings logic and develop more refined information products and services that create explicit added value.

In order to be able to compete, the new products should be designed from a genuinely user-oriented starting point. User-oriented design includes the analysis of current services and processes, identification of customer needs and combination of diverse aspects into novel services. In many cases, the adoption of a data- and service-based model will require taking a completely new role in the value chain. Such changes are not always quick or easy to make, but require an open mind for searching for new solutions and acquiring new capabilities.

Case: Biotalouden tietopalvelut

In the digitalised bioeconomy, data analysis services on natural resources and the consequences of their use will be an increasingly significant part of the bioeconomic output. Applications that filter, combine and analyse data collected from different sources and support the decision-making of consumers, entrepreneurs, public bodies and citizens will play a major role. At their best, such applications will keep track of the previous choices made by their users and learn to offer ever more tailored and precise support for decision-making.

The cornerstone of the data-based bioeconomy is thus a growing situational awareness of the baseline of justifications for production and consumption decisions, such as forest resources, nutrient balances or the ecological footprint and nutritional value of food. Such situational awareness will be made possible by data generated by various actors into shared cloud services, standardised data transfer practices and interfaces between systems, along with applications developed for data analysis. There will also be new, virtual well-being services available.

Next, we will present some examples of services on which the data-driven bioeconomy could be based.

Tailored food service

To the consumer of the future, food will be more than simple nourishment. It will be a comprehensive well-being service and way of demonstrating your values to others. Consumers will decide what kind of meal to cook on the basis of health information from My Data and the energy consumption calculations made by their activity bracelets. The choice will be made easier by the fact that the mobile recipe service will remember which flavours the consumer has enjoyed in the past. The recipe service also knows that the consumer prefers local production and can search for meal suggestions based on local products.

The service orders the required ingredients to the consumer's home or a pick-up point along the consumer's commute. After the meal, the consumer will give positive feedback to the online community established by the producer, read the farm news posted by the producer into the service and recommend the service to the consumer's friends on the social media. The consumer will also update the details of the meal into the online service that tracks his or her energy consumption and intake of required nutrients. In the online service, the consumer can read and comment on the posts of others.

Electronic forest service

The forest owners of the future will receive forest management and logging plans for their forests from online services. These are based on remote sensing data and the open cartographic data from the multisource National Forest Inventory (NFI), supplemented by data generated by international satellite services such as the European Copernicus system or American Landsat satellite. The service will consider the yield and management practice targets specified by the forest owner for his or her forests. A mobile application using the same data keeps the forest owner up to date on the value of his or her forests and helps in deciding whether to accept purchase offers made in the online timber trading service or the forestry service entrepreneurs suggestions on forest management measures.

If the forest owner wants precise information on matters such as the forest management requirements of a specific stand or possible pest damage, he or she can send a photograph of the site to the forestry planning service and receive an evaluation within minutes. The evaluation is generated automatically and supplemented by consulting an expert where required. The service is offered by a Finnish company that provides equivalent services for the international market and uses open forest resource data and an international network of experts in its operations.

Regional nutrient circulation ecosystems

The recycling of the nutrients contained in the side streams of primary production and industry and, to an extent, municipal waste for use by the industry or back into fertilizer or human or animal nutrients will be commonplace in the bioeconomy of the future. The recycling of dispersed streams will be based on local ecosystems that are composed of several operators and share information on available side streams, nutrient types and needs.

The information is shared through a regional, map-based nutrient atlas and the use of nutrient streams is optimised by advanced ERP systems. The operations are mediated by companies specialising in the recycling of nutrients, which accept nutrient-rich side streams, such as manure and plant waste from farms and side streams from the manufacturing industry and service sector (retail, restaurants and catering). The ecosystems

Information services in the bioeconomy

Tailored food service

OBJECTIVE:
A service combining personalised data and several data sources, which proposes suitable meal recipes for the user and orders the required ingredients to the user's home or a pick-up point

ENABLERS

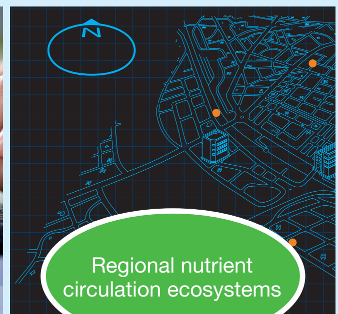
- IoT for data collection and data transmission
- Cloud technologies
- System integration
- Big data technologies and data analytics
- User-oriented development, user experience
- My Data
- Mobile communications

Electronic forest service

OBJECTIVE:
A forest owner's service that generates forest management and logging plans based on real-time information and brings buyers, sellers and forest management entrepreneurs together, creating a seamless service

ENABLERS

- Remote sensing, satellite data
- Cloud technologies
- System integration
- Big data technologies and data analytics
- Mobile communications
- Electronic marketplaces
- Positioning technologies
- My Data
- Multi-actor projects, joint development
- Change in operational culture



Regional nutrient circulation ecosystems

OBJECTIVE:
An operational ecosystem that enables the utilisation of nutrient-rich side and waste streams, based on map data on the availability of nutrient sources and automated control systems that optimise the use of nutrients

ENABLERS

- Sensors, sensor networks
- Printed electronics, IoT, M2M
- Mobile networks, 5G, WLAN
- Big data technologies and data analytics
- Information systems (e.g. the ”nutrient atlas”), system of systems
- Open data, corporate data
- Dashboard, information ergonomics
- Cloud services
- Automation
- User interface, HMI in general

are open to ”pop-up” batches of side streams and customers for specific nutrient types.

In addition to regional situational awareness, efficient nutrient recycling will require farmers to have precise knowledge of the phosphorus and nitrogen statuses and balances of their production processes. This information will steer and regulate processes towards optimal nutrient use, either by the precise dosing of nutrients according to process performance or by improving process performance to utilise nutrients more efficiently. The latter target can be reached by adjusting other production parameters, such as irrigation, timing, other nutrients, plant protection or veterinary activities. The adjustment decisions can be fully automated and made by machines.

This operating model requires the development of affordable sensors suitable for the measurement of ammoniacal nitrogen, nitrous oxide and sulphate concentrations in dispersed systems. In addition to farm production control, the sensors will also be used by the regional ecosystem as part of the automation and monitoring systems of fertilizer and feed production and logistics.

Enablers and obstacles of the data-driven natural resources economy

Finland has excellent potential for becoming an international top expert in the data-driven bioeconomy. The operations will be based on advances in remote sensing and sensor technologies and the openness of data. The development will be hindered by the lack or ambiguity of data collection and transfer standards. The availability and usability of data varies between segments, such as the management of forest resources or nutrient circulation [26].

In addition to expert systems, decision-making will be supported and guided through the social media as people share their experiences and receive feedback on their choices from others. However, the availability of such shared data requires consumers to be motivated to share their data. There has to be some reward for sharing, be it a sense of belonging in a community, obtaining information or a monetary compensation. Questions of data protection also limit the usability of such data, and the practices in this area require development and clarification.

TRANSITION PATH 3:
Networked and collaborative natural resource economy

Factors that revolutionise bioeconomic business activities based on production chains and natural resources management based on hierarchic management models have been compiled into Figure 7. In the smart bioeconomy, agile and networked operating models will arise alongside these traditional models.

There are many small agriculture and forestry operators that could benefit greatly from collaboration, as described in transition path 1. Digital services enable small producers to pool their resources and deliver small batches flexibly according to demand. Digital service platforms also bring consumers closer to the producers, which increases the need and potential to build consumer-oriented bioeconomic business models. In the smart bioeconomy, operations are increasingly defined by various online communities formed by producers and consumers. These communities exchange information on

Data-based bioeconomy

	NOW	CHANGES	IN THE FUTURE
OPERATING ENVIRONMENT	The monitoring of environmental effects is required by international treaties and national legislation. Climate change will further increase this need for monitoring. In the agriculture and forestry sectors, there are many small operators that need solutions for coordinating their cooperation and operations.	• The significance of communities will grow • Supervision of the responsibility of business operations requires attention • The spread of invasive species and climate change will increase the risk of forest damage	Digital platform developers have a significant role in enabling business. More small, agile operators capable of leveraging networks have entered the industry. The importance of responsibility has been emphasised and servitisation has advanced.
SOLUTIONS	The official system of collecting environmental data is suffering from cuts to field resources. Producers have a weak bargaining position with operators in the centralised food production chain. The development of e-commerce solutions will change the nature of commerce.	• E-commerce platforms • Crowdsourced yield, forest damage and genome data • Development of digital platforms and collaborative models for producers • The electronic distribution and marketing of immaterial ecosystem services	Citizens, producers and authorities have functional cooperation networks. The generation of natural resource data has been crowdsourced and producer networks are capable of fulfilling precise delivery requirements on demand. Bioeconomy services are produced by collaborative networks of producers and consumers.
ENABLERS	The proliferation of everyday information technology and mobile applications will make digitalisation a part of everyday life. This change will be supported by the use of social media and easier mobile payments. Amateur naturalists will take part in the collection of natural resource data, for example in game and biodiversity surveys.	• Growth of the platform service business (transport pools, producer-consumer networks) • Uniform systems for collecting natural resource data	The spread of the sharing economy will promote the active role of consumers (prosumers) and small entrepreneurs in the bioeconomy.

Figure 7. A roadmap towards a networked and collaborative natural resource economy.

products, learn from the experiences of others and build customer relationships.

Interactions between producers, citizens and the authorities that supervise the use of natural resources will benefit from online communications, as will practices of collaborative natural resource management. As natural resource management and research resources diminish, digital services can also be used for the crowdsourced monitoring of environmental changes and the impact of natural resource use, based on the initiative of individual citizens, as described in Chapter 2. The need for such data collection will only increase as a result of the uncertainty caused by climate change. Phenomena such as the growing flood of invasive species and increased forest damage risks would require monitoring even now. These phenomena are evident in aerial and satellite photographs, but their more detailed charting would require monitoring on the ground, in which private citizens could be a vital resource.

At its best, engaging citizens in the monitoring of environmental changes and natural resource use will lay the foundation for social acceptance of the bioeconomy sector and natural resource management activities. However, citizens will not be automatically motivated to produce data and cooperate with authorities, and the crowdsourced collection of comprehensive, high-quality and reliable natural resource data is a highly demanding task.

Such cooperation is helped by the proliferation of mobile devices and development of applications suitable for data collection. There is a tradition of crowdsourced natural resource data collection in the monitoring of endangered species and game populations. In these areas, active enthusiasts have been an important source of information for the supervisory authorities for years now.

Networked business models improve the position of small producers in the markets for raw materials and end products produced from natural resources. At present, small-scale operators frequently have difficulties obtaining the best prices for their products and output and getting their production input for the best price. In addition to offering joint product batches, networking will enable the development of flexible and affordable logistics services that make use of available unused space.

Since online service platforms facilitate direct transactions between producers and consumers, the significance of intermediaries, such as wholesalers, in the management of product flows will decrease. However, direct commerce will require marketing and interaction skills from the bioeconomy sector's producers; skills which are not needed for operating in the traditional raw materials chain. For this reason, digital service providers have a key role in the development of online service business for the bioeconomy.

The possibility to market your own products without middlemen and easier cooperation between small operators will decrease the consumers' dependency on the market's gatekeepers. The reorganisation of the bioeconomy's value networks also involves consumers taking an active role in production. These prosumers will take part in tailoring products on service platforms, and may even manufacture the products themselves with new technologies such as 3D printing.

In the best scenario, a more equal balance of power between the various bioeconomy operators in joint delivery and value networks will promote the social sustainability of the bioeconomy. Networked operating models will promote the birth of new types of producer communities and communities of producers and consumers. Increased interaction and transparency will also support responsibility and the building of trust between operators.

Case: Information flow in networks and networked activities in the food production [27]

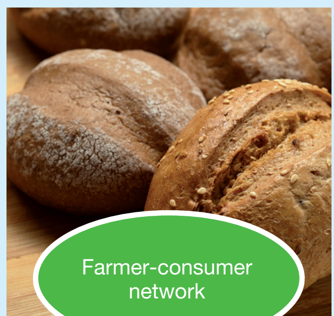
It is vital for the balanced development of the bio-economy that primary producers remain viable and that biological raw materials are produced efficiently and for diverse applications. It would be beneficial for the development of the bioeconomy to be able to separate batches of different qualities in primary production and deliver these batches to refinement processes in a profitable and traceable manner. Valuable quality batches frequently either remain undiscovered or are so small that their separate processing and marketing is not profitable.

Small-scale operators frequently have difficulties obtaining the best prices for their products and output and getting their production input for the best price. A more equal balance of power between the various bioeconomy operators in joint delivery and value networks would be important for the development of a sustainable bioeconomy.

Information flow in networks and networked activities

OBJECTIVE:
A virtual marketplace, enabling farmer collaboration in the marketing of production batches

OBJECTIVE:
A collaborative model for the farming community and processing industry in which farmers will be able to deliver batches of a specified quality with joint liability, regardless of the season



OBJECTIVE:
A service using origin information and augmented reality to enable direct communication between consumers and farmers

ENABLERS

- Development of digital technologies for the data collection and control of IoT production processes
- New sensors
- Cloud technologies
- System integration
- Smart automation and robotics
- Big data technologies and data analytics

Innovation activities

- Culture of experimentation
- Multi-actor projects, joint development

Development of delivery chain tools

- Mobile communications
- Unique electronic batch identifiers
- Electronic marketplaces
- Positioning technologies

The consumer interface

- My Data
- Social media
- E-commerce
- Augmented reality

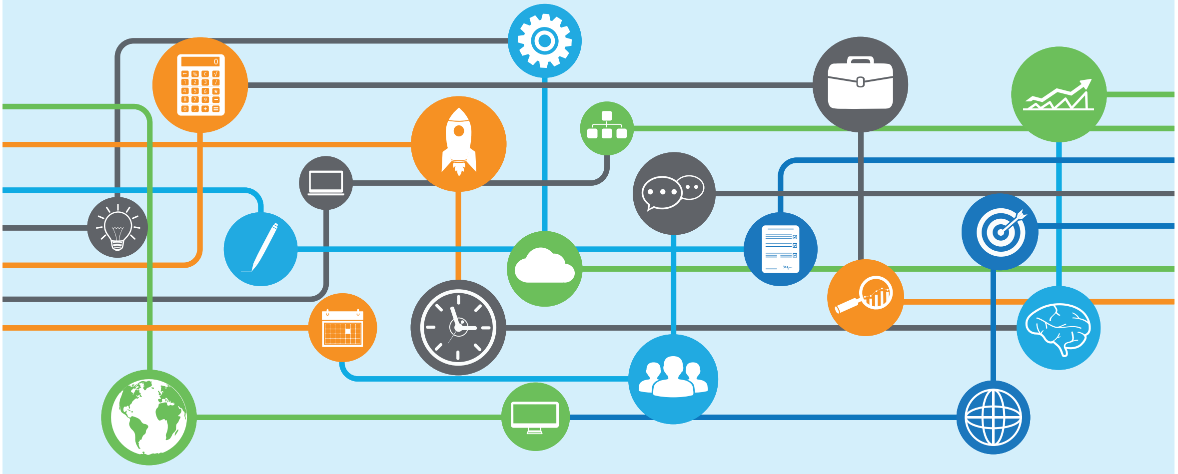
The grain trade is a good example of the raw materials business. Farmers can operate on the open market and sell their grain for the best price on the market after the threshing, or they can accept a contract from a grain buyer. Contract farmers sign separate contracts with the grain buyer. The contract is binding on both parties and clearly defines their rights and obligations. The price of grain can be fixed or left open, to be agreed at a later date.

After threshing, the farmer will deliver a preliminary sample to the buyer in order to determine the quality of the harvest. Based on the sample, the buyer then decides whether the batch of grain is acceptable. If the price has not been fixed, it is agreed at this time at the latest. Depending on the buyer's systems, the contracts can be made electronically through a cloud service or as traditional paper contracts.

The electronic appendix to the report presents a more detailed solution roadmap for three service concepts utilising digital technologies or networked operating models in the food production chain:

- *A virtual peer-to-peer primary producer network would improve the bargaining position of farmers on the market, since it improves predictability and enables collaboration between producers.*
- *Virtual, flexible contract production secures the availability of raw materials and improves the bioeconomy's capacity to produce products with a higher degree of processing.*
- *The consumer-farmer network improves the flow of information between farmers and consumers and enables better services for consumers.*

All three new operating models are dependent on the development of digital solutions and data-utilising tools.



4. The next steps towards a smart bioeconomy

The joint development of digitalisation, new bioeconomic production processes and natural resource management models can initiate radical change that will alter our conception of an economy or society relying on renewable natural resources. Since the change is systemic, some operators and practices will disappear and be replaced by others.

At its best, digitalisation can enable a more viable, competitive and ecologically sustainable bioeconomy. The transition also involves risks, however. This is evident from the upheaval caused by services based on digital platforms, such as AirBnB and Uber, in the accommodation and transport industries. With regard to the bioeconomy, these developments have raised concerns over the environmental impact and social consequences of the increased use of natural resources.

As the conclusions of our roadmap work, we formulated the following four theses to point the way towards a genuinely smart, flexible and collaborative bioeconomy. After the theses, we provide summaries of suggested measures for the various key operators.

Let’s create something new!

We are living in interesting times, as digitalisation is changing the logic of economic activity. At the same time, we are looking for alternatives to the fossil-based economy. This will create new potential for collaboration and revenue for industries that utilise natural resources. However, this potential will not be realised without the bold and open-minded adoption of new practices.

The digitalised bioeconomy of the future does not mean a simple enhancement of the current economic model that exploits natural resources. For digitalisation to create genuinely profitable business for the bioeconomy, we will need an open and unprejudiced dialogue between scientific and technical expertise and the service and manufacturing industries. We also need a bold culture of experimentation. The different orientations of bioeconomy operators and the tech developers of the digital world can pose a challenge.

The silos of the different segments of bioeconomic production will also have to be breached. New business models and opportunities for the digital bioeconomy will have to be found in an agile and fast-moving environment. If a dialogue is not found, the benefits of digitalisation as a driver of the bioeconomy can remain unrealised.

Digitalisation will improve the efficiency of the bioeconomic delivery chain

The most apparent benefit of digitalisation involves the promotion of resource-efficiency, as digital systems will enable the steering of raw materials for optimal use. The increased volume of data, advances in information systems and adoption of predictive systems will accelerate and improve the efficiency of operations. Efficiency will also be improved by the precise solutions enabled by digitalisation, described in connection with precision farming, for example. In the future, farming can be robotised, which will reduce the need for human labour. This would already be possible from a technological standpoint, but the use of autonomous machines still requires the resolution of various questions of safety and responsibility, as well as the development of procedures for the eventuality of malfunctions.

Digitalisation can be used to improve the efficiency of existing production without a major rupture of business models or earnings logic. In animal production, for example, sensor technology and optical imaging methods enable animal-specific precision feeding or the implementation of systems that promote the well-being of animals.

At its best, digitalisation can enable a more viable, competitive and ecologically sustainable bioeconomy.

In the long term, the improvement of efficiency nevertheless requires digitalisation to be seen as a wide-ranging change with a profound impact on practices. Cost efficiency and improved productivity cannot be attained if decision-making systems and organisations are not adapted to the new practices enabled by digitalisation. Management culture and the commitment of operators to the new operating model will thus play a key role in the change.

More value through product-service combinations

The full benefits of digitalisation can only be realised when the products of the bioeconomy are viewed as comprehensive services. This means increasing the value of the end product by adding service elements enabled by digitalisation.

Combinations of products and services should be developed both within the production chains and for consumers. For example, machines can be developed into data generation units for digitalised agriculture and forestry, producing data for decision-making in addition to performing their usual work. The manufacturer could then develop a service offering in addition to its machine sales business, providing services such as maintenance, repair and the remote monitoring and control of robotised solutions. A transition from product-centric to service-oriented thinking can open potential for entirely new types of business and create opportunities for new forms of entrepreneurship.

The servitisation of the bioeconomy and, in particular, development of consumer-oriented solutions is still in the early stages. Technology such as privately owned drones could offer interesting opportunities, producing local digital image data for the service system. Such image data could then be bought by anyone interested in, for example, the logging site or hiking trail. The technological elements and service needs have been identified, but the services uniting these are still in the formative stages.

Thus, the development of service elements is a key focus of further development. Digitalisation creates potential for the development of individual, personalised products. The monitoring of the origin and processing of products enables the use of environmental friendliness and ethicality as a competitive advantage. In addition, products such as food services linked to smart clothes and activity bracelets will provide opportunities to develop new kinds of welfare services.

From data to information, creating added value for the bioeconomy

In the digitalised bioeconomy, information is an essential production factor alongside natural resources. The data collected by sensors, remote sensing systems and monitoring applications is only transformed into information after being processed by information solutions, applications and analysis services. Crowdsourcing can be used to further expand the stock of data. Active people, such as berry-pickers, hunters or scouts can collect valuable data or supplement the data compiled by authorities. Identifying the motivations of such groups of citizens – and motivating them where necessary – is a prerequisite for the development of functional systems and identification of unbiased data. Indeed, the expansion of crowdsourcing will create interesting research tasks in the area of contact between behavioural sciences and technological solutions.

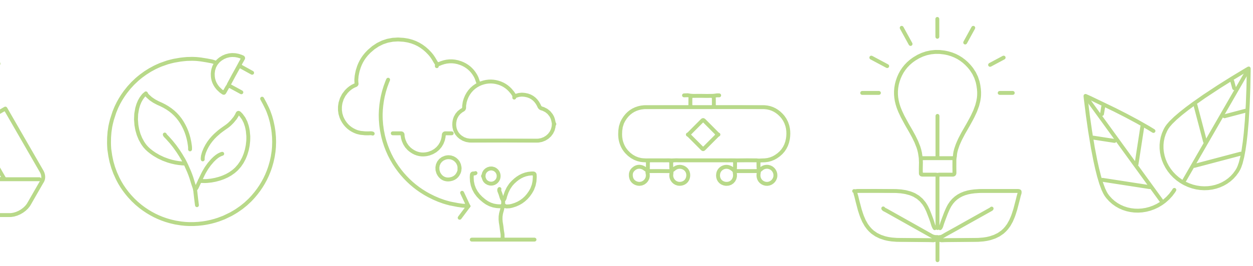
If a dialogue is not found, the benefits of digitalisation as a driver of the bioeconomy can remain unrealised.

In the bioeconomy, the combination of natural resource, raw material and product data with data obtained from other sources will offer new opportunities for the implementation of predictive models. For industrial users, this will mean the improved management of material flows when the raw materials are dispersed and variable in quality and harvesting conditions. On the other hand, the sellers of raw materials will be able to get the best price for their products if real-time market information is available. Public-sector operators can benefit from more precise models to support climate policy, for example.

Digitalisation has opened a discussion on the rules of producing and using public stored of data. Natural resource data collected with public funds has already been opened to commercial use, either free of charge or subject to a fee. For example, highly interpreted forest resource data has been available to commercial operators for several years now.

In the future, biomass resource maps updated from satellite data on a weekly basis or hourly accessibility forecasts based on weather data will open entirely new opportunities for the planning and implementation of timber buying and forestry operations. The machinery, devices and vehicles used in agriculture and forestry will collect highly detailed data on themselves and their users as part of their normal operation.

The open use of this data will be in the interest of the whole sector. However, some questions related to the protection of privacy and ownership of data are still open. Knowledge is also power, and operators that store data and offer data exchange and analysis services will have an even more significant role in the digitalised bioeconomy.



COLLABORATION FOR DIGITALISED BIOECONOMY

The creation of digital services for the bioeconomy will require advances in technology, knowledge and practices. Permanent and functional solutions can only be achieved through the combination of all three perspectives, which will require cooperation.

Table 1 compiles the suggestions made to the various parties as the result of this roadmap. In this context, 'producers' refers to the producers of digital solutions and 'users' to bioeconomy operators who use such services. R&D actors are referred to as 'developers' and 'civic actors' refers to the entire field of civic organisations.

Table 1. Suggestions for the promotion of digitalisation in the bioeconomy.

Suggestions for producers
FOCUS ON THE CUSTOMER • Digitalisation will put the customer at centre stage: the active collection and utilisation of customer data will play a key role in the development of digital solutions. • Identify customer needs and formulate a solution to the problem from the customer's perspective. • Find possible solutions and technologies that answer the need. **CHANGE IN MINDSET** • Digitalisation requires fast action, agility and adaptability. • The promotion and adoption of a culture of experimentation will be vital in this operating environment. • You learn by doing. • Take active part in the concepting, development and piloting of new digital projects. • Look for partners and networks.
Suggestions for users
FIND OPPORTUNITIES AND PARTICIPATE IN DEVELOPMENT • Think about what things could change and where digital solutions could work or create benefits. • Join in the concepting, development and piloting of new digital projects. Voice your needs. **MAKE SURE THAT YOU GET ON BOARD** • Keep up with digitalisation so that you will be able to identify your needs and understand the possible solutions. • Digitalisation is more than just an IT project, but without technological capacities, you can be left behind.

Suggestions for developers

CULTURE OF EXPERIMENTATION AND AGILITY

- Embrace the culture of experimentation.
- Have the courage to try and fail.
- Start by learning things on a small scale, simulate solutions and look for more productive paths.

NEW CONCEPTS AND THE BUSINESS PERSPECTIVE

- Research should highlight new opportunities by always combining a business perspective to technological-scientific development work.
- The creation of new concepts and prediction of the consequences of the business practices related to those concepts should be a key goal.

INTERACTION AND NEW PARTNERSHIPS

- Look for partners and new perspectives, build networks with customers and other experts.
- Focus on the identification and anticipation of the new needs of users and customers.
- Communication and interaction with customers.

Suggestions for civic actors

LEGISLATION

- Digitalisation is a major and rapid change that can pose challenges to the slow process of amending legislation.
- Regulations must be amended to enable new operating models.

INFORMATION SECURITY AND RULES FOR DATA

- Guaranteeing information security is vital to the realisation of digitalisation and digital services.
- It is also essential to clarify the rules of data ownership and exchange and the protection of privacy.

PATIENT MONEY AND RISK FINANCING

- Financing instruments must be developed to enable the development and commercialisation of new solutions.
- Risk financing will be needed.
- Long-term solution development will also require long-term funding instead of short projects.
- For example, the crowdsourcing of natural resource data gathering will require long-term development at first but, in the long term, it can generate new business and improve the efficiency of the use of public funds for the collection of natural resource data.

PREDICTIVE ENABLING

- Authorities must adopt a predictive approach that supports the creation of new solutions.
- The goal should be the digitalisation of official duties where appropriate.
- This will require a systematic review of duties and analysis on the areas in which digitalisation could entail benefits.
- Innovative public procurement and invitations for tenders can be used as a vehicle for the implementation of change.

APPENDIX: THE SCIENTISTS THAT PARTICIPATED IN THE ROADMAP PROCESS

The roadmap is based on data generated in cooperation by the scientists of VTT and Natural Resources Institute Finland. The following scientists have taken part in creating the roadmap at different stages of the process:

Workshop for steering the course of roadmap work, 5 April 2016

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27. See the more detailed description in the appendix to the electronic report (Case 7: Information flow in networks and networked activities in the food production chain).

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Title	Bits and biomass – A roadmap to the digitalisation-driven bioeconomy
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Abstract	Finland has excellent potential for becoming an international pioneer of the bioeconomy. Plentiful renewable resources and profound competence in their exploitation create a foundation for the development of new solutions that enable the transition to a low-carbon and resource-efficient economy. The realisation of this goal is promoted by the ongoing digitalisation process, which will make natural resource data available for the use of a wider group of operators and enable new, networked operating models. VTT Technical Research Centre of Finland Ltd and Natural Resources Institute Finland have drawn up this roadmap, which points the way towards a knowledge-intensive, competitive and collaborative bioeconomy making use of the possibilities of digitalisation. We identified three transition paths to achieve a digitalised bioeconomy and presented sample cases connected to those paths. The transition paths are: 1) Smart biomass flow management, aimed at creating more value from raw materials through the implementation of digital solutions for the optimal use of raw materials, smart logistics and flexible production control systems. 2) Data-driven bioeconomy, compiling development needs related to the generation, analysis and refinement of natural resource data that promotes the bioeconomy. Digital solutions can increase transparency and support predictive decision-making. 3) Networked and collaborative natural resource economy, comprising the development of business models and digital platforms to enable the networked operations of bioeconomy actors. Suggested measures for the various key parties were formulated in the course of roadmap work. Digitalisation requires fast action, agility and adaptability. In this operating environment, it is vital to adopt a culture of experimentation. Research should be steered towards the development of new concepts and anticipating the consequences of business models related to them. It is vital to identify customer needs and see services as an integral part of products. Authorities must adopt a predictive approach that supports the creation of new solutions. The promotion of innovative procurement is one way of promoting the change.
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