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Advanced Technologies for Industry – Product Watch

Photonics technology for high intensity farming

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Section 1

1. Background and objectives of the report

Background

The Product Watch Reports have been developed in the framework of the 'Advanced Technologies for Industry' project and serve to identify and analyse 15 promising ATI-based products and their value chains, with an assessment of the strengths and weaknesses of the EU positioning.

Promising ATI-based products can be defined as "*enabling products for the development of goods and services enhancing their overall commercial and social value; embedded by constituent parts that are based on AR/VR, Big Data & Analytics, Blockchain, Cloud, Artificial Intelligence, IoT, Mobility, Robotics, Security & Connectivity, Nanotechnology, Micro-nanoelectronics, Industrial Biotechnology, Advanced Materials and/or Photonics; and, but not limited to, produced by Advanced Manufacturing Technologies*".

1.1 Background of this report

Changing consumption patterns, increased product quality. The agri-food industry is under pressure to produce sufficient food for a growing population and to accommodate the changing wants and needs of consumers. In the past two decades, global food consumption has increased at a higher rate than global population growth, which can be attributed to income growth and higher consumption at global scale.[1] On average, the share of expenditure on food and drink products is reported to comprise roughly 14% for EU households, totalling €1.5 bn.[2] At the same time, agricultural practices have been further developed in order to increase efficiency and capacity, moving away from seasonal dependencies, e.g. through the increased use of greenhouses for agricultural production, and also introducing a greater diversity of foods available. This trend has simultaneously led to an increased availability in food and a reduced cost of food, thus enabling further changes in consumption patterns.[3] Greenhouses, as an example, are increasingly applied for crop production, with an estimated 405 000 ha throughout Europe. While the degree of sophistication of greenhouse technologies varies based on the socio-economic context, this type of intensive farming is becoming increasingly important in order to increase crop yield, such as depicted in Figure 1, while also to address rising consumer demands in terms of product quality.[4]

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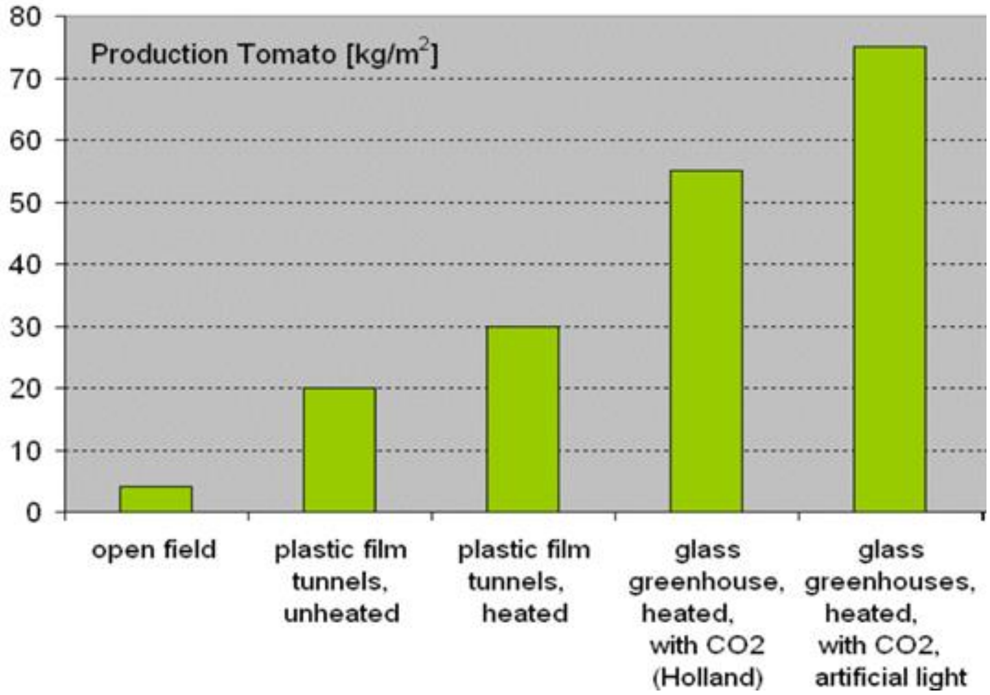
[1] European Commission (2019) Global food consumption growth and changes in consumer preferences, https://ec.europa.eu/info/news/global-food-consumption-growing-faster-population-growth-past-two-decades-2019-sep-10_en

[2] Food Drink Europe (2019) Data & Trends EU Food & Drink Industry 2019, https://www.fooddrinkeurope.eu/uploads/publications_documents/FoodDrinkEurope_-_Data__Trends_2019.pdf

[3] Kearney, J. (2010) Food consumption trends and drivers, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2935122/ and OECD/FAO (2019) OECD-FAO Agricultural Outlook 2019-2028, https://www.oecd-ilibrary.org/docserver/agr_outlook-2019-en.pdf?expires=1591187065&id=id&accname=guest&checksum=7B8EDDE74217990F835581338C5F533A

[4] FAO (2017) Good Agricultural Practices for greenhouse vegetable production in the South East European countries, http://www.fao.org/3/a-i6787e.pdf

Figure 1: Protected cultivations (such as greenhouses) offer better conditions for growth



Source: Vintges, M., 2020

Reducing food losses and waste and increasing food security. While ensuring to deliver enough food and provide food security, the agri-food industry is also pressured to be efficient and reduce food losses in production. Losses during production are estimated to be significant, with roughly 44% (dry matter) lost prior to human consumption for crops. [5] Causes for food losses range from weather damage, diseases and pests, to poor or poorly timed harvests as well as a lack of labour to adequately conduct harvest, or even no harvest at all due to low prices.[6] Agricultural machinery, communication and farm management, as well as quality control during harvest plays a key role in ensuring that production processes, resource use and harvest remain efficient.[7] Applying technologies to support these processes, allows to limit food losses in production, increasing the amount of food yield per hectare and thus contributing to food security through increased production. For example, the FreshFruit pilot project of the S3 High Tech Farming partnership,[8] aims at providing farmers with timely and precise overview of the fruit ripening in the field, allowing a selective harvesting in different plots and guiding relevant agronomic operation to maximise the yield along the production cycle (irrigation, fertilisation, crop protection and covering, etc.).

Role of technology in farming – farm management systems and other technologies. The role of technology has been essential in supporting increased food production, food quality and limiting food losses, e.g. through the increased mechanisation, automation and precision of farming practices (see Figure 2). Precision agriculture, which refers to modern farming practice that relies on digital techniques to monitor and optimise farming practices targets improved ratio between input resources such as water, land, energy, fertiliser and agricultural output i.e. food.[9] Precision farming, sometimes also referred to as smart farming[10], has applications in yield monitoring, crop scouting, field mapping, variable rate application (e.g. targeted irrigation, seeding, fertilisation, pesticide use), among others.[11]

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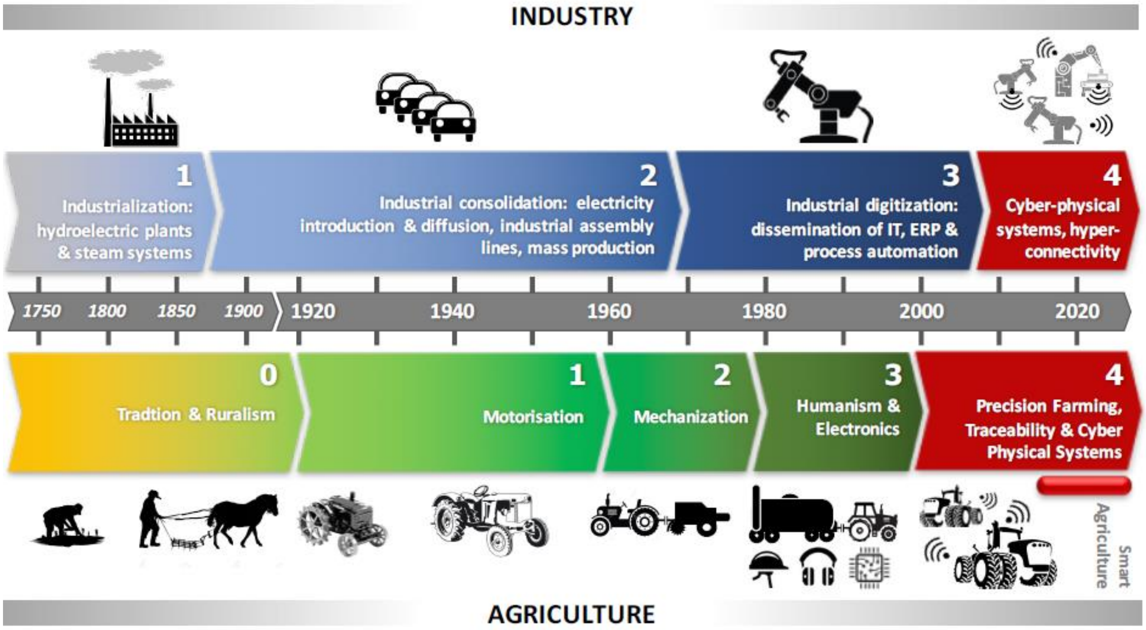
[5] Alexander, P, et al. (2017) Losses, inefficiencies and waste in the global food system, https://www.sciencedirect.com/science/article/pii/S0308521X16302384
[6] RaboResearch Food & AgriBusiness (2020) Do the right thing (right) – A guide to sustainability in the fresh produce business, https://www.fruitlogistica.com/media/fl/fl_dl_all/fl_dl_all_fachbesucher/Fruit_Logistica_Trend_Report_2020.pdf
[7] Markets and Markets (2013). Pre-harvest Equipment Market, https://www.marketsandmarkets.com/Market-Reports/pre-harvest-agri-equipment-market-1210.html
[8] European Commission (2020). High Tech Farming, https://s3platform.jrc.ec.europa.eu/high-tech-farming
[9] Schrijver, R., Poppe, K., Daheim, C. (2016) Precision agriculture and the future of farming in Europe, https://op.europa.eu/en/publication-detail/-/publication/40fe549e-cb49-11e7-a5d5-01aa75ed71a1/language-en and EPRS| European Parliamentary Research Service, Precision Agriculture, https://www.europarl.europa.eu/thinktank/infographics/precisionagriculture/public/index.html
[10] Wageningen University and Research, Precision agriculture - smart farming, https://www.wur.nl/en/Dossiers/file/dossier-precision-agriculture.htm#:~:text=Precision%20agriculture%20or%20Smart%20Farming,sensor%20technology%2C%20ICT%20and%20robotics.
[11] Markets and Markets (2020) Precision Farming Market, https://www.marketsandmarkets.com/Market-Reports/precision-farming-market-1243.html

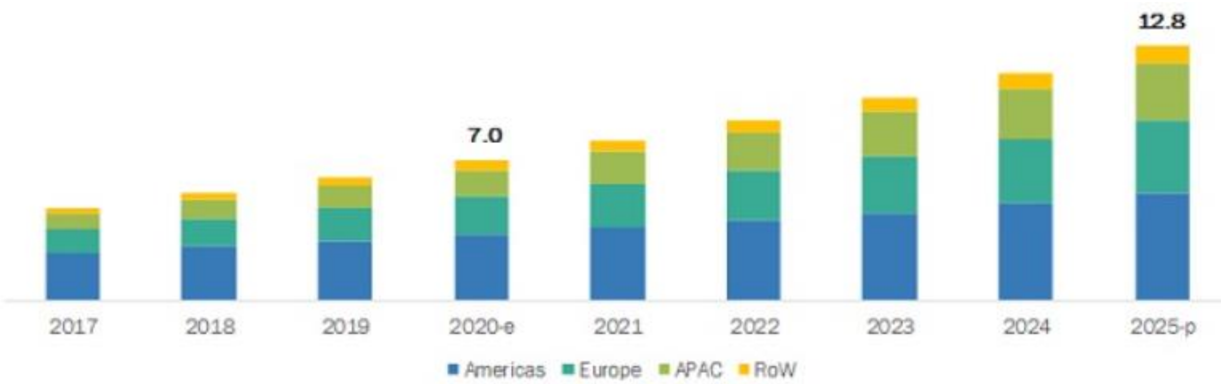
Figure 2: Industry 4.0 versus precision agriculture



Source: Mazzetto, F., 2020

Globally, the precision farming market is estimated at €5.9 bn[12] in 2020, and is estimated to grow to a size of €10.8 bn by 2025 at a Compound Annual Growth Rate (CAGR) of 12.7% and is led by the US (see Figure 3.) due to early adoption of precision farming practices on large size farms.[13] In addition, farm management systems offer the possibility to connect all farm solutions in one centralised hub, allowing a farmer to monitor all farming activities in one centralised tool, enabling traceability, monitoring and overall efficiency. The global farm management software market estimated to have a value of €632 m in 2016, which is expected to grow to €1.6 m by 2023 at a CAGR of roughly 14%.[14]

Figure 3: Size of the precision farming market, by world region (in USD bn), where -e are estimated values and -p are predicted values



Source: Markets and Markets, 2020

Zooming in on photonics technologies. Historically, photonics has a long track record in applications for sensors for example to detect gases in soils. Since then, photonics has evolved to be included for other roles than sensors alone, expanding to uses in other areas of the agri-food sector. Photonics technologies are frequently applied in smart farming or precision agriculture techniques, for a variety of reasons, including soil and crop analysis, to determine need for fertiliser use, forecasting harvest time, supporting machine vision, as well as sorting crops and plants using camera screening techniques combining photonics and artificial intelligence (AI). Photonics for lighting can also be used in

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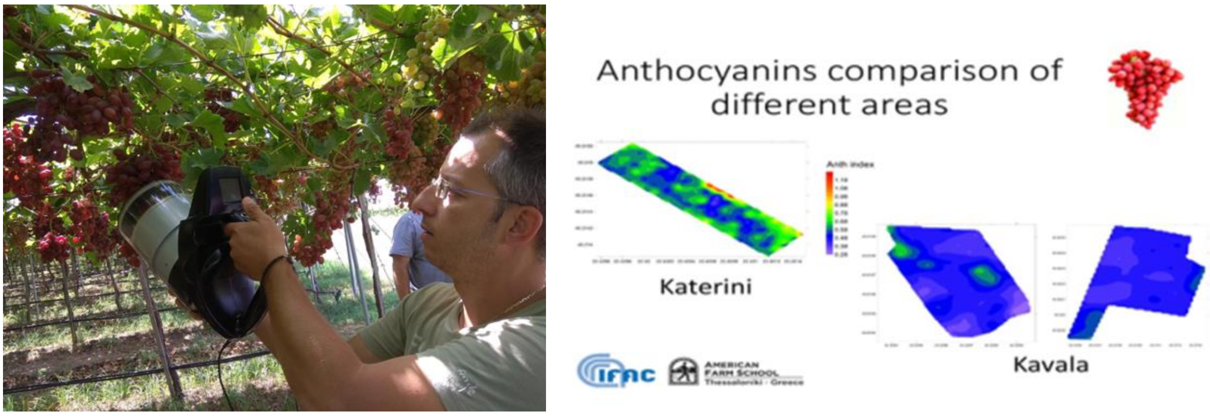
[12] All currencies are based on current exchange rate of 1€ = $US 1.18376, 20 September 2020

[13] Markets and Markets (2020) Precision Farming Market, https://www.marketsandmarkets.com/Market-Reports/precision-farming-market-1243.html

[14] Markets and Markets (2017) Farm Management Software Market, https://www.marketsandmarkets.com/Market-Reports/farm-management-software-market-217016636.html

greenhouses, vertical farms and further support city farming practices.[15] Photonics solutions are able to detect contaminants in vegetables, fruit and plants in order to ensure product quality overall and thus contribute to consumers growing demands towards food products. For example, the Smart Grape solution developed by IFAC-CNR has adopted specific photonics technology to measure the ripening and sugar level contents of grapes on-field and to use it as a maturity index based on a non-destructive approach. The technology allows grape growers to make informed decisions on the quality of fruits and harvest time.

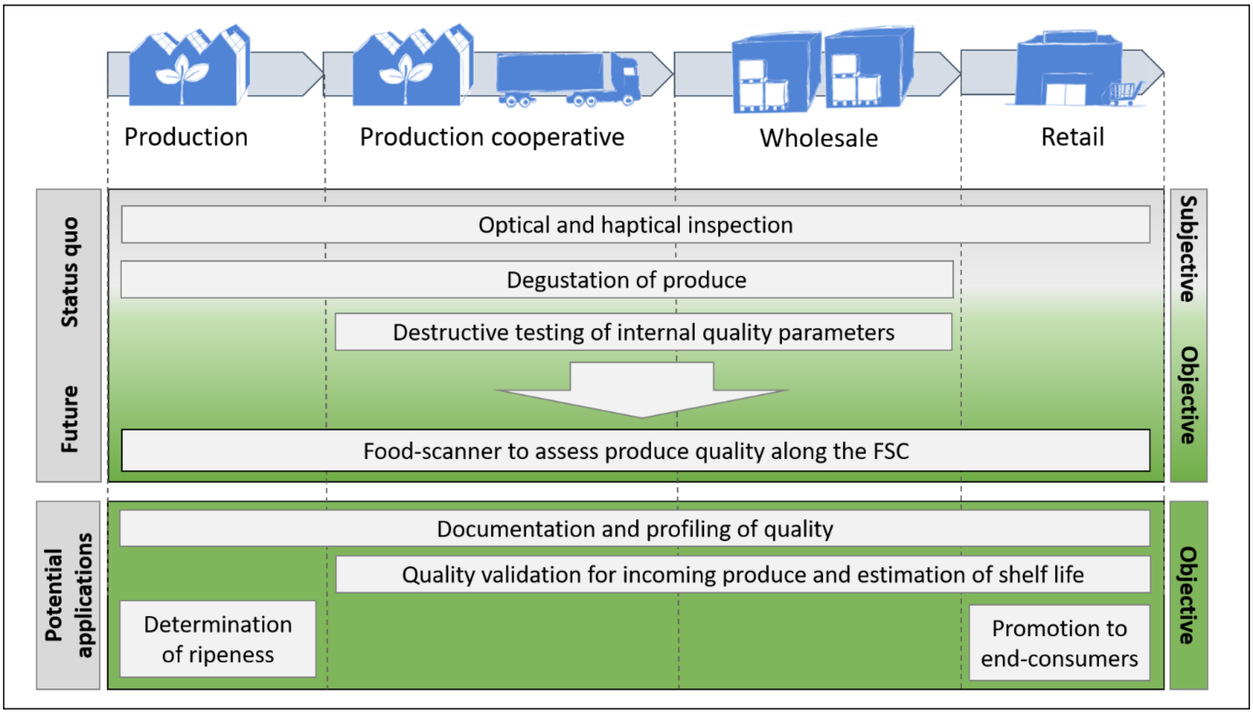
Figure 4: The Smart Grape solution developed by IFAC-CNR



Source: The Fresh Fruit pilot project, American Farm School, 2020

Currently, in the food value chain, food scanners based on photonics technology are not widely applied. Techniques along the value chain are typically destructive or manual relying on optic and haptic inspection by persons. Future applications for food scanners based on photonics solutions, as presented in Figure 5 include documentation and profiling of quality along the value chain or Food Supply Chain (FSC), determination of ripeness and feeding further information towards customers.

Figure 5: Status quo and potential opportunities for application of food scanners along the food supply chain (FSC)



Source: Goisser, Mempel and Bitsch, 2020

In total 15.5% of the global market share for photonic technologies lies in the EU, the second highest after China.[16] Assuming Europe can continue on this trajectory and continue to capitalise on expanding

[15] Lee, C. (2016) Photonics is Everywhere!, http://photonicsgr.com/wp-content/uploads/2016/10/Photonics-is-Everywhere-June-2016-Open-Science.pdf
[16] Photonics21 (2017) Europe's age of light! How photonics will power growth and innovation, https://www.photonics21.org/download/ppp-services/photonics-downloads/Photonics21-Vision-Paper-Final.pdf

markets, European production could reach a value of €200 bn by 2030.[17] The precision harvest market is valued at €8.8 bn in 2018 and is projected to have a value of €14.7 bn by 2023, with a CAGR of roughly 11% during the indicated period (see Figure 6).[18] In addition, post-harvest market technologies, are important to ensure product quality, as they slow down the metabolic processes in foods between harvest and consumption. Photonics technologies are used to monitor the food products, including detecting contamination or microbial growth. This market will become more important in the coming years, seeing also the trend in consumers demand of organic food products and well as higher quality food products.[19]

Figure 6: Precision harvest market, estimated 2018 value and predicted 2023 value

Source: Markets and Markets, 2020

Trends in high intensity farming. High intensity farming is understood to focus on fruits, viticulture, tree nurseries, and protected cultivation of crops such as fruits and vegetables grown in greenhouses. Fruits and vegetables produced through high intensity farming are considered key agricultural products with an annual output value of roughly €57 bn in 2018. In total 60% of the output value comes from vegetables and 40% from fruits, together representing 14% of the overall agricultural output value.[20] Greenhouses in Europe differ in their design based on the geographic location and associated climate. In the northern part of Europe, greenhouses are made of glass and are a controlled environment. In the south, such as Spain, Crete and Sicily, greenhouses are made of plastic, with a focus on keeping out wind and hard rain. Greenhouses and intensive crop farming are perceived as the optimal location for photonics technology applications in the agri-food value chain as they provide stable environments, with a need for precise monitoring of conditions for crop, such as fruit and vegetable production. As an example, precision harvesting is understood to include the use of cameras and sensors to determine the correct moment for harvesting as well as support to the cultivation process.[21] Techniques used in high intensity farming may also apply to less intensive crops such as arable crops, cereals and vegetables.[22] For the purpose of this report, we focus on high intensity farming, understanding it to

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[17] Photonics21 (2017) Europe's age of light! How photonics will power growth and innovation, https://www.photonics21.org/download/ppp-services/photonics-downloads/Photonics21-Vision-Paper-Final.pdf
[18] Markets and Markets (2019) Precision harvesting market, https://www.marketsandmarkets.com/Market-Reports/precision-harvesting-market-194202698.html
[19] Global Market Insights (2020) Post-Harvest Treatment Market Size, Industry Analysis Report, Regional Outlook, Growth Potential, Competitive Market Share & Forecast, 2020 – 2026, https://www.gminsights.com/industry-analysis/post-harvest-treatment-market
[20] EPRS (2019) The EU fruit and vegetable sector - Main features, challenges and prospects, https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/635563/EPRS_BRI(2019)635563_EN.pdf
[21] Data Bridge Market Research (2019) Global Precision Harvesting Market – Industry Trends and Forecast to 2026, https://www.databridgemarketresearch.com/reports/global-precision-harvesting-market
[22] The Product Watch Report on Drones and satellites focuses on low intensity crops such as arables, cereals and vegetables

include in its scope, agri-food areas with high value added products, including fruits, vegetables, grains as well as horticulture, such as ornamental plants, trees and grass grown under intensive growing conditions.

Box 1: Examples of photonics technology in horticulture

Horticulture is included in the scope of the depicted value chain due to the shared high intensity and high added-value nature of the production. Horticulture in this context includes the production, typically in greenhouses, of ornamental plants, grass, trees, flowers, etc. They are typically consumed by cities and municipalities to improve urban environments and town centres and are also bought by individual people of private households. A variety of technologies are applied to improve plant quality, shorten growing time and increase resource efficiency. Given the high added value of the product, investments in technologies are quickly recuperable. For example, plants are grown with LED lights and UV lights in a production similar to vegetables in greenhouses. Startups are using sensors to find out which plants have diseases.

Greenhouses[23] in the Netherlands also rely on camera-based photonics sorting systems to gather information about and sort plants prior to leaving the greenhouse. In case plants such as orchids do not have a sufficient number of buds, they are returned to the greenhouse automatically. The systems are applied in the transition towards automated greenhouses.

Source: IDEA Consult based on Bloemenkrant and Onderglas news articles

1.2 Objectives of this report

Digital technologies are rapidly changing agricultural practices today. Farmers still struggle to adopt the technologies that are suitable for their specific practices, often due to high investment cost, both financially and in terms of skills. Specific evidence for all types of intensive crops are needed to sufficiently encourage farmers to take up the practices in their specific field, where further customisation is frequently needed.

The report specifically zooms in on the use of photonics technologies for intensive farming, providing an overview of the context, value chain and relevant stakeholders. The objective is to map the key players in photonics for the intensive farming value chain, as well as to identify their strengths and weaknesses, also in relation to global competition. Analyses were based on desk-research, interviews as well as on the internal expertise of IDEA Consult on the subject.

[23] Bloemenkrant (2016) Maarel Orchids sorteert feilloos met software, https://www.bloemenkrant.nl/nieuws/algemeen/15304/maarel-orchids-sorteert-feilloos-met-software-?related and Onderglas (2015) Kwekerij Piet Vijverberg stapt over op SmartScan 3D, https://www.onderglas.nl/kwekerij-piet-vijverberg-stapt-op-smartscan-3d/

Section 2

2. Value chain analysis

The following chapter explores the specific value chain of photonics technology for high intensity farming and the associated farm management systems including the key actors and the current state of play of the linkages across the value chain.

2.1 Value chain structure

The photonics technology for high intensity farming value chain. The proposed value chain focuses on 'Photonics technology for high intensity farming'. The value chain is depicted in Figure 7 and consists of six main elements, ranging from the inputs needed for primary production to packaging and cold storage as well as food processing, distribution and marketing, culminating in the end user. The value chain encompasses fruits, vegetables, grains and horticulture (ornamental plants and flowers, trees, grass, etc.). Depicted in grey are the overarching value chain segments. In green, the first level highlights key stakeholders in each segment, where the second level indicates the specificities of this value chain and the application of photonics technologies therein. Depending on the specific subsector, different techniques will be applied.

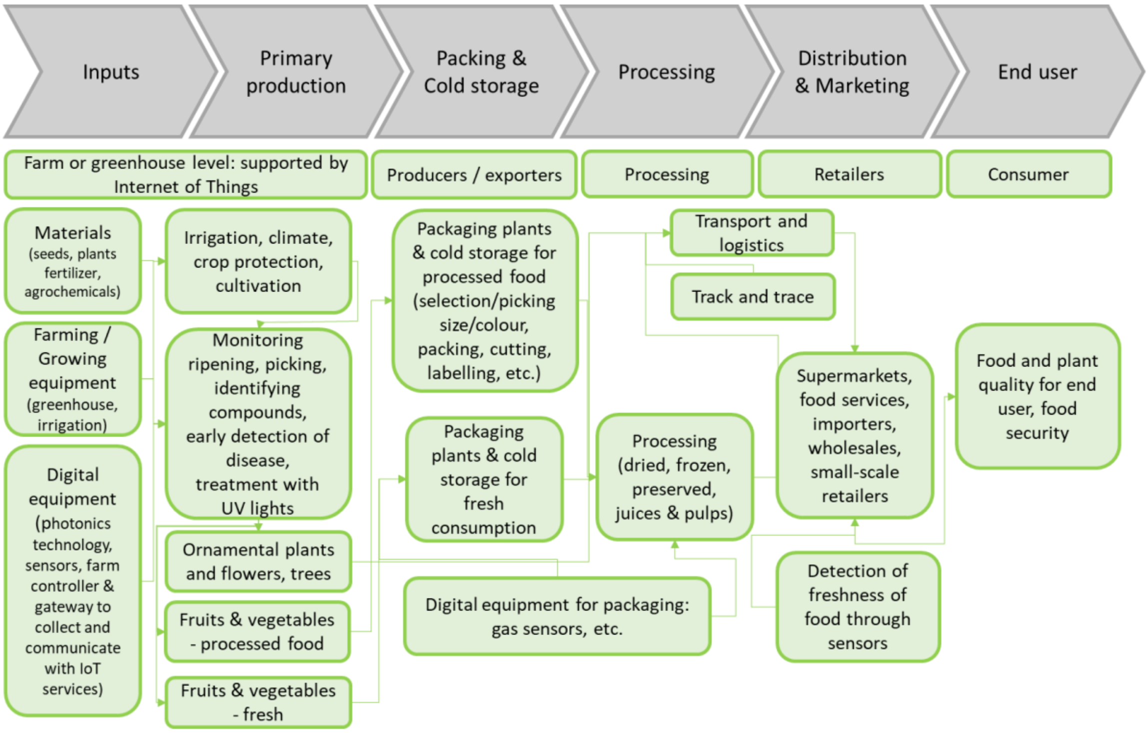
Inputs to the value chain. The inputs to the value chain include all materials and equipment needed for the specific production or product targeted. Equipment includes both physical farming and growing equipment as well as digital equipment. Digital equipment in the selected value chain includes different photonics technologies that will be used at farm or greenhouse level including cameras, lights and sensors.

Primary production. Building on the equipment and materials flowing in from the inputs, primary production focuses on the activities towards agricultural and horticultural production. This includes planting, irrigation, climate control, crop protection and other cultivation activities in a first step. Specific activities at farm level build on and can be supported by the application of photonics technologies including monitoring ripening, picking, identifying compounds, early detection of disease, treatment with UV lights, among others. Seeing the focus of the selected value chain, the outputs from this value chain segment include ornamental plants, flowers and trees, as well as fruits and vegetables.

Packing and cold storage. In this segment, a subdivision between packaging and storage of food for fresh consumption and plants, and processed food is made. Importantly, photonics technologies can be applied here, among others, to detect compounds in the food, to prolong the life of certain fruits, vegetables and plants, and also to encourage the development of certain nutrients – post harvest. In addition, sensors can be placed in food packaging to monitor and detect changes in the foods once packaged, such as gas sensors, based on photonics technologies.

Processing. Applying specifically to foods and plants that require processing, this segment, similar to the packing and cold storage segment, relies on photonics technologies for the placement of sensors in packaging in order to monitor and detect changes in composition (e.g. gases). In addition, this technology enables track and trace mechanisms.

Figure 7: Photonics technology for high intensity farming



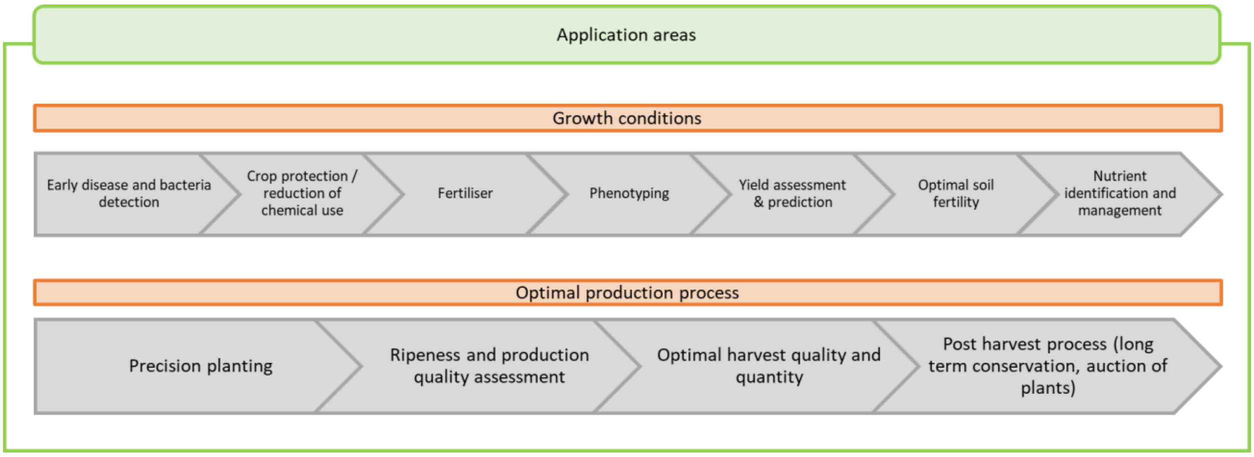
Source: based on Fernandez-Stark, K. Bamber, P., and Gereffi, G., 2011, Pesce et al., 2019

Distribution and marketing. Distribution and marketing deal with transport, logistics, as well as track and trace of food and plant products. Here the detection of freshness of food through sensors powered by photonics technology is particularly of focus. In addition, track and trace mechanisms enabled through technologies based on photonics are interesting for the communication to retailers, resellers, etc. For example, in the horticulture value chain, auctions to retailers of ornamental plants are also built on data gathered about the plants, through cameras or other digital information. These enable the buyers to obtain information without travelling to view plants in person.

End user. Particularly end users in this case are either shoppers at a market or grocery store that are purchasing fruits and vegetables, or shoppers that are purchasing plants, trees or the like. In the horticulture sector, end users can also include municipalities purchasing plants for their municipal works. In the fruit and vegetable context, end users benefit from photonics technology through higher food quality, with more nutrients and better taste, among others, as well as increased food security.

Application areas for growth conditions and optimal production processes. In order to understand fully the opportunities for photonics technologies, which are considered rather varied across the value chain, Figure 8 presents an overview.

Figure 8: Application areas for photonics technology for high intensity farming



Source: Based on Pesce et al., 2019 and interviews

Application areas include:

- Early detection of disease or pathogens on leaves or on fruits, reducing need for pesticides or other crop protection means;
- Reduction of chemical use: the treatment with lights such as Infrared, UV, LED to reduce use of chemicals and other substances;
- Fertiliser: to measure components in the water, e.g. amount of nitrogen, phosphorus;
- Phenotyping, which is used to characterise crops for further breeding;
- Growth conditioning: using specific lights and changes in the light spectrum and frequency applied, certain specific components are created inside of crops, leading to very controlled growth;
- Identifying specific compounds (sugar, colour) on or inside the plant (e.g. lycopene and other antioxidants in tomatoes);
- Precision planting in order to place or localise the positioning;
- Monitoring ripening in order to check product quality in view of harvest;
- Optimal harvest in terms of timing for quality and quantity of harvest;
- Post-harvest processes to increase shelf-life, conservation and support also the auctioning of plants.

2.2 Key actors in the value chain

A series of key actors are essential in the realisation of the value chain. The following list contains the main stakeholders (non-exhaustive) for this value chain, highlighting those which are most prominent. These include:

- Farmers and growers, including suppliers
- Intermediaries and cooperatives
- Photonics technology manufacturers
- Farm management system service providers
- Processing plants
- Greenhouse builders
- Retailers
- End users

Farmers and growers, including suppliers. Farms and farmers as well as growers are the central element of the primary production and key stakeholders due to their importance in growing and harvesting high intensity crops such as fruits and vegetables as well as ornamental plants. Farms and greenhouses have the possibility to implement farm management systems and to apply photonics-based precision agriculture or smart farming techniques to allow for increased resource efficiency, to prevent food losses and to improve product quality. This stakeholder group is focussed on production quality and quantity, while, where possible, increasing their margin to support investments. Farmers and growers are supplied with input materials by input materials suppliers, supplying materials such as seeds and plants from breeders. These stakeholders are also among the forerunners in technology adoption, especially in horticulture.

Intermediaries and cooperatives. Local intermediaries are organisations that have a good relationship with farmers, and act as gate keepers for the introduction of new technologies in the farming and growing ecosystem. Intermediaries can include innovation intermediaries, such as research centres as well as cooperatives that have the trust of the farmers and consultants. While in most cases farmers make the final decision on what technologies to implement on their farm, cooperatives do play a vital role in making recommendations to their farmers on what techniques to take up. Hence, cooperatives can also be key in deciding whether and which sensors are taken up at farms. For example, in France, cooperatives play a key role in validating technologies that are taken up by farmers and growers and their advisory role is highly valued. Most cooperatives have testing rounds using new technologies before advising farmers or growers to use them, allowing them to have founded results and experiences at the basis of their recommendations and advice. Similar to the intermediaries and cooperatives, research centres and consultants play an important role in informing farmers and growers about possible technological solutions that can improve efficiency, product quality, harvest, among others. Some research centres also provide training to farmers. In some cases, even insurance firms could steer the adoption of new solutions.

Photonics technology manufacturers. Photonics technology manufacturers create and develop the technologies that are applied on farms and throughout the value chain.

Table 1 presents a non-exhaustive list of photonics technology manufacturers and the specific application area that they are developing.

Farm management system service providers. Farm management systems are typically software-based solutions that enable farmers to efficiently manage farm resources. These bring together various tools to provide an overview of activities and information at farm level, to support decision making, and enable monitoring and harvesting. Table 2 presents a non-exhaustive list of mapped farm management system providers relevant for the specified value chain.

Processing plants. Processing plants are responsible for preparing food products. Photonics technologies may be applied here to sort fruits, vegetables or plants and to select products based on their quality. This may also include an assessment of nutrient content or even the application of photonics technology to manage these nutrients.

Greenhouse builders. Greenhouses are important buildings and structures in the high intensity farming value chain. Greenhouse builders carry out turnkey projects, selling a greenhouse as a completed product. In that regard, greenhouse builders drive what sensors and what systems are chosen for any specific greenhouse, thus serving as an important integrator of technologies.

Retailers. Retailers play an important role in deciding which products to place in stores in order to reach the end user. If retailers do not decide to give shelf space to high-quality products, such as those that are available through the application of photonics technologies, end users have little opportunity to show their preferences.

End users. End users refer specifically to the consumers of fruit and vegetables as well as ornamental plants. Trends show that end users are increasingly interested in high quality products and their willingness to pay for such products is increasing. Through the application of photonics technology, increased food quality, with higher nutritional value can be offered to consumers, in addition to food security.

Table 1: Photonics technology manufacturers for high intensity farming

Photonics technology manufacturer	Photonics application(s)	Country	Website
A2 Photonics Sensors	Spray analyser	France	http://www.a2photonicsensors.com/
Abundant Robotics	Optimal harvest	United States	https://www.abundantrobotics.com/

Photonics technology manufacturer	Photonics application(s)	Country	Website
AG Leader	Ripeness assessment, Optimal harvest	United States	https://www.agleader.com/
AGCO	Optimal harvest	United States	https://www.agcocorp.com/
Agrobot	Optimal harvest	Spain	https://www.agrobot.com/
Aris	Phenotyping	Netherlands	https://arisbv.nl/en/
AVL Motion	Optimal harvest	Netherlands	https://www.avlmotion.com/
BoMill	Grain sorting	Sweden	https://www.bomill.com/
Cascade	Light technologies	France	https://www.lightcascade.com/fr/
Deere & Company	Early disease detection	United States	https://www.deere.com/
Deka	Temperature, Light sensors	Germany	http://www.deka-s-t.com/Kompetenz-in-Sensoren
Dogtooth Technologies	Optimal harvest	United Kingdom	https://dogtooth.tech/
Energid Technologies Corp.	Optimal harvest	United States	https://www.energid.com/
FaunaPhotonics	Early disease detection	United States	https://www.faunaphotonics.com/
FFRobotics	Optimal harvest	Israel	https://www.ffrobotics.com/
Felix Instruments - F750	Produce quality meter	United States	https://felixinstruments.com/food-science-instruments/portable-nir-analyzers/
Force-A	Ripening assessment, Optimal harvest, Early disease detection	France	www.force-a.com
Fritzmeier	Crop management	Germany	www.fritzmeier-umwelttechnik.com
Geophilus	3D soil mapping	Germany	http://www.geophilus.de/
GrainSense	Measuring grain quality	Finland	https://www.grainsense.com/
Harvest Automation	Optimal harvest	United States	https://www.public.harvestai.com/
Harvest Croo	Optimal harvest	United States	https://harvestcroo.com/
Headwall Photonics Inc.	Crop health	United States	https://www.headwallphotonics.com/remote-sensing
Heliospectra	LED Grow lights	Sweden	https://www.heliospectra.com/
Hiphen	Precision planting	France	https://www.hiphen-plant.com/
Iron Ox	Optimal harvest	United States	https://ironox.com/
Irrometer	Optimal soil fertility	United States	https://www.irrometer.com/
LioniX international	Photonic gas sensors	Netherlands	https://www.lionix-international.com/
Lumichip	Light spectrum technology	Finland	http://www.lumichip.com/Lumichip/Lumichip.html

Photonics technology manufacturer	Photonics application(s)	Country	Website
Merck	Crop protection	Germany	https://www.merckgroup.com/
Metomotion	Ripeness assessment, Optimal harvest	Israel	https://metomotion.com/
m-u-t	Photonics for tailor-made customer solutions	Germany	https://www.mut-group.com/de/agrarindustrie
Narva – G.L.E.	Plant lighting	Germany	https://narva-gle.de/home.html
New cosmos	Gas detection	Netherlands	https://www.newcosmos-europe.com/
Panasonic Corporation	Optimal harvest	Japan	https://amwww.panasonic.com/global/home.html
PepsoCo	Early disease detection	United States	https://www.pepsico.com/
Photon Lines	Early disease detection, ripeness assessment	France	https://photonlines-recherche.fr/
Photon Systems Instruments	Plant phenotyping	Czech Republic	www.psi.cz
Precision Planting	Precision planting	United States	https://www.precisionplanting.com/
Pronova	Agricultural measurement technology	Germany	http://pronova.de/
Protec s.r.l.	Optical sorting	Italy	www.protec-italy.com
Raven Industries	Optimal harvest	United States	https://ravenprecision.com/
Robert Bosch GmbH	Ripeness assessment	Germany	https://www.bosch.com/
Root AI	Ripeness assessment, Optimal harvest	United States	https://root-ai.com/
Senorics	Material Sensing Toolbox	Germany	https://senorics.com/our-toolbox/
Smart Harvest Ltd.	Ripeness assessment	United Kingdom	https://smartharvest.co.uk/
Specim	Spectral imaging	Finland	https://www.specim.fi/
Spectral Engines	Smart farming	Finland	https://www.spectralengines.com/solutions/smart-farming
Sunforest H 100-G	Portable non-destructive quality meter	South Korea	http://www.sunforest.kr/index.php?sm_idx=eng
tec5 AG	Crop management	Germany	www.tec5.com
Trimble	Soil information system	United States	https://www.trimble.com/
Tsenso	Fresh Index	Germany	https://tsenso.com/de/frische-index-statt-mhd/
Trinamix	Spectroscopy	Germany	https://trinamixsensing.com/
Valoya	LED grow lights	Finland	https://www.valoya.com/

Photonics technology manufacturer	Photonics application(s)	Country	Website
Vision Robotics Corp.	Optimal harvest	United States	https://www.visionrobotics.com/
PepsiCo	Early disease detection	United States	https://www.pepsico.com/
Violet Defense	UV light treatment	United States	https://www.violetdefense.com/
WPS	Sorting	Netherlands	https://www.wps.eu/en/
Yara International	Crop fertilization	Norway	www.yara.com/crop-nutrition

Source: compiled by IDEA Consult based on Markets and Markets 2020, EPRISE, Smart AKIS 2020, S3 High Tech Farming Partnership

Table 2: Farm management system service providers for high intensity farming

Company	Country	Website
ABACO SpA	Italy	https://www.abacospa.it/
Agricolus S.r.l.	Italy	www.agricolus.com
Agri Tracking Systems	United States	http://agritrackingsystems.com/
Agrivi	United Kingdom	https://www.agrivi.com/en
AgriXP	Canada	https://agrixp.com/
AgroIntelli	Denmark	https://www.agrointelli.com
AgWorld	United States	https://www.agworld.com/
Conservis	United States	https://conservis.ag/
Cropio	Cyprus	https://cropio.com/
Croptracker	Canada	https://www.croptracker.com/
Cultinova	UK and Germany	http://cultinova.com/
DELOS (ODAS)	Germany	https://www.delos.biz/
Farmatters	United Kingdom	http://www.farm-software.co.uk/
FarmERP	United States	https://www.farmerp.com/
Farmsoft	United States	https://www.farmsoft.com/
Granular	United States	https://granular.ag/
Greenfield	Spain	https://greenfield.farm/en/home/
Greentop	Italy	https://greentop.it/
Hertz	United States	https://www.hertz.ag/
Hoogendoorn	Netherlands	https://www.hoogendoorn.nl/en/
IBF	Italy	https://www.ibfservizi.it/
IoAgri	Italy	https://www.ioagri.it/
MapShots	United States	http://www.mapshots.com/
Netsens s.r.l.	Italy	www.netsens.it
Next Farming	Germany	https://www.nextfarming.de/
Picktrace	United States	http://picktrace.com/
Plantations International	Hong Kong	https://www.plantationsinternational.com/

Company	Country	Website
PRIVA	Netherlands	https://www.priva.com/solutions/horticulture
Raw Data	Spain	https://www.rawdata.es/en/
Robert Bosch GmbH	Germany	https://www.bosch.com/
Trimble	United States	https://www.trimble.com/
Westland Farm Management	Romania	http://www.westlandfm.com/

Source: compiled by IDEA Consult based on Capterra 2020, S3 High Tech Farming Partnership

2.3 Linkages along the value chain

The introduction of photonics technologies in the high intensity farming value chain entails many advantages. In order to fully capture these benefits, several challenges need to be addressed. A first challenge is data sharing. Although farmers are increasingly involved in gathering data, it remains that data is not gathered in the same way at all farms, and it is not communicated well across the value chain as a whole. Specifically, in the Netherlands, efforts are ongoing to introduce data standards in greenhouses for growers to apply new technologies in the same way.[24] Only few are using it until now, however it serves as a good example of how growers come together to work on data usage in the value chain.

In addition to data sharing, also the issue of interoperability of data is important for value chain interaction. Photonics technologies support the gathering of data related to the need for fertiliser use, forecasting of harvest time, sorting of crops and plants, etc. The interoperability issue arises when combining and analysing the different types of data, such as technical interoperability (connection with other systems), semantic interoperability (description and organisation of data, based on existing standards) and legal (the use of appropriate licences that allow the exchange of data between different systems and providers). Interoperability in high intensity farming, is essential to combine the various data sources coming from soil and crop analysis, camera screening techniques, environmental data, agronomic data, etc.

A means by which farmers and growers could further benefit from technological transformation is to encourage the concept of common resources. As technologies are increasingly applied, many small actors have either one piece of technology or a selection of sensors but are lacking all possible tools. Due to the overarching costs, the notion of companies integrating solutions and technologies may result in a transformation along the value chain. This may result in a strong advantage for large players that can integrate multiple solutions in one system.

There is a strong link between the agri-food sector and the research labs. In terms of value chain connectivity in photonics, there are strong links between research facilities and agriculture in support of ongoing research. This includes plant phenotyping and analyses of components, among others. In Europe, the existing strong research labs are well-connected with farmers and the agricultural sector and are sharing and exchanging information to further develop techniques, for the identification of plants as well as other photonics-based applications. In this regard, also advice to growers is provided and information is made available among networks to advance the existing opportunities.

[24] Glas 4.0 (2019) DATAPROTOCOL FOR EXCHANGE OF CROPDATA, https://glas40.nl/en-us/Data

Section 3

3. Analysis of EU competitive positioning

Figure 9: Overview of the strengths, opportunities, challenges and risks for photonics applications in the high intensity farming value chain

• Strong EU position • Technological strengths in applying photonics	Strengths	Challenges	• Digital security • Cost aversion and limited uptake by farmers and growers
• EU as a global supplier • Faster internet & 5G • Technological opportunities	Opportunities	Risks	• Competition is growing • Legislative framework • Risk associated with technology use

Source: IDEA Consult

3.1 Strengths

Strong EU position. Historically, Europe has a strong agricultural sector, characterised by a lot of EU support and commitment through Common Agricultural Policy (CAP), which was motivated by a drive to have a food sector that is not import dependent. The EU also has a leading role in the production of organic products. This is driven by competition of EU entrepreneurs, who push each other to improve in their given subsectors. Photonics technologies are increasingly introduced in the agricultural industry to screen for contaminants in fruits, vegetables and plants, among others. It is further reinforced in those countries with space limitations as there is a need to move towards intensive agriculture based on acute needs.

Technological strengths in applying photonics. Through the application of photonics technologies in the agricultural sector, positive outcomes can be achieved. These include, e.g. the detection of diseases in plants as well as seeds, preventing virus spready, determine optimal harvesting times, as well as enabling decision making based on rapid and cost-effective measurements to further reinforce a well-structured farming sector. For example, the Fresh Fruit pilot project of the S3 High Tech Farming partnership introduces photonics technologies in vineyards so that grape and wine producers have the possibility to optimise the overall farm management by predicting the ripening and yield of the fruits with an improved spatial precision, to take advantages of premium prices offered for higher quality of the fruit on specific markets, and to set specific commercial agreements and contracts to deliver the right quantity at the right moment for the market (improved logistic).

3.2 Opportunities

EU as a global supplier. Building on current trends, the introduction of photonics technologies in the agri-food industry is gaining interest worldwide, also expanding to Eastern Europe and Asia. As Europe currently houses a stronghold in expertise and companies in many photonics and high intensity agriculture aspects and subsectors, there is the potential for European solutions to be exported, globally. In addition, access to global markets remains important in times of crises, e.g. during the former economic crisis in 2008, technology suppliers of greenhouses exported a lot to Ukraine, as still a lot of greenhouses were built in Ukraine during this period.

Faster internet & 5G will be very important as it allows for more rapid communication, close to real time monitoring and will allow for more sophisticated techniques and measurements. 5G allows for better localisation of specific plants, fruits and vegetables, as well as improved access to platforms which also require more and faster internet connections. Several Member States and regions are investing to improve the connectivity and coverage with initiatives focussing on rural areas. For example, the Rural

Broadband project[25] provides broadband infrastructure coverage and affordable connectivity services to the citizens of remote areas of Greece who were previously deprived of the full benefits of broadband. With this project, high-capacity networks reached remote areas where private players would not invest due to its low commercial value. While broadband infrastructure is now provided, farmers still struggle to make efficient use of the infrastructure and support is needed to help them in choosing and installing interesting solutions that can benefit the farmer. Similarly, the Tuscany region is committed to create a publicly owned fibre optic network that will be used to supply market failure in the so-called 'white areas' of the Tuscany Region, in line with the Italian strategy for ultra-broadband and in order to achieve the objectives set by the European Digital Agenda.[26] In addition, also artificial intelligence needs faster computers and internet connections to function well alongside the photonics technologies. Additional technological progress is needed to fully grasp the advantages of artificial intelligence in combination with photonics technologies.

Technological opportunities. As photonics technologies for agricultural applications improve, further opportunities are expected to arise. There is great potential for synergies with other technologies, such as land robotics, long range sensors (LoRa), satellite and drones, artificial intelligence, (real time) biosensing, among others. Furthermore, the potential for the reduction of food losses using light treatment is also present. A few projects are looking at this such as UV Robot[27] which is a test use case in Brittany, with an experimental farm for greenhouse tomatoes. Further areas include improved product quality achieved through photonics, as well as light to lower pesticide use. Other opportunities are linked to the demand for high tech solutions to face new problems linked with climate changes in the ornamental plant district in Westland, which is the largest greenhouse district in the world.

3.3 Risks

Competition is growing. While Europe is considered a stronghold, the United States is getting better fast, together with Israel and Canada. China is less active as they are not pressured to have high intensity agriculture, due to limited space constraints. They are, however, likely to replicate several existing technologies at some point. China is very good in Artificial Intelligence, as well as storing and managing data, which is important for the interpretation of photonics data for decision making. European companies are challenged by excessive competition in regional markets, with limited cooperation among EU companies resulting in missed opportunities and easy entry points for more structured foreign solution providers. Thus, European companies will need to act fast in improving techniques and expanding markets to maintain their position, otherwise they risk being left behind.

Legislative framework. There is huge potential for the market of photonics in the agri-food industry to open further if additionally supported through a European regulatory framework. However, the current legislative framework in the EU is considered strict, especially with regard to organic labelling of products. The current legislative framework indicates that e.g. tomatoes must be grown in soil. However, growers and farmers are working on techniques for advanced greenhouses that are able to grow foods outside of soil in a more resource efficient manner. While such foods are considered organic in the United States, they are not considered as organic according to EU legislation. As a result, growers and farmers may leave in favour of going to the United States market, as they get a better price for the organic product and they get the label, where in EU they would not. A European response and message are needed to unlock this opportunity, especially as e.g. environmental impacts differ based on agricultural sector and its strengths. The unification of legislation across the EU would stimulate a lot of photonics companies to further invest and explore opportunities.

Risk associated with technology use. Location accuracy remains important for the technology and its robust application. Especially in the case of automatic acquisition of data at external sites GPS of fixed location with mobile sensors require a certainty about location accuracy (e.g. for potatoes). This is a prerequisite to have accurate measurements. In greenhouses to accurately locate plants, Wi-Fi or 5G are essential. In a future where every vegetable and plant will have its own data, health check, nutrients and water, the ability to gather reliable, accurate location data remains vital. This could present a possible opportunity for the European Global Navigation Satellite Systems (EGNSS) Service.[28]

[25] https://ec.europa.eu/digital-single-market/en/content/broadband-network-development-white-rural-areas-greece
[26] https://open.toscana.it/web/crescita-digitale-le-proposte-della-toscana/home
[27] Interreg North-West Europe (2020) UV - ROBOT - Innovative UV-robotics to improve existing IPM strategies and to benefit farmers, consumers and the environment, https://www.nweurope.eu/projects/project-search/uv-robot-innovative-uv-robotics-to-improve-existing-ipm-strategies/
[28] https://www.gsa.europa.eu/european-gnss/what-gnss

3.4 Challenges

Digital security. Not only is cybersecurity important for data-driven and digital processes, but also digital security is a challenge that needs to be well addressed. Digital security refers to situations in which, e.g. hardware is stolen, or malfunctioning, or internet is no longer available. Digital safety is often overlooked and remains a challenge for farmers in an increasingly digital agri-food sector. To tackle this issue, it is important to think about the vulnerability of certain systems, as well as backup solutions and protocols, among others. Wireless solutions rely on batteries, which require either charging or resource intensive changing. Dead or dying batteries, but also the ability to change them in time to ensure reliable data readings remains an issue to ensure the delivery of digital information and to be able to continuously support decision making.

Cost aversion and limited uptake by farmers and growers. Profit margins for farmers are the product of tight calculations on farm-level. While certain technologies are clearly evident in their potential to support farmers and growers in increasing yields, efficiency and quality, the visibility of technologies such as photonics is low compared to artificial intelligence. This is coupled with a threshold to use the photonics technology, where photonics is typically part of a smart farm, with autonomous tractors and other equipment. In general, there is a lack of structures (such as demo sites and farms) which can offer farmers a trusted space to learn from practice and their peers. The uptake is often also tampered due to the fact that several farmers are unaware of the existence of particular technologies. In addition, it remains important to ensure that the costs of the technology are as low as possible to support uptake. In addition, it is a huge task for the farmer or grower, who needs either to deal with the technology directly, or hire a company to run the solution together with the farm management system. For example, the farm can collect a lot of data, however it is also important that it is managed in an efficient way such as through cloud usage, as there can be a lot of data generated for one single farm. Introducing companies in the food chain to carry out this technological work is feasible. However, when the company becomes heavily involved, there is also a certain responsibility for issues such as food safety, traceability, which in turn raises questions of legal and ethical responsibility that remain to be clarified in a harmonious way across the sector.

Section 4

4. Conclusions & outlook

4.1 Conclusions

Smart photonics technologies are being increasingly used along the value chain. Photonics technologies show true advantages for uptake in the agri-food sector with clear promise to support food security, food quality for consumers and increased margins to farmers and growers. In the future, more food production is needed for more people, but with less people working in agricultural sector, photonic techniques are needed to make digitising and automation through robots in food production possible. In general, there is a lack of structures (such as demo sites and farms) which can offer farmers a trusted space to learn from practice and their peers. Demo farms give access to 'trusted' and softly regulated environments where local farmers and rural communities can directly participate to the development and deployment of new and innovative photonics solutions. The farmers gain more insight and trust in the photonics solution, being co-creators, while the developers can benefit from direct interactions with end-users asking for the particular solution. While it is only a matter of time before these technologies become the state of the art, more efforts should be done by policy makers and technology providers and solution developers to improve the uptake of photonics technologies. Currently, a high fragmentation and lack of standards for farm management systems prevent and/or slow down the integration of photonics in farming practices.

As mentioned in the Farm to Fork Strategy[29] a food systems approach will be part of the way forward and implementation in the near future. More food losses can be expected if the technologies are not integrated into holistic strategies along the value chain in a food systems approach. At the same time, regional innovation tools should be coordinated with national innovation policy tools. Interregional partnerships like the S3 High Tech Farming partnership can support the modernisation of the agricultural sector through improving the uptake and implementation of photonics solutions across various agricultural sectors and jointly through EU regions, with the objective of keeping Europe at the forefront of progress in high intensity farming. The adoption of photonics technologies in high intensity farming allows for a better programming of field operations (e.g. selective harvest) and a higher degree of automation (e.g. prescription maps for several field operations). It contributes to the current macro-trend which sees the digitisation of agricultural practices as an opportunity to qualifying operators and improving the job market (potentially reducing the brain drain or even generating new opportunities for reducing the abandonment of rural areas).

4.2 Outlook

The overall uptake of photonics technologies in the agri-food value chain has a great potential to contribute to less food loss with early detection of problems and proactive control measures along the value chain. The integration of photonics technologies creates the opportunity to improve several farm operations impacting the soil, water and air quality, hereby contributing to achieving the Sustainable Development Goals in ensuring further food security with lowered food losses. Clear and proactive documentation of quality enables new marketing strategies and differentiation from the mass market. Hence, farmers can greatly benefit from the adoption of photonics technologies within their production to optimise several operations, contributing to a better economic management of the business. At the same time, new technologies enable the consumer to recognise previously unrecognisable inner quality parameters before purchasing, responding to the need for agricultural products that are healthier, traceable, and creating a lower environmental impact The deployment of photonic technologies contribute to the need of consumers to be more informed and create transparency in the supply.

[29] European Commission (2020) A Farm to Form Strategy, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0381&from=EN

4.3 COVID-19 – impact on the agri-food sector

The Product Watch report 'Sensors for farm management of livestock value chain[30]' presents the COVID-19 impact on the agri-food sector.

[30] https://ati.ec.europa.eu/sites/default/files/2020-06/ProductWatchSensorsforAgri-food.pdf

Section 5

5. Annexes

5.1 List of interviewees

Interviewee	Company	Country
Filippos Papadopoulos	AFS Strategic Program Management Office	Greece
Denis Tregoat	Photonics Bretagne	France
Benoit Perrin	Technopole Anticipa	France
Fabio Boscaleri	Tuscany Region	Italy
Giovanni Agati	IFAC - National Research Council (CNR)	Italy
Ivan Stojanovic	Oost NL	The Netherlands
Marga Vintges	Municipality of Westland Department (Greenport)Strategy	The Netherlands
Colinda de Beer	Innovation Quarter	The Netherlands
Heike Mempel	Hochschule Weihenstephan-Triesdorf	Germany

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About the 'Advanced Technologies for Industry' project

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the Advanced Technologies for Industry (ATI) project has been set up. The project provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship;
- Analytical reports such as on technological trends, sectoral insights and products;
- Analyses of policy measures and policy tools related to the uptake of advanced technologies;
- Analysis of technological trends in competing economies such as in the US, China or Japan;
- Access to technology centres and innovation hubs across EU countries.

You may find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project is undertaken on behalf of the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-sized Enterprises (EASME) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

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