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A Case Study

Farm Management Support in Poland

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Setting the Scene

The first days of September always find Marek in a state of excitement. Usually this is simply a mix of anxiety for the new school year which is about to start and of the joyous memories from the "Dożynki", the Polish wheat harvest festival that took place a few days ago. But this year, 2005, is certainly a special one. It is already a year since Poland has entered the EU and just over a month since Marek's father bought a brand new tractor for their farm using some new "EU funds". Since he first saw the new shinny tractor parked in their property, Marek has been yearning for a ride. His father told him that now they can perform many agricultural activities with a precision of even a few centimetres! But Marek won't believe this is actually possible until he sees it for himself. Today, he shall finally have his chance as his father promised to take him along. Oh boy, is this going be a ride! His father turns the tractor on, beep, beep, beep…

As Marek reaches out to turn off the alarm clock on his smartphone, he realizes that he has again dreamt about this first contact with Precision Agriculture. He still finds it amusing, so many years later and after a Ph.D. in Agronomy and numerous hours on the field, that he should be so fond of this particular memory. But, perhaps, this should not come as a surprise. After all, today he will be riding on the new generation tractor to perform the first treatment of fertiliser on the wheat fields. He might be much larger and so much more experienced today than on that first ride with his father, but Marek still gets a sense of thrill when he hops on the tractor to perform satellite-aided farming activities.

This thrill is even greater since he started using the prescription maps provided by SatAgro – who would have thought that a Polish start-up would be offering such advanced services bringing tangible economic and environmental benefits to his farm? Having first heard of them by the regional Grupa Azoty representative, Marek is now using these services for the 2nd year in a row. And as he passes next to the storage area, he can readily recognise that they have ordered less fertiliser this year.

With the skies in Lodz being still very dark, Marek gazes up - as is always his habit - to see how many stars he can identify. It is just then that he notices an object moving fast across the sky, and for a fleeting moment, he is certain he can spot a Sentinel satellite. Marek laughs to himself at this thought and keeps walking slowly towards the tractor and the implements that are now becoming visible in the distance.

The prescription maps must have already been uploaded by his team on the Galileo-enabled onboard units. This will allow to carry out an efficient variable rate fertilisation of a vast area, but Marek knows that even with such help it is going to be a long day in the fields. Yet, even if he could have someone in his team perform the whole process while he monitors its progress from his laptop, Marek would never give up the pleasure of riding the tractor himself. He hasn't done so since that very first time back in 2005…

This story is entirely imaginary, although realistic based on our knowledge gained through the case interviews. The places are real and the characters are inspired by our interaction with different stakeholders on the ground, yet the story should be considered as entirely fictional.

1 Introduction

1.1 The context of this study

The analysis of the *'Agriculture in Poland'* case study is carried out in the context of the 'The Sentinel Economic benefits Study' (SeBS). This 4-year study is looking to develop cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The Sentinel satellites form a crucial part of the EU's Copernicus Programme, providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – is used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the Globe.

1.2 What is this case study about

The agricultural sector today is characterised by a stark contrast: On one hand lies the simplicity of its mission, namely to produce enough food for a continuously growing population. On the other hand, lies the complexity of achieving this mission within an overall context that places significant strains in the execution of agricultural practices. These strains are primarily associated with decreasing farm income[1] - often directly tied to the rising costs of inputs (especially fertiliser and pesticide costs). They are further exacerbated by a higher caloric intake of increasingly wealthy people[2], the problem of post-harvest waste of food (up to 30% in developing countries[3]) and by environmental and climate-change related aspects (with the more frequent occurrence of events such as extreme droughts or floods).

Thus, the farmers of the 21st century are called to carry out strenuous efforts towards enhanced, efficient and sustainable agricultural productivity, whilst at the same time reducing the environmental impact of agricultural activities. Knowing exactly what to do and where and when to do it, as well as achieving more with less have become the mantras of modern agriculture. In this regard, farmers have sought to optimise their practices through the utilisation of science-based and information technology enabled solutions. In practice, farmers exploit a wide range of data – from Earth Observation satellites, drones or ground-based sensors – to observe, measure and respond to site-specific aspects within their fields and variabilities among their crops. This

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[1] See for example the USDA Economic Research Service forecasts

[2] The global middle class will increase from 50 to 70% by 2050 according to the 2015 GAP Report of the Global Harvest Initiative

[3] See the analysis by FAO

modern farm management concept, typically referred to as Precision Agriculture (PA)[4], entails the use of satellite navigation enabled machines (tractors, spreaders, sprayers, etc.) for the application of the appropriate amounts of inputs (fertilisers, pesticides, water) at a precise time and/or location. These Variable Rate Application (VRA) solutions are today an integral component of modern agricultural techniques, having proven their added value in terms of increased yield and productivity, as well as in terms of reduced strain on the environment.

The implementation of VRA relies heavily on the ability to effectively map variabilities in the field. In that regard, the availability of timely and reliable data from Earth Observation satellites is crucial. Thanks to the free, full and open access to Copernicus Sentinel data, VRA-enabling services are steadily proliferating across Europe and beyond. A prime example of such a service, bringing concrete benefits to the actors across the agricultural value chain in Poland and beyond is SatAgro.

This report is presenting both the story and the rigorous analysis around the benefits experienced by different value chain actors. The analysis relies on clear and openly presented assumptions which have been shaped with the help of the stakeholders we interviewed (see 1.4 below). However, we encourage any reader to contact us if they think the assumptions are unreasonable for any reason through emails to Lefteris Mamais (lef@earsc.org).

1.3 More about the study

Each case study analysed in SEBS, focuses on products and services which use data coming from Sentinel satellites and measures the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally-friendly operations, economic gains, improved quality of life, etc. The evaluated and demonstrated benefits can be used by:

- **Decision makers**: Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision makers not only to justify future investments but also to direct them towards areas that most matter in their country or organisation.

[4] In recent years, Precision Agriculture is considered as one key component of the greater concept of "Smart" or "Digital" Agriculture.

- **Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. In this regard, it is both numbers and stories that can resonate with users and attract them to explore further or deeper uses of EO in their operational activities.
- **Service providers:** Solid argumentation around the economic and environmental benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective marketing tool for service providers seeking to promote their solutions and for EARSC to promote the sector.

In the framework of this project 20 case studies will be developed with reports to be published on each one. The study has started in March 2017 and will end in mid-2021.

1.4 Acknowledgements

Producing this case study report would have been impossible without the invaluable insights and kind assistance of key stakeholders in Poland. Not only did they warmly welcome us in Warsaw and Lodz, but they helped us navigate across the various aspects of agriculture management, sharing the story of the people that have been using the EO-based service provided by SatAgro to inform their agricultural practices but also the environmental implications of this. For that and for their overall openness we would like to sincerely thank:

- Przemysław Żelazowski – CEO, SatAgro
- Wojciech Waraczewski – Project Manager, Grupa Azoty
- Krzysztof Stopa – CTO, SatAgro
- Stefan Józefowicz – CSO, SatAgro
- Miłosz Dobrowolski – Farmer, user of SatAgro services
- Artur Magnuszewski – Head of the Department of Hydrology at the University of Warsaw
- Edyta Kiedrzyńska – Deputy Director, European Regional Centre for Ecohydrology of the Polish Academy of Sciences, Lodz
- Ryszard Laskowski – Professor, Terrestrial Ecosystems and Ecotoxicology Group Institute of Environmental Sciences, Jagiellonian University in Krakow
- Elżbieta Ziółkowska - Institute of Environmental Sciences, Jagiellonian University in Krakow
- Lucie Savelkova – Agriculture, Economics and Rural Development Consultant at the Agriculture Paying Agency (SZIF), CZ

2 Agriculture in Poland

Polish agriculture is an emerging powerhouse in the EU. With a comparatively large land area in the Union, a large rural labour force, and continuous public as well as private investments, Poland has become a leading producer and exporter of a range of horticultural as well as commodity crops – supplying the wider EU as well as global market. On a national level, agriculture is economically, politically and socially important. It directly employs 10.6% of the labour force (ILOSTAT, 2018) and amounts to €14 Bn, or 3% of GDP (nearly twice the EU average), as the country's fourth largest sector (EY, 2017).

Nonetheless, Poland faces challenges in its efforts to develop the agricultural sector and provide benefits to the economy and society while safeguarding the environment. The high degree of heterogeneity of fundamental conditions (soil types, farm structure, crops, etc.) is a defining characteristic of this complex sector, and tailored approaches are needed to ensure that continued progress is both beneficial and sustainable.

2.1 Polish agriculture: robust and dynamic

Poland has a utilised agricultural area (UAA) of 14,4 M ha covering 46.1% of the country's total area (WorldBank Data, 2018). 74.3% of the UAA is arable land (EUROSTAT, 2018), well above the EU average of 59%, the rest of which is permanent grasslands and permanent crops. Due to its large agricultural area and large uptake of advanced production approaches, Poland is already a leading agricultural country in the EU. In 2017, Poland accounted for 10.4% of cereal production in the European Union (FAOSTAT, 2018), including a leading position in wheat (4th), barley (6th) and maize (7th). Poland also has significant production of other open field crops: onions (3rd), potatoes (2nd), rapeseed (2nd), and sugar beet (3rd). Finally, the country accounts for 5.1% of fruit production in the EU, as a leading producer of apples (1st), blueberries (1st), raspberries (1st) and cherries (1st).

The current state of the sector reflects rapid and profound changes, whose momentum is still ongoing. There has been growth in the value of agricultural output as shown in the figure below amounting to a 16% rise in the past decade. However, since 2000 there has been a steep 21% drop in the area of agricultural land (WorldBank Data, 2018). This has been marked by higher intensification of production, especially for the rapidly growing cultivation of industrial crops and export-oriented commodity crops. This trend will be examined in greater granularity and detail in section 2.1.2.

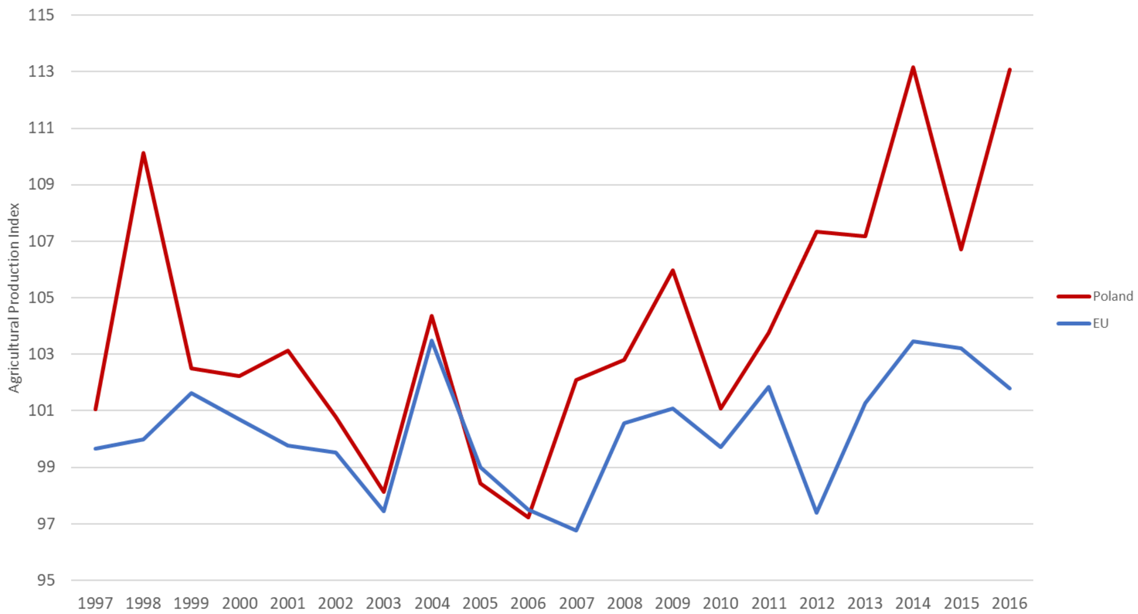

Figure 2-1: Changes in the FAO agricultural production index (calculated average of 2004-2006) – Poland vs EU average

Despite growth in yields, Polish cereal yields are below EU averages: 4.0 tonnes per ha as compared to 5.2 tonnes per ha, respectively, in 2016 (WorldBank, 2018). Cereal yields are also below their calculated theoretical potential for the prevalent natural conditions (Krasowicz et al., 2016), i.e. when water and nutrient availability does not limit crop growth and development (see graph in the next page). However, there is a significant degree of regional disparity with higher yields comparable to European levels and near their theoretical potentials in certain voivodeships, particularly in Opolskie.

Although the potential yield values presented here are only for cereal yields, the importance of cereals in Polish agriculture as well as the parallel development with regards to cultivation of industrial crops implies that, overall, there is still much room for growth and intensification of Polish agriculture. In turn this will bring challenges to balance economic progress with possible consequences for society and the environment, e.g. algal blooms growing on leached nutrients polluting waterways and drinking reservoirs.

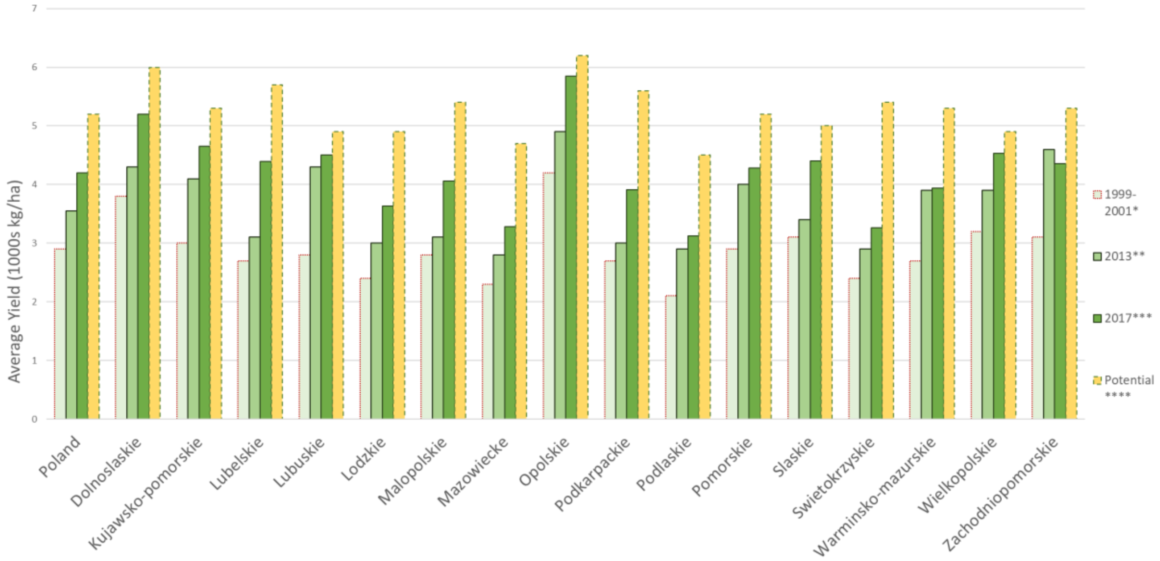

Figure 2-2: Change in average cereal yields between 1999 and 2017 across Polish voivodeships, and potential yields.

*FAO, 2003; **CKPulawy, 2014; ***Statistics Poland, 2018; ****Krasowicz et al., 2016.

2.1.1 Unfavourable natural conditions for agriculture

Since weather is the major driver of open field agriculture, the potential for agriculture is underpinned by the country's natural conditions. Despite the marked growth in the recent past and the sizeable role that Polish agriculture has come to play both nationally and internationally, Poland does not have highly-conducive natural conditions for agriculture.

Poland has a predominance of acidic light soils (e.g. podzols and lesives), low in nutrients and with poor water and nutrient retention capacity. Overall, 50-70% of arable land is composed of medium to very weak soil quality (Krasowicz et al., 2011). As such, applications of lime to balance pH and continuous applications of plant nutrients to enable robust plant growth is necessary to a large extent; in turn, it is important to manage these applications to minimise plant production costs and to avoid possible detrimental effects on the environment. Nonetheless, soil composition is highly heterogenous even on a local level, as shown below. The largest concentration of fertile soils is found in the south-west of the country (e.g. Dolnoslaskie and Opolskie), and – in a more limited fashion – in other major agricultural areas across Western Poland such as Wielkopolskie (FAO, 2003).

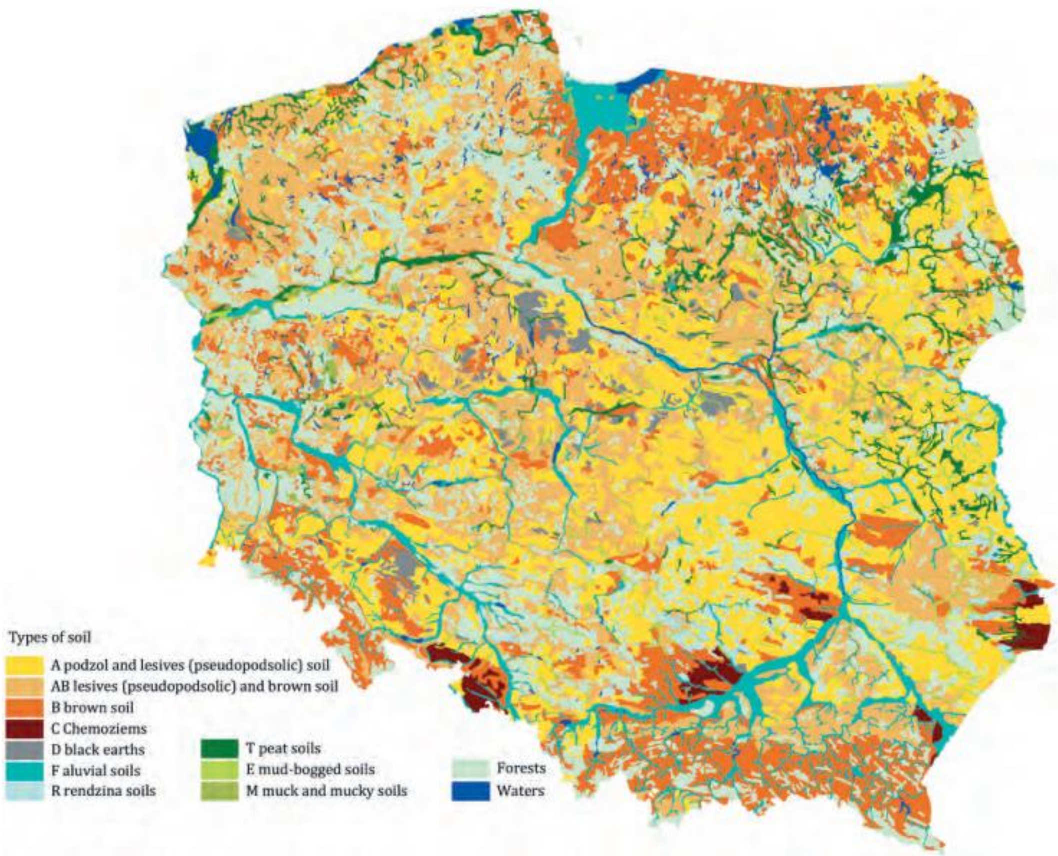

Figure 2-3: Soils of Poland (from: Krasowicz et al., 2016)

The climate is temperate with a limited growing season: between 200-240 days across the country compared to 250 days in Northern Greece or 300 days in Spain (Pastuszak, 2016; EEA, 2017). Winters are cold and summers are hot and dry. Crop water stress is common between May and September, especially for those cultivated on light sandy soils with low water retention capacity (FAO, 2003). Agricultural droughts are more frequent in recent years as a consequence of higher plant needs from higher temperatures (Gorski, 2007). Thus, ground water is an important, albeit yet underutilised resource for agriculture: irrigated area is only 0.3% of UAA (Eurostat, 2018). Most of the country has "medium rich" groundwater resources (Krasowicz et al., 2016) which can be further exploited, although not without risk to water availability and pollution problems when used in mass.

The most conducive conditions in the country for agricultural production are found in the South West, and they deteriorate progressively on a gradient across a diagonal axis (Gorski, 2007). This is shown through a "bonitation index" (see figure on the right). The index is derived from precipitation, temperature and radiation patterns in the country, key parameters which determine the theoretical actual yield of crops when water, nutrient, and pest influences on yield are nil. Several representative crops were used. One important determinant is the greater influence of Atlantic climate on the West of the country, and the fewer days with frost and temperatures below 5°C as a result.

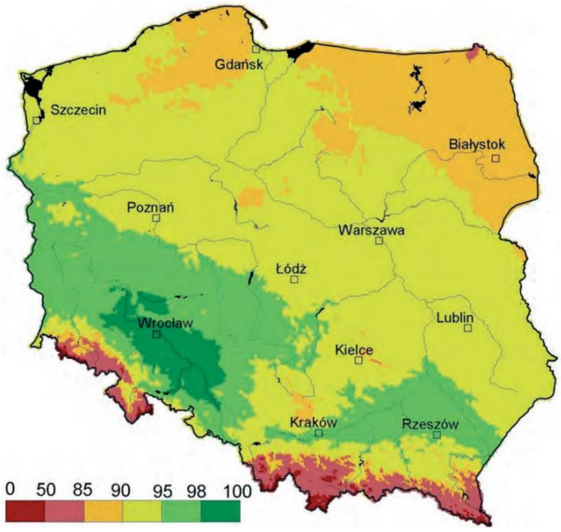

Figure 2-4: Suitability of climatic conditions for agricultural production across Poland (from: Krasowicz et al., 2016)

Despite these challenges, Poland is relatively flat with a high density of waterways across most of the country. That is, 84% of the country's territory has less than 3% slope gradient, implying that there is a low risk of soil erosion and the associated nutrient runoff (Krasowicz, 2016). A flat field slope also allows for various tillage practices to be selected, and thus greater flexibility for land preparation and crop selection. Nonetheless, as discussed earlier, there is a large risk of nutrient loss in light soils.

Overall, the values presented in this section can be interpreted in several ways. One interpretation is that Polish agriculture faces significant natural limitations when compared to other major agricultural-producing European countries. These values are average, and they do not reflect the high heterogeneity of natural conditions in the country and the pockets of favourable natural conditions. There are significant assets available to Polish agriculture – access to capital, access to labour, access to agronomic knowledge and support and access to markets – that can be seized upon to continue the trend of significant improvement in agricultural output. An alternative interpretation is that natural conditions are the context in which continued intensification will continue to occur, and that this development process will seize upon beneficial aspects of the local natural conditions while developing appropriate strategies and tools to avoid recognised threats. Heterogeneity of conditions requires that this process is flexible and is tailored to fit the needs on a local level to the highest degree as it is possible: regional, local, farm, field, and finally intra-field.

There are empirical indications that threats to society and the environment from intensification of agriculture are already manifest: commercially-focused agriculture is not highly compliant with the Common Agricultural Policy (CAP), has a low diversity of crops, has high rates of fertiliser application, lacks greening measures, etc. As CAP regulations undergo revisions expected to enhance monitoring capacity, Polish farmers will be under pressure to adopt different management practices with a restructured use of fertilisers as well as other measures. The use of digital technologies to increase the ability to tailor resource use to intra-field heterogeneity holds large promise to deliver benefits and allow for more nuanced transition to new regulation requirements.

2.1.2 Changing farm structure

There is a high degree of heterogeneity in the structure of Polish farms. In general, large farms are common in the west of the country. They carry out intensive agricultural practices on open field crops, have large fields, mark high productivity, use high-rates of mineral fertilisers, and focus on producing agricultural commodities (e.g. sugar beet, rapeseed, etc.). On the other hand, smaller intensive farms prevail in the east of the country, with thin elongated fields, lower yields, and a focus on traditional crops (e.g. potatoes/ fodder crops). The reason for the geographical difference in farm structure can largely be attributed to the rich history of Polish agriculture. Lands acquired after WWII from Germany were largely organised into big state farms. Areas in the West that were Polish prior to WWII (Greater Poland – wielkopolskie) also have larger holdings (due to earlier and more intense urbanization and industrialization in the region), but most of them have remained family-owned. During the communist period, collectivization of agriculture mostly focused on already large holding in the west of the country, itself a legacy of the partition of Poland in the 18th century. Collectivization of small holdings was never fully implemented, and large state-owned farms co-existed with traditional farms. In the past three decades (and particularly the past decade and a half), state farms were privatised creating large fields and farms available to farmers and agricultural companies to purchase. As such, currently large farms are mostly concentrated in the country's West.

There has been continued growth in the size of Polish farms since accession to the EU. Table 1 shows the difference in farm size between 2005 and 2013 obtained from the EUROSTAT Farm Structure Survey (2015). In this period the total number of farm households dropped by 42%, while the UAA dropped by only 2%. Almost 900,000 very small farms ceased to exist, representing a decrease of 73% of the total in 2005. Similarly striking is the decrease of UAA cultivated by small farms, amounting to almost 900,000 hectares. In contrast, the number of large farms grew by 51%, and the area the UAA they cultivate grew by 18% or half a million hectares. There is a clear process of consolidation, as some farm households are exiting the sector while their land is being taken over by others, which are in turn growing in size.

		Households			UAA		
		2005	2013	*Change*	2005	2013	*Change*
very small	<20	1,217,880	333,590	*-73%*	864,720	438,070	*-49%*
small	20-50	1,141,130	961,410	*-16%*	7,629,230	6,504,700	*-15%*
medium	50-100	110,250	123,050	*12%*	3,689,120	4,423,330	*20%*
large	>100	7,230	10,950	*51%*	2,571,810	3,043,780	*18%*
	total	**2,476,470**	**1,429,010**	***-42%***	**14,754,880**	**14,409,870**	***-2%***

Table 2-1: Changes in Polish farm structure between the Farm Structure Survey in 2005 and 2013 (ef_kvaareg data set).

Large farms in Poland are better available to take advantage of new technologies than smaller farms and reap benefits for quantity and quality of their yield (Jaskiewicz, 2009) – and thus improve their farm income and position vis-à-vis small farms. The availability of EU structural funds has significantly supported the ability to take advantage of emerging technologies, to scale and to intensify. As we heard during our field mission, many Polish farmers had Precision Agriculture (PA) compatible tractors even though they were yet to make use of a PA technology in their operations.

Seemingly, larger farms are better able to take advantage of the opportunities present in the sector: access to capital, access to labour, access to agronomic knowledge and support, access to technology and access to markets. Indicatively, voivodeships with large farms in general have experienced a larger growth in average farm size between 2005 and 2016 implying a larger degree of consolidation. This is shown in the next figure, where the voivodeships marking the highest average farm size in general experienced larger growth. There is also a regional dimension to this growth, with all voivodeships in western Poland except Lodzkie having an average farm size above Polish average, and all voivodeships in eastern Poland except Warminsko-Mazurskie and Podlaskie having an average farm size below the Polish average.

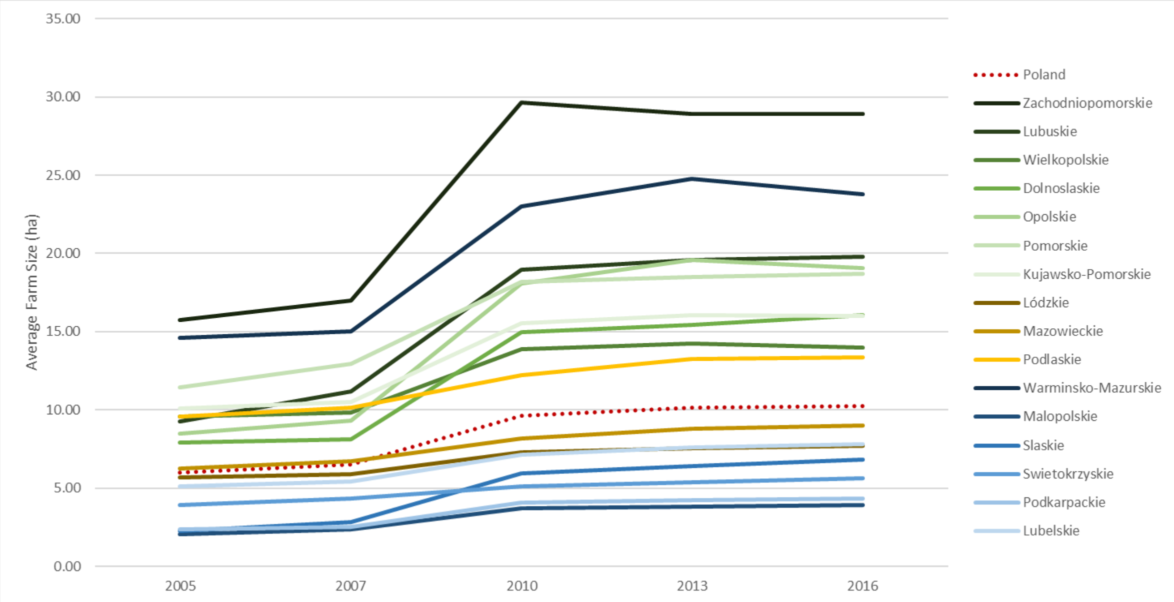

Figure 2-5: Changes in average farm size across Polish voivodeships (ef_m_farmleg data set).

This data overlaps neatly with SatAgro's business experience. The company mostly operates in southwest and northwest Poland, where farmers have the needed machinery to take advantage of PA data; many have above 50ha farm size for which field morphology is more proportional as opposed to small and thin fields which are more difficult to analyse with Sentinel-2 resolution. Such holdings in these areas have a commercial focus to agricultural production, thus seeking and investing in attractive resource-optimisation and yield-boosting solutions.

The increase in farm size begets large adoption of PA technologies, both in terms of greater propensity of farmers to invest in and adopt PA and realise value from its use as well as in terms of greater need for targeted use of resources to mitigate environmental externalities implicit to more intensive farm management common on larger farms.

2.1.3 The socio-environmental context

Precision agriculture is directly tied to the rationalisation (or optimisation) of key inputs for the fields (primarily fertilisers and pesticides). In turn, this is strongly driven by the socio-environmental implications of the use of such inputs and is therefore reflected in the relevant EU and national legislation/regulation. Let us recall some relevant definitions and facts:

- A **fertiliser** is a substance used in agriculture to provide crops with vital nutrients to grow such as nitrogen (N), phosphorus (P) and potassium (K)[5]. Fertilisers can be divided into inorganic fertilisers (also called mineral, synthetic or manufactured) and organic fertilisers. Inorganic

[5] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Fertiliser

fertilisers are chemical mixtures produced by the fertiliser industry, these include simple mineral fertilisers (e.g. urea, ammonium nitrate) and complex mineral fertilisers (e.g. NPK mixtures). Organic fertilisers include manure, compost, sewage sludge, industrial waste.

Nutrients (N, P, K) are absorbed from the soil by plants for their growth. Mineral fertilisers are widely used in agriculture to optimise production, and organic fertilisers are a significant additional source of nutrient input. There is a broad recognition that above-optimal applications of fertiliser lead to an enhanced risk of pollution to watercourses[6]. The associated problem of water quality includes eutrophication – a high concentration of nutrients promoting excessive growth of algae in a water body potentially leading to a loss of aquatic life[7]. Even though direct GHG emissions from fertiliser application are relatively small[8], these are accompanied by indirect emissions from the energy intensive production of mineral fertiliser. In light of this, the EU has put forward a series of legislative acts and regulation[9] concerning the production and use of fertilisers.

According to Eurostat, there was about 5% increase in N-fertiliser use in 28 EU Member States over the period 2006-2015 as compared to 19% decrease in P-fertiliser use over the same time period. In this regard, Poland is well positioned with its less than one percent increase in N-use and 31% decrease in P-use. According to the year 2015 data, Poland is the fourth biggest consumer of both N and P within the 28 EU Member States where Spain, France, and Germany are taking first positions. In terms of per-hectare application rates, Poland is among five EU-28 countries with the highest P-application rates, but at the same time rather on a lower end as it regards N-application rates (Eurostat data for 2015). In the context of the high nutrient load in the Baltic Sea[10], the contribution of Poland whilst considerable, does not appear to be high in a relative sense when Poland is compared with a group of neighbouring countries[11]. The solution of this problem cannot be achieved by a sole reduction of fertiliser use and should address other factors of equal or higher importance e.g. wetland restoration, improved manure management, wastewater treatment.

[6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption

[7] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Eutrophication

[8] Carlson et al. 2016

[9] See for example http://www.europarl.europa.eu/legislative-train/theme-new-boost-for-jobs-growth-and-investment/file-review-of-the-fertilising-products-regulation

[10] Pastuszak M, Igras J, Temporal and spatial differences in emission of nitrogen and phosphorus from Polish territory to the Baltic Sea, 2012

[11] Kiedrzyńska et al, 2014

- A **pesticide** is a chemical substance used in agriculture to kill or limit organisms which are considered 'pests' because they may endanger agricultural crop output. Pesticides can be subdivided into categories e.g. fungicides (against fungi), herbicides (against plants considered to be 'weeds'), and insecticides (against insects)[12]. The use of pesticides plays an important role in agricultural production by ensuring less weed and pest damage to crops and a consistent yield. However, their use can have negative environmental impacts on water quality and terrestrial and aquatic biodiversity because of persistence and toxic effects on non-target species[13]. Pesticide residues in food may also pose a risk for human health[14].

  The environmental risk of pesticide use varies considerably from one to another, depending on the intrinsic characteristics of their active substances (toxicity, persistence, etc.) and use patterns (applied volumes, application period and method, crop and soil type, etc.). As a result of their potential toxicity, often even at very low levels, the application of pesticides in EU is strictly controlled by Community legislation since 1991 (by national legislation prior to 1991)[15]. Policy control measures in the EU are driven by the objectives of protecting human health and the environment (consumers, operator safety, protection of water quality and biodiversity). Recent studies suggest a change from regulation of a pesticide in isolation, towards the consideration of pesticide management at landscape scales and provision of biodiversity benefits via inclusion and testing of mitigation measures[16], which puts the problem into a broader context. The recent research in ecotoxicology points out the needs for very detailed datasets (field maps), while accepting the fact that the biggest problem is not pesticides at the current application level, but rather the monoculture – large fields and low biodiversity. A promising approach to solve this problem would be to split fields and increase biodiversity, while still using pesticides for crop protection[17].

  According to Eurostat, there was an increase in pesticides sales in 2011-2016 demonstrated by several EU Member States. With this regard, Poland is positioned reasonably well (about 12% as compared to e.g. about 18% in France). Poland is not the biggest consumer of pesticides within the 16 EU Member States, where Spain, France, and Germany are taking first positions (fungicides, herbicides, and insecticides).

Details on the specific impact of fertilizer and pesticide use in the case of Agriculture in Poland are discussed in section 5.1.4.

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12 http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Pesticide

13 European Food Safety Authority Panel on Plant Protection Products and their Residues, 2015

14 http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_pesticide_risk

15 http://ec.europa.eu/eurostat/statistics-explained/index.php/Pesticide_sales_statistics

16 Topping et al. 2015

17 Discussion with Dr Ryszard Laskowski and Dr Elżbieta Ziółkowska, Institute of Environmental Sciences Jagiellonian University in Krakow, Poland

2.1.4 Farmer challenges and the role of precision agriculture

There are clear macro-level indications of the increased suitability of PA in Polish agriculture. The key question is whether users have a reason to adopt these technologies.

The foundation of a strong business case for PA technologies rests on delivering strong economic value by addressing significant challenges facing farmers. To a large degree, Polish farmers are facing the challenges facing Europe's farmers:

- **Downward pressure on income**. Although the picture is highly complex, many EU farmers are experiencing a long-term cost-price squeeze. On the one hand, agricultural commodity prices have been falling since 2008 and are expected to continue a long-term trend of decline (Bellmann & Hepburn, 2017). On the other hand, prices of inputs are rising: in EU-27 between 2007 and 2012, fertiliser costs grew by 46%, seed input cost grew by 24%, pesticide costs grew by 26%, and overhead costs grew by 33% (including a growth of 43% for energy costs) (EP, 2015). The result has been "*a fall in the real value of net margin between costs and revenues remaining to the sector as a whole, and thus a fall in the relative position of average rewards to productive resources (in particular labour) in agriculture compared with those available in the rest of the economy*". However, there is important disparity within average figures. For large farms, which already have larger incomes than small farms, there are indications that income has risen, particularly for those engaged in field crops. This correlation is so strong that it accounts for differences between Member States with different patterns of farm structure.
- **Income instability**. Oscillations in year-to-year income make it hard for farmers to plan into the future and may require loans to address shortfalls in cashflow (i.e. to purchase inputs). 55% of large farms and 38% of small farms across the EU experience income volatility of ±30% (EP, 2015). The reason for these oscillations can be traced to (i) changes in farmgate prices of agricultural produce, in large part influenced by global supply and demand, (ii) as well as yield. Greater stability in yield can address this challenge to some degree. It should be noted that many farms engage in non-agricultural activities that can generate income on a farm (e.g. care farm, tourism, hospitality, etc.) and engage in off-farm income generating activities (EP, 2015), which can soften income oscillations for farm households.
- **Competitive pressure from a globalised market**. In general, Europe has high input costs for agricultural production compared to global levels (e.g. labour and land) (EC, 2017). In addition, European farmers have addition costs related to complying with the most stringent environmental regulation in the world (e.g. Water Framework Directive, Nitrates Directive, greening in the Common Agricultural Policy, etc.), which limit agricultural options and may require additional investments, entail additional operational costs as well as necessitate additional time to accomplish agricultural tasks. There are also other macroeconomic factors, for example exchange rates, that impact international competitiveness of European agriculture. The Euro is expected to appreciate against major world currencies in the medium-term which will make European products comparatively less competitive (EC, 2018).
- **Climate change**. Weather is the major driver of open field agriculture. Changes in climatic

conditions include temperature rises, changes in precipitation patterns, frequency of extreme weather events, changing wind patterns, etc. Their consequences – e.g. diminishing water resources, new pests, drier summers, *force majeure* damage events, etc. – will have a profound effect on the sector. There is a large need in the long-run for adaptation measures in management, infrastructure and choice of crops.

As implied in the descriptions above, the challenges are highly interconnected and fundamental. Facing these challenges, there is a clear need for innovations that can generate cost-savings, increase resource use efficiency, increase sustainability, save time, stabilise yield, and help adapt to climate change. PA has large potential to address several of these challenges by improving resource-use efficiency, farm profitability and sustainability.

2.1.5 Will precision agriculture be a mass or a niche market?

PA is still at an early stage of adoption in the Polish agricultural sector. Commercially-oriented farmers in Poland are well positioned to take advantage of these new technologies as they mature, and there are strong indications that they are in fact interested in these technologies. As discussed earlier, land consolidation has led to larger farms with a greater specialisation and commercial focus (family farms and corporate holdings). These farms are more productive and profitable (EP, 2015), thus more suitable customers for PA technology: they have larger overall benefits resulting from the sum of marginal benefits over a large area and they have preferential access to knowledge and credit.

Furthermore, Poland has a comparatively young generation of farmers (EUROSTAT, 2018) as shown in Table 3. 10% of farmers are below 35 years of age, compared to 4% in the EU, and 23% are between 35 and 44 years of age, compared to 13% in the EU. Young farmers are more familiar with technology, more willing to invest in learning how to use new technologies, have longer investment time-horizons, and are more willing to adopt technological solutions compared to older farmers (National Research Council, 2002; Pierpaoli et al., 2013; Barnes et al., 2019). It is perhaps not entirely surprising that 86% of farms in Poland enjoy Internet access, 71% of farmers consult the Internet when making decisions, and 40% of them view “state-of-the-art agricultural machinery as key success factor” (CK Pulawy, 2014).

Age group	<35	35-44	45-54	55-64	>65
Poland	10%	23%	30%	24%	13%
EU	4%	13%	22%	25%	36%

Table 2-2: Age distribution of farmers in Poland and the EU (ef_kvaareg data set).

Most of SatAgro customers had the capacity to use the data they provide. Poland is a major beneficiary of EU subsidies – in fact the single largest one in the 2014-2020 financial framework (EY, 2017) – whose support has helped spur farmer investment in new machinery (Wojcicki and Kurek, 2011). Agricultural subsidy programmes have begun to prioritise farmers that make a case for PA applications. It is likely that a large farm can obtain the necessary machinery to use PA if they have not already purchased it.

Furthermore, SatAgro has found that prescription maps for variable rate applications are already fairly common in southwestern Poland. The business model is quite different, in that it relies on data being collected by drones and analysed by agronomists. It indicates farmer interest in data-driven agronomic support services, that they recognise the value and are willing to learn how to use new tools. This has also been the overall experience found by SatAgro. In fact, around 50% of their customers are using variable rate application maps for the first time.

2.2 Informed decisions, coordinated actions and effective interventions

How are my crops growing in different parts of my field and over time? When should I apply fertilisers, pesticides, fungicides, and how much should I use for each section of my field? Which fields need more water? These and many other similar challenges are shaping the farmers' everyday reality, especially in relation to the most important interventions throughout the year (spreading/sowing, fertilising, spraying, irrigating, harvesting, etc.). Informed decisions, coordinated actions and effective interventions in response to such challenges affect the overall production of the farm. Understanding what is happening, where and when is thus of utmost importance. To that end, modern farming practices entail the collection and interpretation of a wide range of information on the different conditions that affect crop growth and quality (e.g. soil composition and moisture, weather and climate aspects, crop health, surface temperature, etc.). In this context, we provide below a short review of the agricultural practices that are carried out to optimise the overall yield of a farm.

2.2.1 Crop Monitoring

Being able to monitor the status and growth trends of their crops, helps farmers to maximise their yield and to react to potential threats. In practice, crop growth monitoring entails an observation of changes on the crop status in relation to abiotic factors such as water stress and biotic factors such as insect infestation. Thus, farmers seek to monitor specific crop growth parameters such as crop vigour, crop stage, biomass and leaf area index. As a result, problems related to nutrient deficiencies or the occurrence of pests and diseases can be detected early and treated appropriately. Indirectly, crop growth monitoring can help in delineating different management zones at sub-parcel level for variable rate application of fertilisers and plant protection products.

2.2.2 Soil Sampling

Soil sampling is one of the critical steps in crop management, given that the crop yield variability is strongly correlated to different soil characteristics in different sites within a field. Precise Soil Sampling enables the execution of farming practices that take this site-specific variability into account. In essence, by collecting accurate, site-specific information about soil characteristics such as fertility, soil-borne diseases and soil contamination, farmers can avoid over- or under-application of nutrients and other chemicals in different areas within their fields. In turn, this has a direct effect on increased yield productivity and reduced environmental impact.

2.2.3 Precise application of inputs

Precision Agriculture (PA) consists in the application of the "*right treatment in the right place at the right time*"[18]. Enabled by precise positioning through GNSS and relying on the combination of various other technologies (e.g. proximal and remote sensors), PA enables fine-scale, site-specific management of agricultural production. Thus, by being able to precisely guide their farming machinery and accurately apply different inputs taking into account the variabilities of their fields, farmers have been able to minimise soil compaction, reduce the use of fuel, pesticide and fertilisers, and increase productivity. Other significant benefits include the reduction of environmental impacts and increased work safety.

2.2.4 Collecting the necessary data

So, how do farmers go about performing these activities? What aspects do they need to observe, and how do they manage this? In general, there are two relevant categories of data generation: (i) process-mediated (PM) and (ii) machine-generated (MG)[19].

PM data are related to key agricultural processes such as purchasing and applying inputs (e.g. fertiliser), seeding, etc. This data is typically stored in some form of "farmer's diary". In that regard, farmers consult agro-meteorological data[20] (e.g. precipitation, sunshine, solar irradiation, air temperature, humidity, etc.) as it directly informs the ideal timing for different activities (e.g. harvest, cultivation). Meteorological observations are also essential when it comes to preparedness for impending extreme weather events.

MG data derive from the multitude of sensors on-board agricultural machinery (e.g. proximal sensors), or observation platforms (e.g. drones, airplanes, satellites). Such sensors allow the measurement of parameters such as soil moisture i.e. the water available in the soil for plant growth and development, as well as surface temperature or crop characteristics (e.g. with hyperspectral cameras looking into biophysical and chemical properties). The precise collection of MG data is enabled by accurate positioning offered by GNSS.

Translating the different types of data into actionable information and, eventually, into effective interventions, lies at the core of integrated farm management approaches. In turn, and thanks to the overall digitalisation of the sector, this has become the cornerstone of the agriculture 4.0 era, whereby everything is connected! Thus, the new farming paradigm – to be solidified over the next years, sees farmers accessing and cross-analysing weather, crop or operations-related information and, eventually, managing their entire agricultural holding on a computer or mobile device.

In this data-enabled agriculture, remote sensing by satellites has a central role to play. Let us then see how.

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[18] Gebbers and Adamchuk, *Precision Agriculture,* 2010

[19] For details see Wolfert *et al., Big Data in Smart Farming – a review,* 2017

[20] For a thorough overview see WMO's [Guide to Agricultural Meteorological Practices]

3 The use of Sentinel data

3.1 General introduction on the use of satellite data for agriculture

Remote sensing techniques are being increasingly used for the provision of timely and accurate data on several aspects related to agricultural production. The combination of satellite imagery with meteorological data, agrometeorological and biophysical modelling and statistical analyses allows the continuous monitoring of agricultural areas and the extraction of valuable information that can guide efficient farming practices. In this context, the ability of satellites to gather information on different crop and soil properties as well as to identify pests or other threats (e.g. floods or droughts), over large areas and with a high revisit frequency, is leveraged in multiple applications:

- Crop growth monitoring (incl. crop damage, crop health)
- Crop yield monitoring and forecasting
- Soil moisture estimation
- Soil mapping
- Biomass monitoring

Before entering into the specifics of the agricultural services studied in Poland, it is important to understand how satellites can capture changes on the surface of the Earth giving rise to information that is extremely valuable to farmers.

3.1.1 How can satellites enhance the knowledge of farmers

Broadly speaking there are two main classes of Earth Observation satellites[21]:

- Those carrying **passive sensors** able to detect the sun's energy as it is reflected from the Earth's surface. These "optical" satellites are affected by cloud coverage (at it hinders solar radiation) and can only observe during day time. Typically used sensors in this category are radiometers (incl. imaging and spectro-radiometers) and spectrometers.
- Those carrying **active sensors** capable of emitting their own energy (in the form of electromagnetic radiation) to illuminate the scene (and objects therein) they observe. Such satellites send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Typically used sensors in this category are radar, scatterometers and lidar. Satellites carrying such sensors – for example Synthetic Aperture Radar (SAR) satellites – are unaffected by cloud coverage.

[21] A nice overview of passive and active instruments on board earth observation satellites is provided in https://earthobservatory.nasa.gov/Features/RemoteSensing/remote_08.php

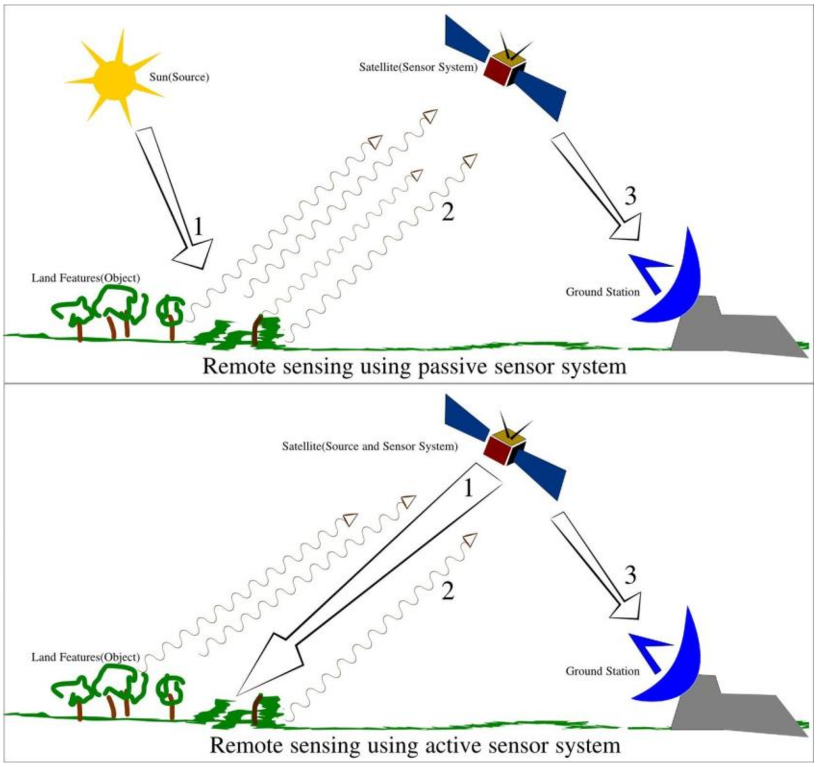

Figure 3-1: Illustration of passive vs. active remote sensing[22]

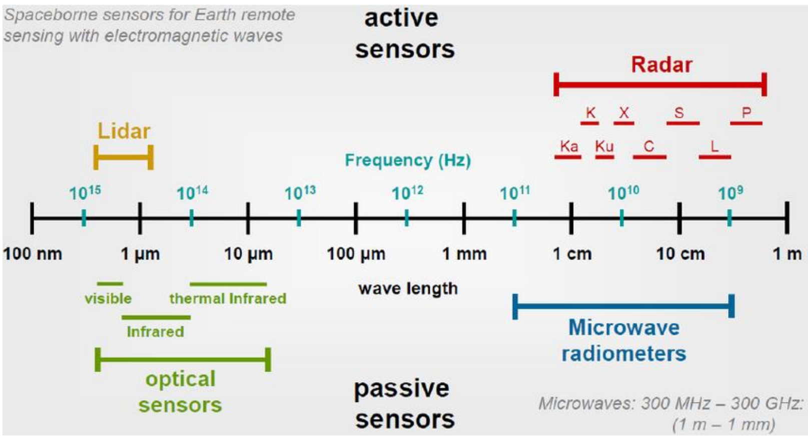

Figure 3-2: Active and passive sensors used for Remote Sensing[23]

As seen in figure 3-1, active and passive sensors emit/collect electromagnetic signals of different wavelengths. In practice, different materials on the Earth's surface reflect electromagnetic waves in a different manner. These reflectance differences allow Earth Observation (EO) satellites to distinguish between grasslands, water surfaces, forests, buildings, etc. When more than two wavelengths are used, the separation among objects is even more evident. Thus, satellites

[22] Graph taken from Dall (2017)
[23] Graph taken from Lefeuvre, F & Tanzi, Tullio. (2014).

equipped with multispectral sensors (i.e. utilising different bands of the spectrum) can provide data that allow the quantitative classification of different types of land cover in a given scene.

During the cycle from sowing to harvest, agricultural vegetation changes as a function of variables such as temperature, sunlight, and precipitation. Soil and plant characteristics, as well as the impact of the specific farming practices in use can further affect the growth of vegetation. Changes in the health, density, vigour and productivity of crops affect the optical properties of the canopy. The use of remote sensing - especially in red and infrared spectrum - and other proximal sensors enables the mapping of changes (essentially related to vegetation reflectance) across a field and with time, thus enabling the monitoring of crop development and growth. Land cover classification can also be achieved using SAR satellites. Contrary to optical satellites – which essentially produce photographs, the SAR imagery is a measure of how much energy is scattered back to the sensor after being reflected on different types of materials.

In all cases, the data collected by EO satellites is transmitted via radio waves to properly equipped ground stations. There they are translated into a digital image that can be displayed on a computer screen. Each satellite image is composed of pixels and each of these pixels represents a square area on the image that is a measure of the sensor's ability to resolve (see) objects of different sizes. The higher the resolution the greater the ability of the sensor to discern smaller objects, but also the narrower the strip of land that can be surveyed by the satellite.

Measuring plant properties

Thanks to this stream of data, a wide range of advisory services for agriculture can be developed. The most common entails the measurement of the Normalised Difference Vegetation Index (NDVI). NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. But it absorbs more red and blue light. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1). Knowledge of the distribution of this index across a given field and in connection to the applied farming practices (e.g. fertilisation), allow farmers to make informed decisions on what is needed where and when.

3.1.2 The role of Copernicus Sentinels and other initiatives

Copernicus, offering vast amounts of free and open data via the Sentinel missions, is significantly contributing to further advancing the use of remote sensing techniques in precision agriculture. For example, Sentinel 2 provides a 10-metre resolution that can be relevant even to individual land parcels, whilst its revisit time stands at 5 days making it highly relevant for crop dynamics monitoring. By measuring the energy reflected in visible and infra-red bands, Sentinel 2 enables the calculation of NDVI[24].

Sentinel-1 SAR[25] mission enables remote sensing regardless of the weather conditions (i.e. cloud masking). Finally, the optical instruments[26] of Sentinel 3 may also contribute to large-scale vegetation and crop condition mapping.

Apart from Copernicus and other missions that secure the use of Earth Observation satellites for agriculture (Landsat-8) several initiatives exist at a regional, continental or even global scale. Indicatively, a number of systems exist providing crop monitoring, alerts and forecasts:

- the GEOGLAM Crop Monitor[27], organised as a GEO initiative;
- FAO's Global Information and Early Warning System (GIEWS)[28];
- JRC's MARS providing EU agricultural production estimates and food security assessments[29];

The landscape of satellite-based decision support solutions is completed by the recent rise of private ventures such as Planet, offering higher resolution and revisit time.

3.1.3 Advantages

The most important advantages of satellite-based agricultural applications include:

- The **capability to acquire data anywhere in the world** without any limitation by weather conditions (when combining optical and SAR) or the impact of the phenomenon itself. Satellites offer a **robust source of near-real time[30] information** to aid food production.
- The ability to generate **consistent, comparable and relatively objective** (i.e. not depending on individual interpretation/observation) information, **collected systematically on multiple scales, from local to regional to nation-wide**;

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24 For details see https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-2a/algorithm

25 For details see https://sentinel.esa.int/web/sentinel/missions/sentinel-1

26 Ocean and Land Colour Instrument (OLCI) - 300m resolution; Sea and Land Surface Temperature Radiometer (SLSTR) - 1km resolution http://www.copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Sentinel-3_fiche.pdf

27 https://cropmonitor.org/

28 http://www.fao.org/giews/en/

29 MARS: Monitoring Agricultural Resources https://ec.europa.eu/jrc/en/mars

30 "Near real-time" has a different meaning based on the application being studied. In the context of agriculture, near real-time is understood to be a few days. For a comprehensive overview on this we recommend a recent publication by Defourny et al. (2019) https://www.sciencedirect.com/science/article/pii/S0034425718305145

- The capability to supply **regular, detailed updates on plant status** on a local, regional or national basis. By combining different satellites, this can be even done on a **daily basis** offering an invaluable resource to farmers
- Satellite images offer spatially continuous data coverage of the entire field, with no further interpolation required, in contrast to ground based discrete sampling. As such, they can serve as a basis for interpolation of information gathered in situ.
- Finally, whilst EO satellite data are a complementary data source to in-situ data (as well as airborne data, socio-economic data, and model outputs) in most countries, they **can be the only reliable source of information in countries lacking the ground infrastructure**.

3.1.4 Limitations

When compared to alternatives such as on-site or aerial surveys, satellite-based agricultural mapping presents the following limitations:

- resolution and active sensor limitations
- still non-daily revisit times for high resolution, non-commercial optical satellites
- possibility of gaps in data availability due to cloud cover

On-site surveys in particular offer information about soil chemistry and physical properties at different depths below ground which cannot as of yet be fully replicated with either satellite or aerial remote sensing. These soil characteristics tend to be less dynamic by nature than crop growth and in consequence do not have to be reassessed as often.

Until a few years back, another potential limitation was the cost of acquiring satellite data. That has progressively changed, first thanks to Landsat, and then with the advent of the Sentinel era – producing vast amounts of data under the Copernicus full, free and open data policy.

3.2 SatAgro services

3.2.1 Overview

SatAgro is a service that assists farmers in the implementation of precision farming by offering them access to intuitive online tools and to a wealth of information that can inform their agricultural practices. This information is generated by using satellite (from Sentinels, Copernicus contributing missions, Landsat and private operators) and weather data. The information is provided at field level and allows farmers to perform site-specific management of their crops. In this way, SatAgro is a perfect complement to advanced machinery – increasingly available for farmers in Poland and beyond – as it allows them to execute variable rate application of agrochemicals and other inputs.

Accessing SatAgro services

The entry point for users to access SatAgro services is a web-based application. The user creates an account and uploads the location and boundaries of the fields that they want to monitor. SatAgro then gathers weather and satellite data for those fields from numerous providers, processes it in a way that it becomes easily digestible and delivers the outputs to the user in near real-time. This allows farmers to have a reliable basis for the execution of well-informed farming practices in their fields. This online app is accessible through a standard web-browser. Thanks to this web-based approach, the app has no software or hardware requirements. In parallel, SatAgro is developing an Android smartphone app with a subset of the web-based app functionalities.

In designing these interfaces, SatAgro has placed strong focus on compatibility and ease of use. The service's user interface is meant to be easy to learn and operate for anyone comfortable with navigating modern webpages; in this way, SatAgro aspires to reduce barriers to entry into precision agriculture technologies.

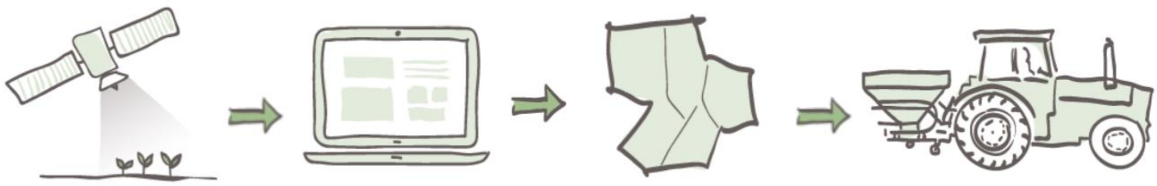


Figure 3-3: The SatAgro Service concept – from satellites, through an application that produces prescription maps that enable VRA on the field

The Dashboard

After logging in on the web-based application, the user gains access to their main dashboard. In this they get an overview of their account including:

- Rudimentary meta statistics – number of fields, account subscription status
- Weather forecast
- Calendar with past image acquisitions available in the application and upcoming flyover/opportunities for image acquisition

From there, the user can navigate to other parts (or "tabs") of the application using the bar at the top of the page. This includes:

- **Fields** - the Field list, where the farmer can manage areas monitored by the application, modify crop history, as well as inspect basic variables.
- **Diary** – where users can view a chronology of actions they have undertaken within the application, e.g. by creating prescription maps, as well as automated events, such as weather alarm triggering.

- The **Explorer** tab is where the user spends most of their time in the app. Information presented here is at the centre of the data analysis and transformation services offered by SatAgro and its' decision assistance capabilities.

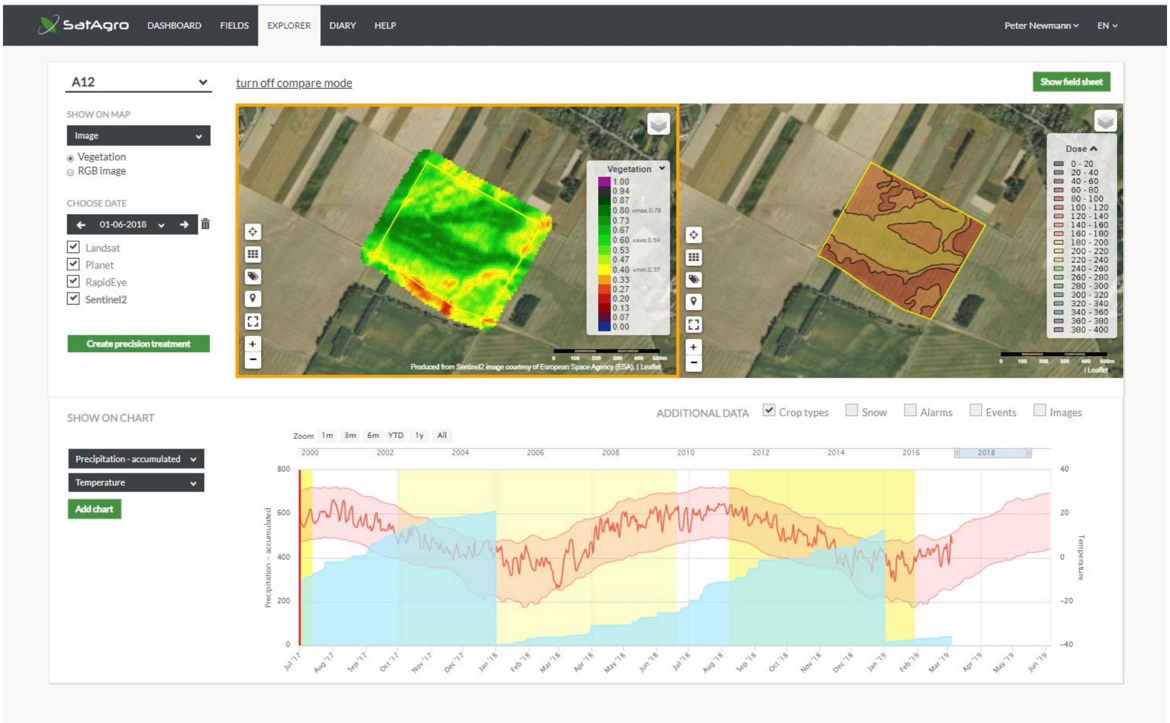


Figure 3-4: The SatAgro application dashboard

To better understand how the SatAgro services work let us look into the different modes on the "explorer".

The **Map Area** allows users to inspect their fields using a wide range of datasets. For example, different satellite imagery sources can be activated (Sentinel-2, Landsat, Planet). Data sources, acquisition dates and fields can be cross-analysed using the "compare mode". Datasets generated using satellite data and covering the entire farm can be displayed for all fields at once. Thus, SatAgro provides

- Normalized Difference Vegetation Index (NDVI) biomass maps
- Natural light RGB compositions
- VRAs generated within the application
- Soil sampling results
- User generated data, e.g. yield maps

The **chart area** allows users to inspect their fields' history in terms of various timeseries going back to, in the case of weather data, the start of the century. Variables include:

- **Weather data** from the nearest public weather station or the farmer's own station:

    - Precipitation (daily and yearly cumulative)
    - Temperature
    - Growing degree days – agronomic measure used as a heuristic for crop growth stage – crop specific and generic.
- **Satellite-derived environmental parameters**:
    - Enhanced Vegetation Index (EVI) calculated based on high frequency, low (230m) resolution MODIS data – field-wide average, serving as a record of generalised crop well-being going back to 2002. In the future, Sentinel-3 data will be integrated in a similar fashion.
    - Snow cover occurrences detected with MODIS sensors.
- **Crop history** entered into the system by the user

In addition, **SatAgro account metadata** are marked, including:

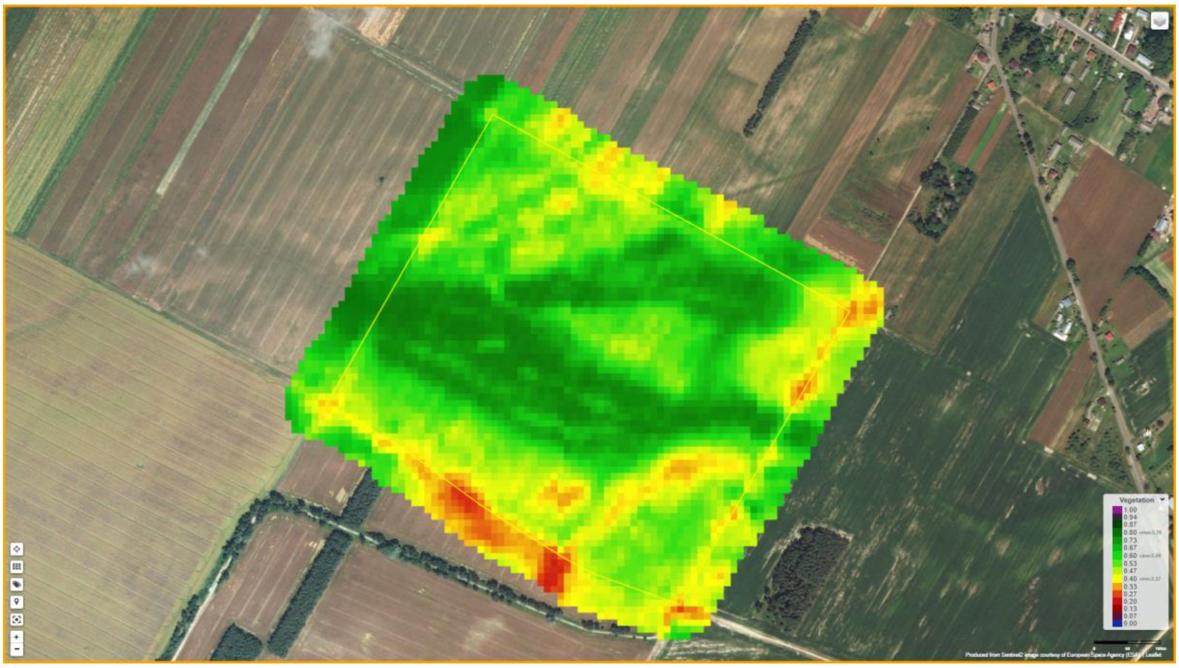
- High resolution image acquisition dates
- VRA use dates
- A visualisation of all active alarms

Understanding the key SatAgro Services

Figure 3-5: Overview of SatAgro services

Having gone through the basic functionalities of the main interfaces it is now important to look more closely at the key services offered by SatAgro

3.2.2 Scouting



The purpose of this service is to provide farmers with an accurate view of the state of their fields. This was historically the 1st service that SatAgro rolled out. The information on the farm's current condition is provided through the "Explorer" mode and via the chart and map areas. Farmers can be informed about the temporal and spatial variability of vegetation of field crops. To that end, they can access satellite-based visualisations, which thanks to Sentinel-2 data are now available every week (except for periods with persistently cloudy conditions which tend to occur in in autumn and winter). Farmers also gain access to meteorological data for forecasts; these are sourced from WMO stations, web-integrated hardware on farms, grid weather data for precipitation, MODIS, GDD, etc. This set will be enriched with Sentinel 3 data in the near future. The benefits from using the scouting service is that farmers can see all their fields in one place; this is especially relevant for owners of large holdings and/or those who own distant fields. In addition, crops such as corn grow tall thus making it very difficult to assess its condition in the middle of the field. With this service farmers overcome such barriers.

3.2.3 Historic data

SatAgro provides users with a minimum 2-year back catalogue of satellite imagery of their fields upon account creation, as well as the almost two decades of weather data going back to the start of the century. These two, in conjunction with the farmer's knowledge of past actions and crop performance, can be used to perform elaborate analyses that provide actionable knowledge for the future.

3.2.4 VRAs

Variable Rate Application of agrochemicals is a cornerstone of precision agriculture. By enabling the execution of this approach, SatAgro helps farmers to reduce or rationalise the use of inputs leading to significant economic and environmental benefits. To do so, SatAgro allows farmers to produce prescription maps informed by indices that are generated using satellite data. In practice, this service takes into account the measured variability of crops status across the field to inform the application of fertilisers or other inputs. This is done by using satellite imagery and derived applicable indices (e.g. NDVI), which can be complemented by results from in-situ analysis of soil chemistry.

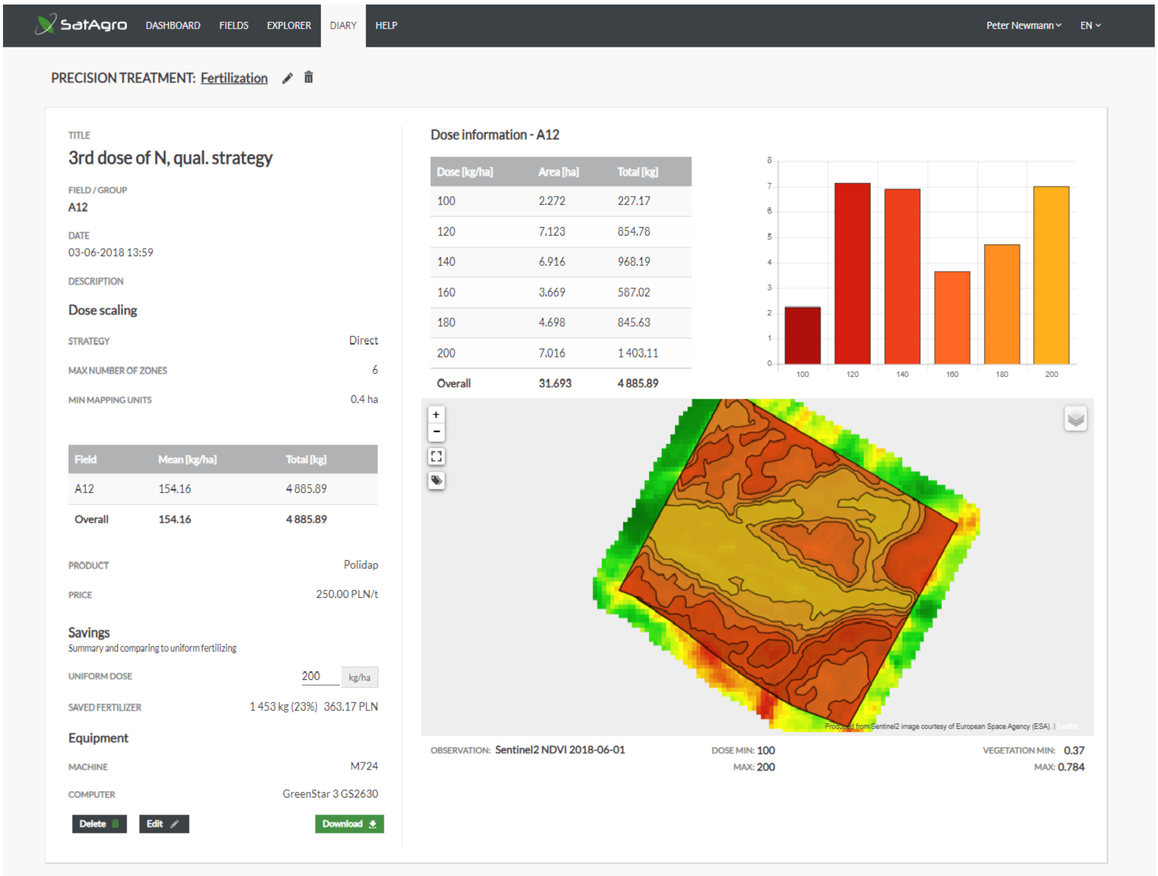


Figure 3-6: The dashboard offers a prescription map and details guiding the 3rd dose of Nitrogen for winter wheat.

The prescription can be directly proportional to plant needs (levelling), or to performance (inversely related to plant needs). The main focus is on Nitrogen (N), which is most suitable for such monitoring, but the inclusion of soil sampling results allows to expand it onto Phosphorus (P), Potassium (K) and other nutrients. The service is especially suitable for wheat and rape seed which require multiple fertiliser treatments (unlike maize, sugar beet and potato). The farmers are able to insert specific information on their own practices (i.e. which product they use and how much it costs, as well as which equipment/tractor). The service then produces an estimate of difference in cost between the VRA and uniform application. The final prescription maps are easy to upload on VRA-enabled tractors thus allowing the actual execution of site-specific fertilisation.

SatAgro has been also running tests for fungicide applications, with recommendations on timing being based on meteorological data. This could help address needless use of pesticides resulting in pointless pollution of the environment and to avoid "blanket" applications by taking into account spatial variability of biomass. In this context, SatAgro expects reductions of up to 10-15% for the 2nd application and up to 5-10% for the 3rd application.

3.2.5 Other services under development or enhancement

Other areas in which SatAgro is focussing to hone its offering are alarms and soil sampling support and visualisation. For the latter, the key consideration is that that crop well-being is a product of several factors, with soil chemistry being a pivotal one. Biomass maps can be used to infer to a degree the underlying nutrient distribution. SatAgro thus seeks to let its users transform NDVI images into zones for soil sampling, that better capture the variability of soil chemistry than a simple geometric grid. Furthermore, by doing a historical assessment of vegetation, particularly during years of stress, different treatment zones can be produced. This information is then provided to 3rd parties to guide soil sampling; the results can be then integrated into the SatAgro platform to be visualised on a map and guide even better informed VRA solutions.

SatAgro is looking into water stress monitoring and precision irrigation using Sentinel 1. The first tools in this area will be offered in the 2020 season.

Figure 3-7: Different visualisations of prescription maps on the same field

Let us now look how these satellite-enabled services are used across the value chain (chapter 4) before digging deeper to quantify the value they produce.

4 Understanding the value chain

4.1 Description of the value chain

The use of satellite data for the development of services supporting more efficient agricultural practices gives rise to a concrete value chain. In this particular case, SatAgro makes use of Sentinel data – together with other ancillary data – to provide services that can help its clients optimise their agricultural activities. This is done either directly with individual farmers or through the strategic collaboration with Grupa Azoty – the 2nd largest fertiliser producer in the EU – who incorporate SatAgro services in their offering to selected farmers. In both cases, the use of Satellite data at the entry point of the value chain, results in enhanced information or improved operations that bring value for each link further down the chain. Ultimately, the implementation of more sustainable farming practices (both from an economic and an environmental point of view), results in benefits experienced by citizens or environmental agencies at the far end of the value chain. But before we dive into the individual links and attempt to quantify the benefits (this is done in chapter 5) it is instructive to understand how the use of satellite data helps actors along the value chain to address the challenges that shape their own operational reality. Thus, in the following sections we provide details on the interests and responsibilities of the stakeholders in each tier.

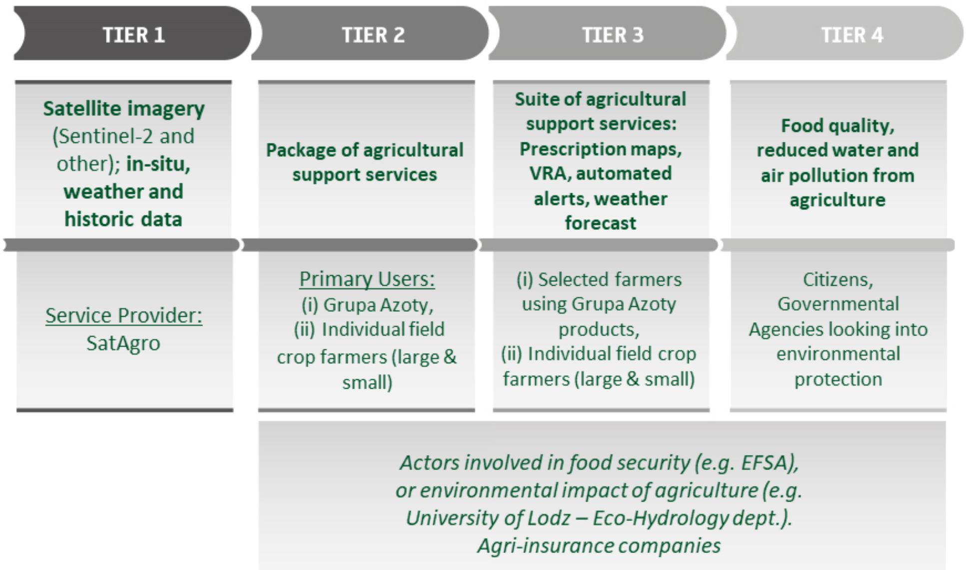


Figure 4-1: The value chain for Agriculture in Poland

4.2 Stakeholders interests and responsibilities

4.2.1 Tier 1 – SatAgro

SatAgro is a direct result of the lack of tropical forests in Poland, combined with scientific excellence, technological aptitude and the right amount of risk taking. It was back in 2013, that Przemysław Żelazowski, a former researcher at Oxford University and consultant for FAO, decided to bring his skills and vision back to his homeland. Building on his experience in analysing satellite images for the protection of tropical forests, Przemek readily identified the need for technology-driven optimisation of agricultural productivity in Poland. Whilst the Polish agriculture market was already sizeable, the uptake of cutting edge solutions that help increase agricultural output and make farming more sustainable was still very low. Przemek, now an assistant professor at the Centre of New Technologies (CeNT) - University of Warsaw, considered this to be an opportunity for the delivery of satellite-based services that bring value to a range of agricultural practices (see section 3.2). Together with Krzysztof Stopa, he founded SatAgro shortly before Sentinel satellites went online. With seed funding and start-up support from EU cohesion funds for innovation in the digital economy as well as private funds, SatAgro started honing their agriculture services portfolio over the course of a few years, with the prototype going live online in early 2015. Thus, starting with monitoring of crop health (scouting) by Landsat 8 alone, SatAgro has since moved on to expand their offer in step with the growing availability of satellite data. The service now provides prescription maps in support of Variable Rate Application (VRA), automated weather alarms and more. To that end, the free, full and open access to Copernicus data (and in particular Sentinels) has been instrumental. It has essentially enabled SatAgro's business model, supporting the company's success in the market.

Figure 4-2: Przemek and Krzystof featuring on the InvestEU success stories

This success and innovative output have been recognised on multiple occasions. SatAgro was awarded the Gold Medal in the Premieres category at the Polagra 2016 International Trade Fair and also received the Minister of Economy's Passport at the 'Start-ups in the Palace' event held by the President of the Republic of Poland. It was in this meeting, that executives of Grupa Azoty – the undisputed leader of the Polish fertiliser and chemical market and the 2nd largest EU-based manufacturer of nitrogen and compound fertilisers – first heard of SatAgro. Over time, SatAgro has developed a strategic partnership with Grupa Azoty, in a great example of a "win-win" scenario. Thanks to this collaboration, but also to its outreach to individual customers[31], SatAgro managed to serve about 0.8% of field crop land in Poland in 2018, i.e. about 80k ha (40% of this being individual customers, whilst 60% was secured through the collaboration with Grupa Azoty). The company expects to cover over 140k ha in 2019, a fact underlining its rapid growth. This is further reflected on SatAgro's recognition as one of the "hottest" startups in Poland[32]. This rapid growth has led to collaborations with partners in Poland, Czechia, Spain and other EU countries.

Today the dynamic SatAgro team (currently employing 11 highly-skilled and very hospitable people), is looking to further exploit Sentinel data, improve its offering and expand its market footprint. The primary focus is placed on "champion farms", i.e. those that have access to machinery fit for VRA. Another area of development is related to adding precision irrigation features in their offering (possibly exploiting Sentinel 1 to that end).

4.2.2 Tier 2 – The Primary users: Grupa Azoty

The presence of Grupa Azoty in this value chain might at first seem paradoxical! How can a leading fertiliser manufacturer company benefit from the use of satellite-based services which directly inform farmers how to save on fertiliser? To understand this paradox, we should look into both the history of the company and the recent developments in the greater context of agriculture.

With over 90 years on its back, Grupa Azoty has established itself as the leader of the Polish fertiliser and chemical market and one of the key players in Europe. It is the 2nd largest EU-based manufacturer of nitrogen and compound fertilisers, and its other products, including melamine, caprolactam, polyamide, oxo alcohols and titanium white, enjoy an equally strong standing in the chemical sector, with a wide range of applications in various industries. Nonetheless, the company has been experiencing a falling market share (currently at around 60% in Poland) due to different factors. Firstly, there is increasing activity of illegal importation of fertilisers from the East; secondly under the new CAP and national policies more stringent requirements are placed with regards to the environmental footprint of farming. Moreover, Grupa Azoty competitors are also providing tools for the precise use of fertilisers. These aspects have led Grupa Azoty to rethink its corporate strategy and seek greater diversification of its offering.

[31] Here we are referring to paying customers

[32] https://www.quora.com/What-are-the-hottest-startups-in-Poland

In this context, Grupa Azoty is seeking to build strong competitiveness on value-added services in connect to smart agriculture[33]. This started already back in 2012 with the launch of the “FARMSTER”, a mobile application offering recommendations on fertilisation. In parallel, Grupa Azoty has introduced support services on soil sampling.

This is embedded on their unique ‘Grounded in Knowledge’ programme[34] launched in 2015. Its aim is to develop fertilisation technologies and fertiliser products adapted to the needs of the Polish agriculture. Benefits available to each farmer that qualifies for the programme include free examination of 15 soil samples (sufficient for about 50 ha of land) in terms of the content of nutrients. The programme has been appreciated by the farmers and recognised during the International Agricultural Fair CTR 2016 with the prestigious ‘Golden Crane of Agriculture’ award.

In May 2017, the Group further updated its strategy until 2020. The key development areas cover finalising the Group’s consolidation, reinforcing leadership in agricultural solutions in Europe, strengthening the second operating pillar through expansion of the non-fertiliser business, and generating and implementing innovations to accelerate growth in the chemical sector. In line with this strategy, Grupa Azoty decided to spend 1 percent of its revenue on R&D and innovation projects. To that end, Grupa Azoty participates in the Polish President’s ‘Start-ups in the Palace’ programme – the occasion in which they met SatAgro as one of the awarded companies. In addition, Grupa Azoty has been independently looking into innovative start-ups that could support the Group’s growth by offering agricultural services, new products in the Group’s existing segments, or other products and services in segments the Group has not as yet been present in.

As part of this effort, Grupa Azoty launched in 2017 a strategic partnership with SatAgro[35], under which satellite imagery would become available to its farmers. Thus, the aim of this partnership is to provide its customers with the tools developed by SatAgro – relying on Sentinel and other data – towards efficient farm management. As its President of the Management Board noted:

“The project fits in with the recently presented updated strategy of Grupa Azoty until 2020. We have been making a consistent effort to strengthen our position among leading providers of farming solutions, including through offering additional and innovative services. Our embrace of new technologies, cooperation with start-ups, and focus on delivering value to customers are key drivers of the Grupa Azoty Group’s success in the Agro sector”

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33 http://raport.grupaazoty.com/en/strengthening-market-position/growth-through-smart-agriculture/

34 https://nawozy.eu/grunt-to-wiedza.html

35 http://grupaazoty.com/en/wydarzenia/stawiamy-na-innowacje.html

Following some initial feedback received by farmers in 2017, last year (2018) has been the first in which a large amount of Grupa Azoty customers used the tools offered by SatAgro. To match farmers' preferences, SatAgro introduced a simplified map edition and improvements on the interface. This underlines the tight partnership between SatAgro and Grupa Azoty. Thanks to this partnership, SatAgro gets a prime channel to the market allowing it to gain a larger share of farmers and to tune its offering based on their feedback. On the other hand, Grupa Azoty – which is anyway facing a reality in which fertiliser use is rationalised – can retain its customers by offering them added-value services. In addition, it strengthens its corporate profile by underlining its commitment to farming practices that are more environmentally friendly. All of this is fundamentally enabled by the use of satellite data, as this is the backbone of the SatAgro services offered to the farmers.

4.2.3 Tier 3 – Farmers

As discussed in section 2.2, farmers need reliable information to help them with a number of decisions throughout the crop cycle. How much fertiliser or pesticides should I apply in different locations of my field? What is the current status of my crops and soils? When is the ideal time to intervene? What are the weather conditions I should take into account when planning my farming activities? How much yield shall I expect? Providing well-informed answers to these and many more questions, relies on the ability to monitor what happens, where and when across their fields. This is where precision agriculture enters the picture. In Poland, as in most other relatively advanced countries, the uptake of modern precision agriculture has been driven by larger farms and has started with the utilisation of GNSS-equipped tractors. Thus, thanks to the precise positioning of machinery and implements enabled by satellite navigation[36], farmers have been able to perform precise seeding, spraying, harvesting, etc. As the story of the adoption of precision agriculture unveils, the role of its protagonists becomes clearer.

- On one side, we find "**farmer-champions**". These are typically younger, technology-savvy farmers, often with a solid education or at least good understanding of agronomy. Once they take over the management of family-owned farms, they seek to prove their worth by maximising the farm's profits. To that end, they are keen to introduce and experiment with precision agriculture approaches, often going beyond the standard GNSS-enabled guidance of machinery and using instead all cutting-edge solutions at hand.
- On the other side, we find **innovative market players** – such as SatAgro – who develop the appropriate decision-support tools using satellite data, sensor technologies, machine learning and big data processing techniques. When these two sides are in full sync, we see farms that are making the most of the latest technologies, increase their productivity and reduce their environmental footprint!

[36] For a comprehensive overview see here https://www.gsa.europa.eu/newsroom/news/gsa-special-report-highlights-user-requirements-pnt-agri-sector

This was exactly the case of Miłosz Dobrowolski, who has gracefully agreed to meet us at his farm in Lodz and share valuable insights on his use of SatAgro services.

Figure 4-3: On-site meeting at the farm of Miłosz Dobrowolski[37]

Back in 2007, when Miłosz was still a high-school student, he had his first contact with precision agriculture. Miłosz rode his father's tractor, which was equipped with GPS to eliminate overlaps when performing spraying activities. As he shared with us, he considered this to be a "very cool experience". Whilst many years have passed since then, and precision agriculture technology has made significant strides forward, the "coolness" effect is still there. Yet, with 900 ha of fields (wheat, rapeseed, corn, beetroot, grass and field peas) under his responsibility, and a solid educational background, Miłosz's motivation to use advanced solutions is driven by many additional factors. Firstly, Miłosz seeks to increase efficiency of input use (i.e. amount of fertiliser) and ensure that these inputs have the best effects (e.g. are applied at the right time to the right parts of the field). Secondly, Miłosz underlined his commitment to be more environmentally

[37] From left to right: Lefteris Mamais, Miłosz Dobrowolski, Wojciech Waraczewski, Przemysław Żelazowski, Igor Milosavljevic

friendly (in part driven by the recommendations of his girlfriend who is doing her Ph.D. in GMO-related research). Finally, he recognised the role of policy and regulation, where it is expected that future implementation of the CAP will be pushing towards more rational use of inputs. In Poland, the subsidy system has changed to incorporate prioritisation and ranking. In practice, this means that if a farmer is using innovative approaches and more advanced equipment, they get more points in the evaluation of their subsidy claims and have a higher priority than someone following traditional methods and standard tractors. Eventually, this system may cover up to a half of the advanced tractor cost – thus fostering the adoption of precision agriculture.

These factors, alongside his willingness to prove to his father the value of these modern technologies, have shaped Miłosz's approach towards advanced precision agriculture. Thus, in May 2018, when he received the suggestion by his local Grupa Azoty representative to adopt SatAgro's services, Miłosz was very keen to do so. He earmarked a specific segment in his fields, used the web-based application to map it, and produce prescription maps. He then found it particularly easy to upload these maps on his VRA-oriented tractor allowing him to execute concrete applications using the advice provided by SatAgro, including the 3rd spreading of urea[38]. Miłosz has been very happy with the results and is keen to use SatAgro further, hoping that it will also make soil sampling (which he performs every 3 years), easier.

Whilst Miłosz's case might seem to reflect an ideal scenario of an educated, tech-savvy, large-holding owner, it underlines three important points, **(i)** the primary motivation for the use of SatAgro is avoiding over-fertilisation – thus saving money and protecting the environment, **(ii)** the larger the farm, the larger the benefits from the use of SatAgro (and subsequently the easier to secure such clients in the first place), **(iii)** the ease of use and integration of SatAgro as reported by Miłosz, is the key for SatAgro and Grupa Azoty – through their partnership – to break through to smaller farmers.

4.2.4 Tier 4 – Citizens, businesses and governmental agencies

The availability of satellite data and the richness of the information extracted from it is directly felt by all three previous tiers. This is not the case for the fourth tier, where we find citizens, businesses and governmental agencies. These stakeholder groups are typically unaware of the fact that satellite-based services have allowed farmers to implement more efficient, productive and environmentally friendly farming practices. Yet, there are certain effects from the implementation of such approaches that do trickle down this far end of the value chain. Thus, well-informed fertilisation allows in some cases not only to save on inputs but also to improve on quality. This is true, for example, for rapeseed oil, where higher protein content means a better product for the **end-consumer** and hence a better selling price for farmers to the mills. Moreover, when looking at agricultural production as a whole – and not at an individual field only – it

[38] https://en.wikipedia.org/wiki/Urea

becomes apparent that reduced use of fertilisers (or pesticides and fungicides) results in environmental benefits. This is because the excess nitrogen is easily washed out of the fields by rain, and then it flows down to the rivers and seas. In Poland, this can trigger, among others, toxic blooms of cyanobacteria in the Baltic Sea, which is a sign of disturbance of the state of balance in the ecosystem and leads to a reduction of oxygen in the water. As a result, some of the organisms living near the bottom are killed and tourism may be impacted. Such effects are studied and monitored by **research institutes** in Poland, such as the European Regional Centre for Ecohydrology of the Polish Academy of Sciences. Another area that has a direct stake in this discussion is that of **food security**. With a continuously growing population and changing consumer trends (including greater awareness on production methods, points of origin and environmental aspects), authorities such as the European Food Security Authority (EFSA) are monitoring and communicating risks on the food chain. In that regard, the ability to have better quality, less – exposed – to – chemicals food, is highly sought and appreciated. This is primarily reflected on the recent trend around **organic food**.

An exception to this general rule of Tier-4 stakeholders being ignorant towards satellite-induced benefits, is related to **agricultural insurance**. In this case, satellite imagery is crucial as it can provide a Big Data bedrock on which improved actuarial calculations and damage assessments can be built. In practice, insurance companies are faced with high operational and administrative costs for claim verification and monitoring, damage/loss, and control of fraud events, driven by the remoteness and dispersion of agricultural production/crop fields. Moreover, damage/loss assessment is highly subjective to the human assessor and the highly limited data to which they have access, with the process lacking transparency. These challenges can be largely overcome by using satellite imagery. Thanks to its inherent ability to provide neutral assessments, near real time and on different spatial scales, satellite imagery is fast becoming an integral tool in the hands of insurers, allowing for more precise and less-subjective to measurement errors assessments.

5 Assessing the benefits across the value chain

Now that we know which effects the service is causing in the subsequent tiers of the value chain, we can establish the economic benefits that are sparked thereby: which financial value can we attribute to the availability of the service? Which environmental or regulatory benefits can we identify? These are the questions we are addressing in this chapter. In this regard, it is useful to recall our value chain picture whilst adding the last two layers to it.

	TIER 1	TIER 2	TIER 3	TIER 4
Services	**Satellite imagery** (Sentinel-2 and other); **in-situ, weather and historic data**	**Package of agricultural support services**	**Suite of agricultural support services: Prescription maps, VRA, automated alerts, weather forecast**	**Food quality, reduced water and air pollution from agriculture**
Beneficiaries	Service Provider: SatAgro	Primary Users: (i) Grupa Azoty, (ii) Individual field crop farmers (large & small)	(i) Selected farmers using Grupa Azoty products, (ii) Individual field crop farmers (large & small)	Citizens, Governmental Agencies looking into environmental protection
		Actors involved in food security (e.g. EFSA), or environmental impact of agriculture (e.g. University of Lodz – Eco-Hydrology dept.). Agri-insurance companies		
Type of Benefit	Large area, continuous monitoring capability. Less costly with satellites	(i) Better decision making on the farm leading to greater input use efficiency and cost savings; (ii) value-adding service	(i) Better decision making on the farm leading to greater input use efficiency and cost savings; (ii) value-adding service	Environmentally friendly food production, reduction of water and air pollution (e.g. NOx)
Manifestation of value	Savings and simplicity in sourcing data enable profitable **business models**	(i) **Savings** from reduced inputs, (ii) Retaining or expanding **customer base**	(i), (ii) **Savings** from reduced inputs	Increased health of rural populations, higher, better state of ground water and waterways, cleaner air

Figure 5-1: The type of benefit and manifestation of value for each Tier in the value chain

5.1 Calculating the benefits

Before going into the calculations for each of the tiers, it is instructive to point out three important considerations:

1. The value arises primarily from the execution of variable rate applications informed by satellite data

As discussed in the previous chapter, satellite data (primarily Sentinel-2 but also from other constellations), is used to produce indices that can be projected onto prescription maps. These prescriptions maps – thanks to the ease of use and compatibility that SatAgro has ensured – can be uploaded on the on-board units of GNSS-enabled tractors, who are in turn used to perform site-specific management of the fields. In practice, this means applying fertilisers or other inputs (fungicides, pesticides) in variable rates depending on the accurate needs and condition of crops across the field. This gives rise to significant cost savings for the farmers and reduces the environmental footprint of their practices. In that sense, this is the driving force for all types of benefits experienced across the value chain, both directly and indirectly.

2. The generated value rises over time thanks to increased technical performance of the service and users' capability to use it

The full realisation of benefits associated with precision agriculture services relies on two interconnected factors **(i)** the "technical performance" of the service itself, i.e. how accurate is the advice offered to farmers for precise treatments, **(ii)** the ability of the farmers themselves to follow this advice and perform more efficient farming practices. These two aspects – essentially the two side of the same coin – are improved over time as more data on the actual use of the service become available and as farmers become more familiar (or better educated) in its exploitation. This general rule applies to SatAgro services as well, as they are also evolving through machine learning processes, where the basic algorithms are trained year after year against the reality that farmers experience. In practice, this means that for the same field, the SatAgro offering improves over time as there is better validation of the EO-based services with "ground truth", and as farmers understand better not only the interfaces but also how to translate the offered advice into actual decisions. This observation is even more applicable since Sentinel data have not been available long enough to have many growing seasons concluded, analysed and assessed. Therefore, the value proposition of SatAgro will grow over time, reaching a ceiling value in a short of "S-curve" fashion[39].

3. Winners and losers

In our study – as we did in previous ones and will do in future ones - we are concentrating on the positive economic effects brought about by the availability and subsequent usage of the Sentinel data in the value chain. That being said, one needs to realize: where there are winners, there must also be some losers. Put differently, innovation and subsequent economic benefits will partly come at the expense of existing stakeholders. However, recent studies demonstrate that 'on balance' and at macro level, there is a distinct positive effect. Annex 3 holds some further observations on this subject.

All that said, the next section presents a systematic analysis of the economic value ("adding a price tag") arising from the use of satellite data (and in particular Sentinels) in each Tier.

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[39] See for example the discussion in the section 5.2.2 in "Farm Management Support in Denmark"

5.1.1 Tier 1 – SatAgro

The successful roll out of SatAgro services is tightly linked with Copernicus free, full and open data policy and the availability of world-class Sentinel data. As Przemek repeatedly underlined, this made the **SatAgro business model viable**, as it ensured three fundamental prerequisites:

- **Continuity**: The revisit time of Sentinel-2 satellites allows for a meaningful monitoring of the designated fields of SatAgro's clients. This would not be the case if only Landsat8 were to be used as in Europe their revisit frequency is not adequate. Of course, when prolonged periods of cloud cover are observed, SatAgro had to resort to commercial providers' data, but, overall, Sentinel-2 have proven to be more than adequate[40].
- **Adequate spatial resolution and accuracy:** The other key factor when considering solutions that can enable variable rate applications is the ability to produce accurate prescription maps. Landsat cannot meet the required spatial accuracy in that regard (at least not in Poland), and thus, the arrival of Sentinel imagery was perceived quite literally as "manna from heaven". This is especially so since the Sentinel-2 resolution (and the quality of its data thanks to its multi-spectral instrument) enable services that can yield measurable benefits for farms over 30 ha[41].
- **Zero-marginal cost per ha for an automated solution:** The cost of the necessary imagery is critical for the viability of the business model. The free, full and open policy of Copernicus ensures that zero marginal costs are required for every additional ha. This is not the case of commercial providers' imagery who are typically charging by the size of the area of interest. Thus, for a scalable, automated solution such as SatAgro the availability of Sentinel-2 imagery is critical. Of course, higher-tier customers, may ask and receive higher resolution data sourced from commercial providers. It can be strongly argued however, that even in this case, the availability of Sentinel data is driving the cost of this data down, making it more profitable for companies such as SatAgro to roll their services out.

The importance of these three fundamental factors cannot be overestimated when considering the success and growth of SatAgro. From the get-go, the company managed to secure EU funds - approx. 100k€ under the EU "Innovative Economy" Operational Programme - which allowed to cover more than half of the original investment costs, i.e. expenses on programming and marketing. This was followed by additional public and private investment which SatAgro used to further hone its offering, incorporating the use of Sentinels in its services. As Przemek highlighted, this was a decisive step for the company, as Landsat8 did not provide adequate spatial accuracy and frequency to offer the desired services (in 2015, when SatAgro offered its initial services

[40] SatAgro has produced an informative blog post on the subject of cloud coverage that can be found here (in PL) http://blog.satagro.pl/index.php/pl/8-blog/21-co-z-tymi-chmurami

[41] In the specific case of SatAgro a nice demonstration of benefits for a farm of 50ha has been produced

without the use of Sentinels, the company did not manage to assist some clients sufficiently). Eventually, the exploitation of a key EU asset (i.e. Copernicus and especially Sentinels) allowed SatAgro to provide high-impact services in a sector as important as agriculture and to capture a small yet decisive percentage of the Polish market (1.3% of field crop land in 2019). In part, this was secured through SatAgro's collaboration with Grupa Azoty, which has been developing into a clear win-win situation[42]. In this regard, it is also interesting to note that all Grupa Azoty's communications on the subject underline the importance of bringing satellite imagery in the hands of farmers.

Figure 5-2: Screenshot from Grupa Azoty's website presenting the collaboration with SatAgro

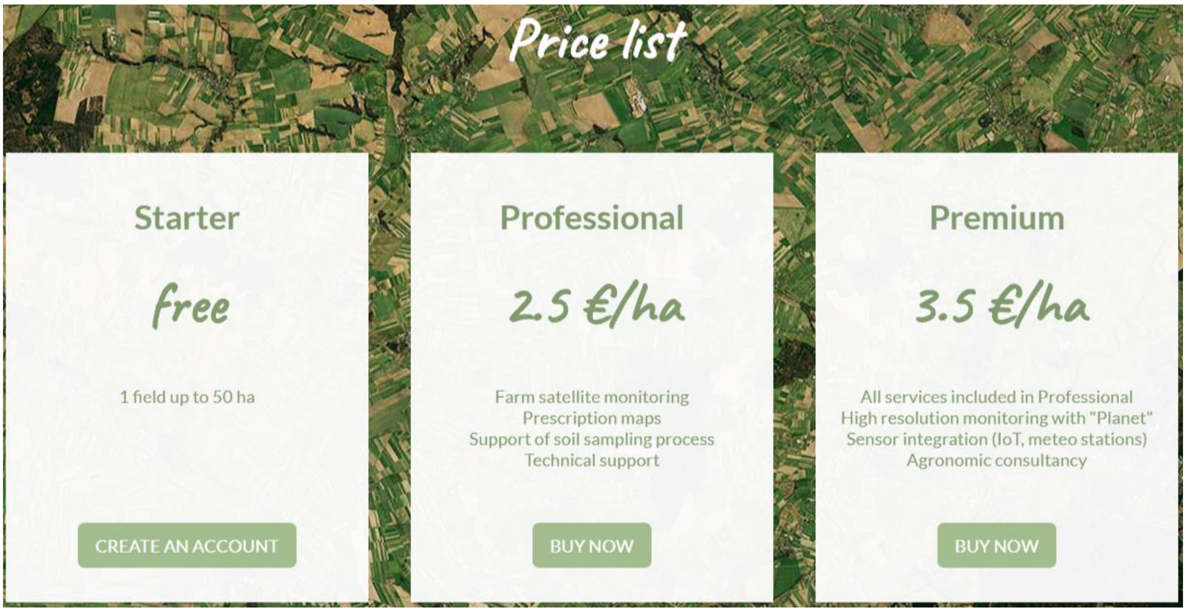
All these considerations concerned, the impact and value of Sentinel imagery on SatAgro is materialised in three dimensions:

Generation of revenue

SatAgro offers three packages:

- The **starter** package allows farmers to test SatAgro's services for free for 1 field up to 50ha.
- The **professional** package provides farmers with a suite of services, including satellite-based monitoring, prescription maps and soil sampling support
- The **premium** package offers all the above plus higher-resolution observations (through Planet imagery or in-situ sensors). It also includes dedicated agronomic consultancy.

[42] A testament to this is the fact that this case study has been quoted in scientific papers on collaborations between start-ups and big companies in the agri-food industry. For more see here https://mpra.ub.uni-muenchen.de/84756/1/MPRA_paper_84756.pdf



On top of this, for cases of large acreage, SatAgro is offering tailor-made services.

At present SatAgro services are used for an area corresponding to 205 thousand hectares. However, most of its users are still using the free package, registering fields under 50ha. In 2018, SatAgro's paying customers amounted to an area of 80 thousand hectares; so, if we estimate the corresponding revenue on the basis of the professional package this would yield **200,000€**. The area corresponding to paid customers is projected to increase to 140 thousand hectares in 2019, bringing a corresponding **increase in revenue of 75%**. Assuming that a slightly improved fraction of paying vs. non-paying customers will be observed (currently at 0.39), SatAgro expects its revenues to continue to rise[43] - on the basis of our assumptions it could reach over 1.2M€ annually by 2023. This shows the strong momentum achieved by SatAgro.

Employment

SatAgro currently employs 11 people, including its founders, technical stuff (developers, EO experts, agronomists) and a sales support unit. This team has come together to support the increased uptake of the SatAgro services, win over new clients and improve the overall technical offering. Following the discussion with SatAgro CEO, Przemek, we can practically ascribe all jobs to the use of Sentinel data within SatAgro's services.

Savings

The impact of Sentinel imagery on SatAgro can be further quantified in terms of savings associated with the reduced need for commercial providers' data. In practice, if there were no Sentinels available, the company would have to resort to either Landsat or commercial data. In

[43] It must be stated that the calculations provided here are estimates based on the available data and do not represent the actual total revenue of SatAgro.

the first case, the frequency and spatial accuracy is not adequate to produce the same level of quality for the services provided by SatAgro. Thus, it would be necessary to obtain commercial data for the continuous monitoring of the farming area. In such case, and for similar characteristics – same total area covered, same frequency of imagery (i.e. once per week) and similar resolution (i.e. close to 10m), same computational needs for processing – the cost of acquiring commercial satellite data would be very sizable. If we look at the benchmarking efforts done by Sozzi et al.[44], and we take the example of RapidEye (5m resolution, similar bands, practically same revisit time), we see that for 10,000 ha the cost would be at least 218€. For the 80,000 ha currently covered by SatAgro for its paying customers, this would amount to a total of approx. 90,000 € annually (weekly acquisition multiplied by the number of weeks). As can be readily seen, scaling a business such as SatAgro with a minimum commercial imagery cost of just under 100k€ becomes particularly difficult. When this is projected into the future (i.e. 2023) then the cost for this imagery would be approx. 570,000 €.

Instead, thanks to the free, full and open availability of Sentinel data we can estimate annual savings of practically one euro per hectare covered for SatAgro paying customers[45].

On top of that, the use of commercial providers' data in the current operational workflow of SatAgro adds significant overhead. This is associated with the need for regular placement of orders, drawing carefully the specific areas of interest. Instead, with Sentinels this is all automated and rather simple[46]. Finally, it should be underlined that certain aspects of agricultural monitoring cannot be done the typically more simplistic (even if higher-resolution) payloads on commercial satellites. In other words, the MSI on Sentinels can "see" things that the sensors of other satellites cannot. All these aspects considered, it is no surprise that Sentinels are also pushing the prices of commercial providers' imagery down, making it easier for companies like SatAgro to integrate it in their offering when needed. This, too, translates into savings but, given its *ad hoc* nature, we are not attempting to quantify it here.

5.1.2 Tier 2 – The Primary users: Grupa Azoty

In 2017, when Grupa Azoty launched its partnership with SatAgro, the agrochemicals heavyweight was looking to

- **React to increased competition in the agrochemicals sector**: Both in Poland and beyond, Grupa Azoty was challenged by EU competitor companies. Maintaining its existing client base meant offering added value services.

[44] Sozzi, Marco & Marinello, Francesco & Pezzuolo, Andrea & Sartori, Luigi. (2018). Benchmark of Satellites Image Services for Precision Agricultural use.

[45] This finding is perhaps reflected onto the difference between the professional and the premium package of SatAgro users.

[46] SatAgro currently uses Sci-Hub and Google to access Sentinel imagery.

- **Diversify its portfolio and strengthen its corporate profile:** In line with its new strategic outlook, Grupa Azoty was keen to venture into innovative, environmentally friendly endeavours. In this regard, bringing satellite imagery in the hands of its farmers (through SatAgro) has been a powerful message helping the company's profile.
- **Expand into new markets:** Capturing the pulse of the modern agriculture playing field, Grupa Azoty, is seeking to expand to new markets through the value-adding services enabled by SatAgro[47].

Thus, by partnering with SatAgro and offering Sentinel-based services to its clients, **Grupa Azoty has sought to build a win-win-win situation**, whereby all parties experience concrete financial benefits.

- Grupa Azoty farmers: On top of buying agrochemicals, farmers gained access to SatAgro's service, allowing them to make more rational use (**savings**).
- SatAgro, through this B2B partnership secures a larger market share (**increased revenue**)
- Grupa Azoty manages on one hand to **retain the total number of customers** and on the other it can **offer added-value services**.

In simple terms, farmers save money, SatAgro earns more, and Grupa Azoty keeps customers and potentially earns clients in new markets! In order to quantify the part concerning the Sentinel-enabled benefits for Grupa Azoty, we proceed with each of the different components individually.

Reduced losses

The lion's share for Grupa Azoty's business is the production and supply of agro-fertilisers. It has traditionally amounted to about 50% of the company's annual revenue. This can be nicely projected across the geographic areas covered by Grupa Azoty and the different revenue components (see figure below). The percentage under each geographic region (e.g. Poland 55%) corresponds to the share of this region against the total revenue. The percentages in each pie chart represent the relative importance of each revenue component (agro-fertilisers, plastics, etc.).

[47] But also (and actually more prominently) through moves such as the recent acquisition of COMPO EXPERT – a market leader in high-added value specialty fertilisers

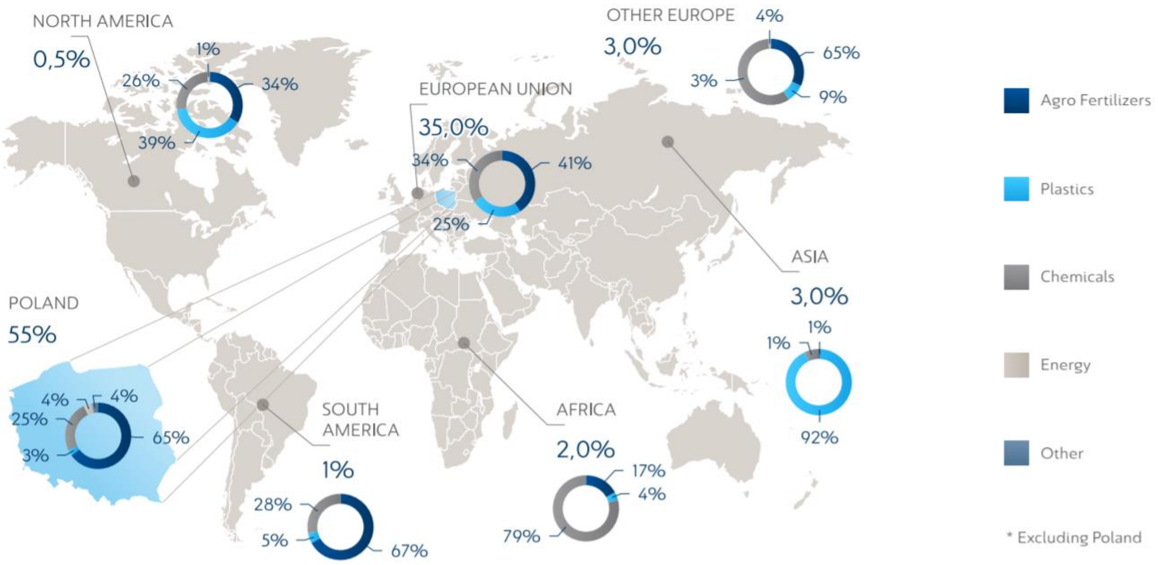


Figure 5-3: Geographic structure of Grupa Azoty business in 2017[48]

Looking now at the total shares (all geographic regions combined) we clearly see the prominence of agro-fertiliser business (see figure below).

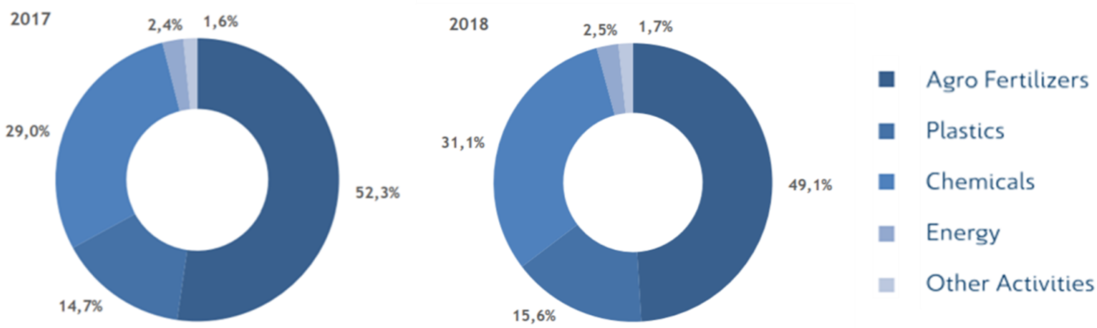


Figure 5-4: Revenues by segment in 2017 and 2018

As already indicated in the graph above, the relative share of agro-fertiliser revenues is decreasing over time. Enhancing this picture with data from 2015 and 2016 we are able to depict the evolution of total revenues and agro-fertiliser revenues over time more cleary. All quoted figures have been taken from publicly available financial reports of Grupa Azoty[49].

[48] From the [Integrated Report 2016-2017]

[49] Namely the Consolidated Financial Statements of 2016, 2017, 2018. These reports can be accessed here: http://tarnow.grupaazoty.com/en/relacje/raportyokresowe.html

	Total Revenues		Year to Year change	Agro-fertilisers		Year to Year change	Share vis-à-vis total
Year	PLN	EURO		PLN	EURO		
2018	9998967	2299762	4%	4904051	1127932	-2.5%	49%
2017	9617495	2212024	7%	5027929	1156424	1%	52%
2016	8966804	2062365	-10%	4970294	1143168	-18%	55%
2015	10007896	2301816	NA	6057906	1393318	NA	61%

Table 5-1: Evolution of total and agro-fertiliser revenues between 2015-2018[50]

How can this decline be explained? According to our exchanges with Grupa Azoty representatives, this is due to competition), as well as increased awareness by farmers around more rational use of inputs. Thus, we observe a steady decline of the revenue share associated with agro-fertilisers, from 61% in 2015 to 49% in 2018.

Aware of this trend, Grupa Azoty has embarked onto a strategic approach that would allow it to "*reinforce leadership in agricultural solutions in Europe".* In practice, this translates into developing specialty products (i.e. customised fertilisers), and "*placing strong emphasis on innovative IT systems for farmers and rapid agricultural analysis, technologies that promote precise fertilization*". Thus, in its integrated report 2016-2017, Grupa Azoty underlines SatAgro as one of its key services. In view of these considerations, we can argue that by offering added value services (enabled by Sentinel-2 imagery) to its customers, Grupa Azoty aims to **reduce the decline observed in agro-fertiliser related revenues.** In simple terms, we can foresee two processes that would contribute to this effort:

- Best possible number of clients: The same competitive pressures that led Grupa Azoty to seek greater diversification are also threatening the size of its client base. Undoubtedly a large part of reduced revenues, in the past years, can be associated with this. The strategic partnership with SatAgro is helping counter this effect. A technologically-excellent, easy-to-use and proven on the field solution becomes readily available to Grupa Azoty-associated farmers. Why would they then look to get alternative solutions if this works so well for them, through a partner they already trust? In other words, **thanks to the Sentinel-based SatAgro services, Grupa Azoty can better retain its client base and reduce associated losses**. Therefore, if we look at the subset of Grupa Azoty customers that have gained access to SatAgro services (1% of the total), we can assume that 98 out of 100 remain with Grupa Azoty, whereas only 95 out of 100 remain out of those who don't get access to SatAgro services. This means 3% better client retention and translates in 3% avoided revenue losses annually. Projected against its full client base this would mean a **potential financial benefit for Grupa Azoty of approximately 31 Million Euro per year**. However, as the sample of farmers currently using SatAgro services is still small (1%), the current financial benefit does not spill over the whole client base. Instead it amounts to **338k€ annually**.

[50] All figures are in "thousands", i.e. we are looking at €Bn-level revenues. The conversion rates have been taken to be 1 zloty = 0.23 euro.

- New clients in new markets: Aside from keeping its current clients, Grupa Azoty has stressed the dynamic offered by the collaboration with SatAgro in relation to entering new markets. Whilst Grupa Azoty does have a solid distribution network for its agro-fertilisers, **the ability to market new products (i.e. offering access to SatAgro services on-top of the inputs themselves), allows Grupa Azoty to target new customers**. Throughout our discussions with Grupa Azoty representatives this point was strongly stressed out. Yet, the financial benefits associated with it cannot be yet quantified as it is at a nascent stage.

5.1.3 Tier 3 – Farmers

Whether reached through Grupa Azoty, or directly by SatAgro, farmers are at the epicentre of this case. The SatAgro services, developed with the aim to support more efficient farming practices, offer a multitude of benefits, discussed and quantified below.

Improved usage of fertilisers

SatAgro uses Sentinel-2 imagery together with other data (commercial satellites, in-situ, weather, historic) to produce prescription maps that are then used to apply fertilisers as much as needed, where and when it is needed. This translates into **significant financial benefits associated with savings from the reduced use of fertilisers.** To quantify this, we need to consider the following:

- **Acreage**: As a general rule, larger farms experience larger financial benefits from the better informed application of fertilisers. This is true both in absolute terms (as farmers need larger amounts of fertiliser, they have larger savings) but also in relative terms since in-field variability is typically more prominent in sizeable farms. Nonetheless, as the sample of farms serviced by SatAgro is still relatively small, we decided not to introduce a "size coefficient" in our calculations. Thus, we treat the total acreage uniformly.

- **Crop type:** Different crops have significantly different needs on fertiliser both in absolute terms (i.e. total per year) and also in terms of how many fertilisation cycles are observed. Thus, vegetables or cotton have higher needs than cereals, etc[51]. However, in the context of this SatAgro case, our focus is placed on N-fertilisers, for which the applicable crops (wheat, barley, rapeseed, etc.) have comparable needs (in terms of total amount). Thus, for the calculation of the related benefits we take an average of 172.8 kg/ha[52]. Of course, a more in-depth analysis per crop could yield interesting insights (see scalability discussion in 6.2). Furthermore, a distinction between crops which require multiple fertilisation cycles/treatments could be made, as SatAgro farmers have reported different rates in savings. More concretely this amounts up to 10-15% reduction in the quantity used in the 2nd application and 5-10% reduction in the 3rd application. Nonetheless, following SatAgro's own conservative calculations on their current sample it was

[51] See for example http://www.fao.org/3/Y4711E/y4711e07.htm. The data is not recent but the relative needs between crops are still fully applicable.
[52] For reference check https://knoema.com/atlas/Poland/Fertilizer-consumption

considered that a **global reduction of 7%** would represent well – if not too modestly – the current situation. Therefore, below we consider this global reduction in our calculations of savings.

- Market share: When looking at the subset of paying SatAgro customers, the total area of field crop land serviced in Poland in 2017 was 30,000 ha, representing 0.3% of the total area in Poland. However, since we are focussing on paying customers (i.e. those using the service for over 50ha fields) we should take the total addressable market that corresponds to fields larger than 50ha in Poland. According to table 1, 50% of Polish fields are over 50 ha, therefore it is reasonable to extend this percentage to field crop land. This way the market share of SatAgro in 2017 was 0.6% of the total addressable market. This rose to 80,000 ha in 2018 and is expected to reach 140,000 ha in 2019. Therefore, we introduce a "potential benefit" based on the projections SatAgro currently has with regards to the total acreage it will be serving in the coming years. To reflect this, we quote below current and future benefits, and we introduce an appropriate "expansion rate". This has been taken to be a baseline of 25% natural growth, plus boosts thanks to strategic partnerships (i.e. first with Grupa Azoty, then with BNP Baribas, and eventually with additional customers coming either through them or over and above this). We took these boosts to be 50,000 ha every two years (this is justified on the basis of the actual boost achieved through the relationship with Grupa Azoty).

With these input parameters in place, we can proceed with the calculation of the financial benefit associated with N-fertiliser savings for SatAgro farmers. In this calculation, we have assumed the fertiliser cost per ha to be 44.24 € annually[53]. The results of the calculation are depicted on the table below.

year	Total area of SatAgro paying customers	Boosts from strategic partnership	total land covered (absolute)	total land covered (from TAM)	fertiliser cost (without SatAgro)	savings (7%)
2017	30000		0.3%	0.6%	€ 1,327,104	€ 92,897
2018	80000		0.8%	1.5%	€ 3,538,944	€ 247,726
2019	140000		1.3%	2.6%	€ 6,193,152	€ 433,521
2020	225000	50000	2.1%	4.2%	€ 9,953,280	€ 696,730
2021	281250		2.7%	5.3%	€ 12,441,600	€ 870,912
2022	401563	50000	3.8%	7.6%	€ 17,763,840	€ 1,243,469
2023	501953		4.7%	9.5%	€ 22,204,800	€ 1,554,336

Figure 5-5: Calculation of annual savings for farmers

As can be readily seen, the **use of SatAgro services will result in savings in N fertiliser consumption for farmers on the order of more than 400,000 €.** Moreover, in the very modest scenario we have built (in terms of growth and annual savings rate), the **benefit for farmers will rise up to 1.5M€ by 2023**. What is more, even for the same total area covered by the services, one can expect that the benefit will be rising in the future. This is a direct result of a) improvements of the SatAgro service over time, b) optimised use of the service by farmers as their technological maturity improves.

[53] This is calculated based on the available data for Poland as provided by FAO and the World Bank

In addition to the reduction in applied quantities, there is potentially another (indirect) positive impact stemming from the use of SatAgro services for field zoning and consequent agronomic soil sampling. SatAgro allows its users to transform NDVI images into zones for soil sampling, that better capture the variability of soil chemistry than a simple geometric grid. The potential benefit of better soil sampling and its environmental impacts have to be substantiated in future case studies.

Informed interventions thanks to early warning

Sentinel-2 imagery used by SatAgro allows the consistent monitoring of fields all year long (notwithstanding cloud cover limitations). Beyond informing the precise utilisation of fertilisers, this ability to constantly monitor the fields enables early warning and alerts related to the current state of the crops and the impact that weather conditions (including extremes such as drought, heavy wind and hail) or pests may have. With such information readily available, farmers are able to act rapidly and accurately (i.e. at the sections of their field that require most of their attention). In practice, this has a **potential impact on the actual yield**, as farmers may be able to protect or reinforce those crops that are in danger or need. In that regard, our discussions with Polish stakeholders, have underlined that whilst such a benefit is tangible, its calculation (in connection to Sentinel-based services) is rather complex as several other parameters are involved. Nonetheless, we can attempt to quantify this by looking at the average yield per hectare, which for cereals in Poland is 4,000 kg[54]. Given that the price for cereals in the EU is about 200€/tonne[55], we gather that in Poland each ha of cultivated land (for cereals) yields about 800€ annually. Assuming that the use of Sentinel-based SatAgro services helps farmers to rescue or improve 0.5% of their yield, this allows us to construct the table shown below.

Year	% improved yield thanks to SatAgro	Total benefit per year
2017	150	€ 120,000
2018	400	€ 320,000
2019	700	€ 560,000
2020	1125	€ 900,000
2021	1406	€ 1,125,000
2022	2008	€ 1,606,250
2023	2510	€ 2,007,813

Table 5-2: Yield-related benefits

[54] 2016 data accessed in https://tradingeconomics.com/poland/cereal-yield-kg-per-hectare-wb-data.html

[55] https://ec.europa.eu/agriculture/sites/agriculture/files/markets-and-prices/price-monitoring/dashboard/commodity-price-dashboard_012019_en.pdf

We must once again underline that this is should be treated more as a potential rather than as an actual benefit. As better methodologies are being established for the correlation of improved or rescued yield with variable fertilisation[56] these benefits will become better defined.

Saving time and fuel

Another type of benefit discussed with Polish stakeholders and potentially associated with the use of Sentinel-based SatAgro services is savings in time and fuel. Here we must underline that **whilst time saving is a commonly "advertised" benefit associated with precision agriculture practices, the farmers we reached have noted that it is not really there**. Their point was that whilst they do save time doing certain things they don't just sit back observing the farm run itself (perhaps in a fully digitised future this will become more of a reality). Instead they use this time to carry out other activities related to their farm. Therefore, we have decided to avoid any hard calculations for this point.

As far as fuel is concerned, the greatest part of the benefit is associated with precise positioning of tractors, i.e. satellite navigation. Nonetheless, the discussions with SatAgro and its clients did bring an interesting aspect to the surface. **Farmers who own many parcels that are located far from each other benefit greatly from the constant monitoring of their fields' state and health through the SatAgro platform and minimise their investigative trips between fields**. This certainly has an impact in terms of fuel saving; yet, for a meaningful calculation to be made we would need a critical mass of such examples.

Transforming the farming profession

All the previously discussed benefits have a tangible (or at least will have in the near future) impact on farm economics. Less fertilisers, improved yield, saved fuel. However, another area that has perhaps the most profound impact, is the **transformative power of digital solutions such as SatAgro services to the farming profession as a whole**. With new generations of farmers such as Miłosz Dobrowolski taking the helms of farm management, these tools become almost as necessary as shovels and spades once were. What is more, this better educated new generation seeks not only to increase profits in their farms; they also care more about the environment and the impact agriculture has in that regard. This is exactly the type of benefit discussed for the last tier of the value chain. But before we do so, let us summarise the total economic benefits for farmers using Sentinel-based SatAgro services.

[56] An interesting read in that regard can be found in Mezera et al., 2017

Year	Benefit from fertiliser savings (annually)	Potential benefit from improved yield (annually)	Total economic benefit for farmers
2017	€ 92,897	€ 120,000	€ 212,897
2018	€ 247,726	€ 320,000	€ 567,726
2019	€ 433,521	€ 560,000	€ 993,521
2020	€ 696,730	€ 900,000	€ 1,596,730
2021	€ 870,912	€ 1,125,000	€ 1,995,912
2022	€ 1,243,469	€ 1,606,250	€ 2,849,719
2023	€ 1,554,336	€ 2,007,813	€ 3,562,149

Table 5-3: Total economic benefits for farmers (SatAgro clients, annually)

5.1.4 Tier 4 – Citizens, businesses and governmental agencies

The impact of using Sentinel-enabled SatAgro services dilutes as we progress down the value chain. Thus, whilst in the previous tiers we were able to establish concrete relationships between the availability of Sentinel-2 imagery as a tool to produce prescription maps and enable better use of fertilisers and other benefits, for citizens, businesses and governmental agencies in this tier, such a relationship is not direct. Yet, there are tangible impacts on society as a whole that can be certainly traced back to an overall more efficient and environmentally friendly farming sector. Following this line, we focus in this section on the environmental benefits associated with reduced use of fertilisers and pesticides.

To properly understand these benefits, we need to look back at the practices of farmers using SatAgro services. Thus, as discussed in the previous section, farmers are able to perform variable rate applications allowing them to reduce the amount of fertiliser (at least by 7% annually). This is very likely larger when considering the different treatment cycles and in special cases such as periods of drought. There are also farmers that use SatAgro to optimise the spatial distribution of fertiliser while keeping the total quantity constant. The share of farmers who are reducing fertiliser use vs. those who are just redistributing the same quantity of fertiliser was not specified during our interaction with the local actors. Nevertheless, we can safely assume an overall 15% reduction in the use of plant protection products (only fungicides)[57].

Thus, the potential reduction of fertiliser used and the reduction of pesticides, as enabled by Sentinel-powered SatAgro services, results in a potential **positive effect on the environment and human health especially when seen from the perspective of risk avoidance.** This statement is justified by pesticides' persistence and inherent toxic effects on non-target species as well as lack of evidence on long-term impacts including those on human health. Even though this impact is hardly quantifiable at this point, the positive potential should not be neglected.

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[57] This assumption is built following our discussions with Polish experts in Eco-Hydrology and Toxicology

Policy-implementation related benefits

Another important area in which the use of Sentinel-enabled services has a key contribution is the effective implementation of the Common Agricultural Policy (CAP). We had the chance to explore such benefits with Lucie Savelkova, representing the Czech Paying Agency. Lucie provided us with a thorough background of the evolution of the CAP and the recent amendments that will explicitly see increased use of Sentinel data. The result of these discussions is summarised below.

Sentinel contribution to the implementation of the Common Agricultural Policy

The Common Agricultural Policy (CAP) establishes the legislative framework around a system of subsidies and other support programmes for agricultural activities in the European Union. Since 1962, and throughout a series of reforms, the CAP has not only supported farmers in their efforts to supply EU citizens with good quality and safe food; it has also been guiding the implementation of sustainable agriculture across the EU. The recent amendment to the regulation, introduced in May 2018, attempts to modernise the implementation of checks for area-based payments and for cross-compliance requirements. This landmark change foresees that modern solutions such as geo-tagged photos, E-GNSS enabled receivers, drones and data from Copernicus Sentinel satellites are used to carry out checks. This **new "monitoring approach"** promises significant benefits for farmers and administrations alike. The new rules will allow those member states that wish to do so to eventually replace or complement on-site checks with automated and less burdensome controls. This is **primarily enabled by the availability of Sentinel data**. Several member states have already indicated their intention to immediately start using Sentinel-based approaches as well as new technologies such as geo-tagged photos. The transition to fully operational services in this domain follows the implementation of several R&D efforts, such as ESA's SEN4CAP and H2020 RECAP project.

This approach will be further pursued in the next years in Europe. A strong drive in that direction is provided by the latest legislative proposals of the European Commission for the future of the common agricultural policy. These are organised around 9 clear objectives and consider technology (including Galileo, EGNOS and Copernicus Sentinels) as a key enabler for CAP2020+.

5.2 Summary of Benefits

All the benefits presented in this report have been extensively discussed, and where possible, quantified. Thus, when we look at the cumulative economic benefits presented in the table below, **we see that the use of Sentinel-enabled SatAgro services yields a current economic benefit of more than 1M €, whereas by 2023 this could rise to over 5M €.** As can be readily recognised, the current benefits are nicely distributed between the tiers. In the future, however, most of the value will be felt by farmers.

Nonetheless, what is **perhaps the most important message coming out of our analysis is that this is just the beginning**! As farmers get more acquainted with Sentinel-enabled services, they will be able to enjoy greater value from its use in their farming practices, further benefitting both the environment and the commercial actors supplying them with these services.

<table>
<tr><th rowspan="2">Tier</th><th rowspan="2">Benefits identified</th><th colspan="2">Annual economic value stemming from the use of Sentinel-enabled SatAgro services (in €)</th></tr>
<tr><th>Current</th><th>Potential (by 2023)</th></tr>
<tr><td rowspan="2">Tier 1 (SatAgro)</td><td>Generation of revenue from the delivery of farm management services</td><td>200,000</td><td>1.2M</td></tr>
<tr><td>Counterfactual: Savings from not having to buy commercial providers' data to provide equivalent service</td><td>90,688</td><td>570,000</td></tr>
<tr><td rowspan="2">Tier 2 (Grupa Azoty)</td><td>Avoided revenue losses associated with better client retention</td><td>338,379</td><td>NA</td></tr>
<tr><td>Higher revenue thanks to new clients</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="2">Tier 3 (Farmers)</td><td>Benefit from fertiliser savings</td><td>433,521</td><td>1.5M</td></tr>
<tr><td>Benefit from improved yield</td><td>560,000 [58]</td><td>2M</td></tr>
<tr><td rowspan="2">Tier 4 (Citizens & Gov.Agencies)</td><td>Reduced impact of agricultural activities on the environment and on public health</td><td>NA</td><td>NA</td></tr>
<tr><td>Increased efficiency and accuracy within the CAP monitoring approach</td><td>NA</td><td>NA</td></tr>
<tr><td colspan="2">TOTALS</td><td>1.1 M €</td><td>5.3 M €</td></tr>
</table>

Table 5-4: Summary of Benefits

6 Additional considerations and conclusions

6.1 The impact of Sentinel data

The analysis performed for this case has underlined the important role of Sentinel data in the context of farm management solutions. Seen from the point of view of the service provider, the free, full and open access to world-class Sentinel-2 data, allows the development and delivery of farm management services that bring concrete value to their clients. **Without Sentinel-2 data, the SatAgro service would not be viable. Therefore, we can confidently associate 100% of the value**

[58] The improved yield figures are not included in the calculation of the total actual benefits as they are to a large degree potential by nature. They are however included in the calculation for total potential benefits.

SatAgro brings to its customers to the use of Sentinel-2 data, even if additional datasets (e.g. weather data and at times higher resolution/revisit time data) are used in the service.

Furthermore, this case gives rise to what on first sight is a paradox: the use of Sentinel-enabled services delivered by SatAgro to help farmers reduce (or rationalise) the use of fertilisers is also bringing significant value to a major agro-fertiliser company such as Grupa Azoty. This value is primarily associated with Grupa Azoty's ability to respond to market pressure (i.e. initiatives of competitors, regulation, general environmental awareness of farmers) and diversify its portfolio of services by promoting Sentinel-enabled services to its clients. The actors of the 3rd tier in our value-chain analysis, i.e. the farmers, are the epicentre of this case, benefitting in multiple ways from the use of Sentinel-enabled services. Thanks to these, they are able to perform variable rate application of fertilisers (primarily) and pesticides resulting into significant cost savings. In parallel, they benefit from a potential increase in yield, which, with time, will be substantial. Finally, other actors in the value chain, such as public authorities and – predominantly - citizens, benefit from the environmental benefits associated with more rational use of fertilisers and pesticides.

6.2 Scalability

Agriculture is certainly one of the sectors that greatly benefit from the availability of Sentinel data and the delivery of services exploiting this data. It is not uncommon to listen to companies developing Sentinel-enabled farm management solutions talking about how the Sentinels brought a revolution in their domain and enabled the deployment of a profitable business model. To a large extent this is also due to the scalability perspectives which are inherent to the agricultural sector. Yet, whilst certain specificities apply, these can still be discussed within 3 key scalability dimensions: (i) geographic extension, (ii) increased market penetration and (iii) improved technological maturity. Below we discuss these dimensions in the context of this case.

- **Geographic extension**

Agriculture is a sector of paramount importance for human societies. Increasing population pressure, decreasing availability of arable land and continuing pressures from climate change are some of the key factors driving the need for increased efficiency in the sector. In turn, this has caused a steady shift towards increasing digitalisation in the agriculture sector opening up significant markets for innovative solutions. Satellite-enabled services (and in particular Sentinel-enabled ones) are giving rise to profitable business models, whilst also helping value chain actors realise significant benefits. **These considerations are not specific for Poland**; **instead they have global application**. Thus, not only is agriculture a very substantial market sector; it is also **a domain where the key beneficiaries of the services (i.e. agro-fertiliser companies and farmers) are witnessing very similar challenges across the globe**. Therefore, in principle, companies such as SatAgro – developing farm management tools – have the possibility to roll out their services in multiple countries. A key factor in this regard is the minimum size of agricultural holdings for which the use of Sentinel-enabled services is meaningful. As this case has underlined, the threshold could be put at about 30-50 ha. It is beyond this size, that farmers can start benefitting more from variable rate applications and thus optimise their use of fertiliser. Nonetheless, several efforts are currently ongoing to bring the benefits of Sentinel-enabled precision agriculture to smallholder farmers (e.g. APOLLO).

- **Increased market penetration**

SatAgro, and practically all other similar services, are offered to farmers through widely spread user interfaces (i.e. web services, smartphone apps, etc.). This, in itself, means **that such services have mass market potential**. What is more, the back end of these services relies on the processing of different sets of data (satellite observations, in situ, meteorological) which are typically provided at scale. In the specific case of Sentinels, the extra "handling costs" might not be negligible but they are certainly not restrictive for companies that want to serve multiple users simultaneously. Moreover, thanks to the proliferation of automated workflows, there is large growth potential. This may well be supported by the recent rise of services (such as Copernicus DIAS[59]) offering cloud computing services "next to the data".

Another factor that will soon have a great impact on scaling opportunities and greater market penetration is regulation. Thus, P-fertilisers are soon going to be regulated by the EU – like N already is. This means that a need to rationalise its use (other elements too) will trigger increased demand and usage for SatAgro and similar services. In addition, a better accounting for water availability in fertilisation plans will bring further savings. In view of these observations, it is important to stress that the savings component is definitely underestimated in the current practices but even more so in relation to future developments. Regulation-induced developments in the context of the Common Agricultural Policy (see dedicated discussion inside the box at the end of chapter 5) will also certainly act as a catalyst for greater adoption of Sentinel-enabled services in Agriculture.

- **Improved technological maturity**

Technological maturity should be understood here as (i) the capacity of the users to make optimal use of a given service (even when this service remains unchanged over time), (ii) the ability of the providers to improve their value proposition using the feedback (and data analytics) from their customers. In both cases, the effect is that, over time, Sentinel-enabled services will yield more significant economic benefits for farmers (and consequently greater revenue for providers). A prime example underlying this scalability factor is the proliferation of a) VRA-enabled farm machinery, b) standardised protocols (i.e. ISOBUS-compliant[60]) that allow different types of machinery or software tools to "speak" to each other. Practically, the more hardware and software solutions are "communicating with each other" the more farmers are able to make optimal use of Sentinel-enabled services and the information these unlock.

[59] See here: https://www.copernicus.eu/en/access-data/dias
[60] See here: http://www.agleader.com/blog/what-is-isobus/

The quantification of these effects is very complex and rather subjective at this stage. In the case of Denmark, we have attempted to make some first inroads in this dimension; here, however, our discussions with the Polish stakeholders did not yield a conclusive estimation of what this effect would amount to in terms of potential benefits. Therefore, we would rather resist the urge to quantify it.

We can, however, venture into a simple projection of the potential Sentinel-enabled SatAgro impact onto the whole of EU-28. If we take the cut-off threshold to be at 50ha then we find a total of almost 115M ha in EU-28. So, by 2023, if instead of the 10% we have assumed for coverage in Poland (amounting to 503kha) we project just 0.5% penetration in EU-27[61] for SatAgro, this gives another 524ka served. For simplicity we can see that this would, in principle, double the projected benefits. However, here we should constrain ourselves to SatAgro and farmers only, excluding Grupa Azoty from this picture as it would add extra complexity from having to consider their market penetration as well. Nevertheless, **through these very modest considerations we still arrive at an extra of 10.5M € worth of economic benefits from the potential use of Sentinel-enabled SatAgro services in EU-28 by 2023**. The greater the penetration the more this would scale.

6.3 Final Thoughts

Free, full and open access to world-class Sentinel-2 data (having adequate resolution and revisit time) has allowed a young generation of entrepreneurs to build a solid business case, attract the tangible interest of corporate heavyweights (Grupa Azoty and now BNP Paribas) and provide significant value to farmers (economic) and the general public (environmental). This is a very important observation that seems to be mirrored in many other European countries as new start-ups (or established companies) offering Sentinel-enabled farm management tools arise.

The economic benefits of such services – as showcased herein with SatAgro – are significant. This is true even with the very modest assumptions we have presented here. Yet, throughout our interaction with all value chain actors but also in the ensuing analysis presented here, we have tried to underline that there is an even brighter future for such services, as the market penetration (also across borders) increases, the maturity of those using the services develops and the technical capabilities of the providers improves.

Similar conclusions were also drawn in the "sister" study of Farm Management in Denmark. Whilst, we have attempted a few different approaches (e.g. with regards to how the model yielding the economic benefits for each tier is built) here, the key findings remain the same. It would be worth however to perform complementary studies (within or on top of the Sentinel Economic Benefits study) trying to establish more robust indicators for a) different crops, b) varying treatment cycles, c) different levels of technological maturity at farm level. The first two

[61] EU-28 minus Poland to avoid double counting.

points would add finer structure in the economic model. The last point would help to shed more light on the different edges of the spectrum, i.e. large, technologically savvy farms on one hand and smaller holdings on the other. The findings of recent R&D projects could be leveraged in that direction.

Annex 1: References and Sources

The list below covers only the main sources used extensively throughout the study. The reader can find more references in the form of footnotes or hyperlinks throughout the text.

1. CK Pulawy, 25 years of Polish agriculture: Food security in Europe, 2014: Link.
2. (EY) Ernst&Young, Doing business in Poland, 2018.
3. (FAOSTAT) Food and Agriculture Organization of the United Nations Statistics, Crops, May 2018: Link.
4. Grupa Azoty, Consolidated Financial Statements (2016, 2017, 2018), Link
5. ILOSTAT, Employment by sector – ILO modelled estimate, May 2018: Link
6. EARSC-ESA, Sentinel Economic Benefits Study - Farm Management in Denmark, May 2018, Link

Annex 2: General Approach and Methodology

This is the 5th case of a new set to be analysed following the 3 cases published in 2015/16. It follows the same basic methodology[62] based on establishing a value chain for the use of a single EO service with the addition of an analysis of the environmental impacts.

For each new case, a comparison of the methodology which has been used will update our perspective on the overall methodology to be used for future cases. In that regard, what have we learned from this case?

In this case the following points stand out:

- The “main protagonist” of this case are fertilisers. Thanks to SatAgro services, farmers can apply fertilisers in variable rate across their fields, optimising their yield and cutting down on costs. This central feature is captured very strongly in this case since the primary user we have seen in our value chain is Grupa Azoty, a major agro-fertiliser company, which has seen the partnership with SatAgro as a unique opportunity to differentiate its portfolio and react to market pressures. Reduced use of fertilisers leads to environmental benefits too.
- Even with very modest assumptions we have shown that SatAgro services bring significant value to its clients. For future assessments, it is advisable to pursue finer structure in the analysis (see concluding remarks above).
- The availability of Sentinel data is absolutely critical for this case. If it weren’t for the free, full and open access to this data, the business model that SatAgro has built would not be viable.
- The environmental impacts of this case are significant yet hard to quantify. The reduction in fertiliser or pesticide most certainly has a positive impact on the environment. However, tracing reduced algal blooms in the Baltic to more efficient use of fertilisers in mainland Poland is still a very complex process as many parameters are involved.

[62] SeBS Methodology; June 2017.

Annex 3: Winners… and losers?

The creation and subsequent usage of Sentinel data down the value chain has a significant economic impact. Quite prominently, product and process innovation based on the availability and subsequent application of the data, lead to positive effects where new products and services emerge, and existing processes can be run more effectively and efficiently. Conversely of course, there are also 'negative' consequences as jobs are displaced and sometimes even destroyed, creating technological unemployment.

> As we have shown in our study 'Winter navigation in the Baltics' as the captains on the icebreakers in the Baltics could suddenly rely on Sentinel based ice charts providing a fully synoptic picture of the ice, the helicopter pilots they traditionally relied upon, became abundant.[63] Similarly, in our study 'Forest Management in Sweden' the Swedish Forest Agency could reduce the number of forest inspectors, as Sentinel data allowed for a reduction of in situ inspections.[64]

How technological progress and innovation are related to employment has been an area of fierce debate for centuries. From fairly recent studies appear that product innovation spark new economic activities, creating new sectors, more jobs, whereas process innovation[65] is more job destroying, although market mechanisms can sometimes largely compensate for the direct job losses, mitigating the ultimate impact on demand for labour. Such price and income compensations can derive from a decrease in wages, leading to an increase in demand for labour or the effects of new investments (enabled by accumulated savings) creating new jobs elsewhere. Obviously, the speed and impact of such effects are highly dependent on the flexibility of markets, the level of competition, demand elasticity, the extent of substitutability between capital and labour and, of course, possible institutional rigidity.[66]

> A German study on the co-evolution of R&D expenditures, patents, and employment in four manufacturing sectors concluded that patents and employment are positively and significantly correlated in two high-tech sectors (medical and optical equipment and electrics and electronics) but not in the other two more traditional sectors (chemicals and transport equipment).[67] Similarly,

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[63] Sawyer, G. and De Vries, M. "Winter navigation in the Baltics." Copernicus Sentinels' Products Economic Value: A Case Study (2015)
[64] Sawyer, G. and De Vries, M. "Forest Management in Sweden." Copernicus Sentinels' Products Economic Value: A Case Study (2016)
[65] As process innovation is defined as producing the same amount of output with less labour (and sometimes other) inputs, logically the direct impact of process innovation is job destruction when output is fixed.
[66] Vivarelli, M. "Innovation and employment: Technological unemployment is not inevitable—some innovation creates jobs, and some job destruction can be avoided." IZA World of Labor 2015: 154

[67] Buerger, M., T. Broekel, and A. Coad. "Regional dynamics of innovation: Investigating the coevolution of patents, research and development (R&D), and employment." Regional Studies 46:5 (2012): 565–582.

a study using a panel database covering 677 European manufacturing and service firms over 19 years (1990–2008) detected a positive and significant employment impact of R&D expenditures only in services and high-tech manufacturing but not in the more traditional manufacturing sectors.[68] Another study found a small but significant positive link between a firm's gross investment in innovation and its employment based on longitudinal data set of 575 Italian manufacturing firms over 1992–1997.[69]

Clearly, this tells us that the ultimate 'net' impact of innovation – both at product and process level - brought about by the availability of new technology, such as Sentinel data, will be closely related to the market and institutional settings in which they become effective. However, on the whole the conclusion seems justified that the 'negative' effects, in the form of possible loss of employment, is largely outweighed by the positive economic effects throughout the value chain.

Accordingly, in this study – and likewise for the past and future ones - we will concentrate on the positive effects brought about by the availability of the Sentinel data throughout the value chain. That there are also (temporary) 'negative' impacts is a given, but the net effect at macro level will always be positive.

[68] Bogliacino, F., M. Piva, and M. Vivarelli. "R&D and employment: An application of the LSDVC estimator using European data." Economics Letters 116:1 (2012): 56–59.

[69] Vivarelli, M. "Innovation, employment, and skills in advanced and developing countries: A survey of the economic literature." Journal of Economic Issues 48:1 (2014): 123–154 as well as "Technology, employment, and skills: An interpretative framework." Eurasian Business Review 3:1 (2013): 66–89.

Annex 4: About the Authors

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Lefteris is a strategy consultant with a very good knowledge of programmatic, strategic and business aspects of EU Space Programmes (Copernicus and Galileo). In the past 8 years, Lefteris has been extensively involved in various studies and projects related to the development, market uptake and exploitation of EO downstream applications. He has been advising clients and partners across the full spectrum of the EO value chain, including EU institutions (EC, EEA, SatCen, ESA), universities and private companies.

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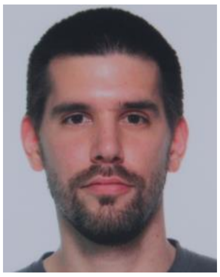

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