TRANSFARM 4.0 – D.T2.3.2

BRIEFING PAPERS OF CROSS-CUTTING INNOVATION ITEMS REQUESTED BY MARKET

Briefing Paper 1 – Social, labour, ethical impact
Briefing Paper 2 - Compatibility with international ISO standards
Briefing Paper 3 - Environmental trade-off

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A. Briefing Paper 1 – Social, labour, ethical impact

1. Work safety and health situation in the farming sector

Agriculture is one of the most dangerous professions in Europe. According to official Eurostat statistics covering people employed in the sector, the incidence of fatal accidents in agriculture (fishing and forestry) is the fourth highest of all sectors at 4.4 per 100,000 workers, after mining, construction and transportation which is only slightly higher at 4.8 per 100,000 (Eurostat, 2019). A similar pattern occurs for non-fatal accidents, with a high level of accidents affecting the sustainability and viability of the sector. Over the last 10 years, there has been an average of over 500 deaths per year in the agriculture, fishing and forestry sector (although the figures dropped to 408 in 2017) and over 150,000 non-fatal accidents per year. Even so, experts in the sector are convinced that there is a huge under-reporting of both fatal and non-fatal accidents. The main challenge is the lack of reliable data concerning the recording of accidents for the self-employed, irregular or temporary workers, retirees and family members. And this situation is even more alarming if we consider that the major part of the agricultural and forestry working population belongs to these categories.

According to the literature and available data on work accidents, the main sources of risks for workers in agriculture derive from transport accidents, falls from height, being struck by falling or moving objects and contact with machinery (unguarded moving parts). Age is also a risk factor. Farmers over 65 years of age make up 32 % of the EU farm workforce (European Commission, 2020).

Farmers are also exposed to pesticides, fertilisers and a wide range of other hazardous substances in farming. Workers may be exposed to pesticides in a wide variety of ways, including working in a field where pesticides have recently been applied; breathing in pesticide ‘drift’ from adjoining or nearby fields. The health problems that can be caused by working with hazardous substances range from skin irritation to severe effects, such as cancer. The European Commission (EC) is actively promoting the reduction of pesticides through its integrated pest management (IPM) policy, under the Sustainable Use of Pesticides Directive (2009/128/EC). IPM is an agricultural management practice aimed at minimising or removing the use of pesticides in agriculture. The success of IPM in reducing pesticide use still needs to be proven and EU legislation on pesticides and chemicals is quite complex, especially for small farms, which find it challenging to map out a coherent approach. New technologies (such as weeding robots or automated spray applicators/lasers and drones) have the potential to limit the extent and frequency of exposure of farmers and farm workers to pesticides.

Market demand is increasingly oriented towards technological applications ensuring high-quality and high safety standards for farm workers at reasonable prices. Security and health concerns must be taken in due account in the development of precision agriculture technologies and innovations.

These are general terms used to refer to the use of digital technologies such as drones, sensors, global positioning or satellite systems, automation and robotisation, big data, the Internet of Things (IoT), Artificial Intelligence (AI), augmented reality, etc. Precision agriculture is a component of overall ‘technology’ adoption and has the potential to improve labour, safety and health in agriculture.

Issa et al. (2019) indicates that agricultural engineering developments in the United States of America (USA) played a key role in cutting down the fatal casualties by 63 % between 1992 and 2015 by removing and reducing workers’ exposure to hazardous environments.

2. Occupational, safety and health improvements

Precision technology application has the potential to decrease workload for farm workers and reducing risk exposure. Examples include mechanical harvesting of crops and forestry harvester technology. However, working in a technological environment demands a more technologically skilled workforce. Concurrently, though, challenges remain in many areas of agriculture owing to the irregularity and unpredictability of the work environment (soil, topography, flora and fauna, weather, etc.). An intermediate step will most likely be the use of ‘co-robotics’ or ‘cobots’ — designing robots to work alongside human workers, with the robots handling simple tasks while people continue to perform the more complex and delicate actions.

Precision spraying equipment integrating control of droplet size and nozzle flow rate which can spray at distance and reduce the quantity of chemicals used provides the opportunity to reduce occupational exposure to hazardous pesticides, as well as reducing their impact on the environment. New technology will provide the opportunity to improve machine and vehicle safety, e.g. force-torque sensors, tactile and pressure sensors, safe maximum speeds, proximity sensors, area detectors and cameras, and emergency stop buttons. Surroundings sensors and vision technologies, as developed in the motor industry, are not as well developed and widespread in the agricultural vehicle and machinery industry or in forestry harvesting technology at present. Application of modern technologies offers potential to increase gender equality in agriculture as a result of fewer physical demands and more flexible work arrangements. Considering that farmers over the age of 65 years represent an increasing share of the EU agricultural workforce, new technologies offer the potential to increase older worker engagement and employability in a safe and healthy manner. New technologies, such as computer-aided controls and emergency stop systems can help older people to work more safely. New technologies can support disability management in farming. New technologies offer potential to assist people with disabilities with their lifestyle and to enable them to continue to farm.

New smart monitoring technologies could improve safety and health on the farm particularly through the use and wearing of smart devices using GPS (global positioning system) apps; smart devices that could monitor health vital signs and exposure to hazardous substances. Nonetheless, ethical and privacy issues would need to be considered, as well as user acceptability.

3. Barriers to and risks of smart and precision technology uptake and ethical implications

The large-scale uptake of smart and precision farming technologies is undermined by a series of barriers affecting the socio-economic and the psychological and health spheres of the farmers.

Concerning the socio-economic barriers, **low income** is a major obstacle to the large-scale adoption uptake of new technologies. Apart from temporary fluctuations due to external contingencies, low EU and national food prices mean that many small farmers struggle financially and are unable or reluctant to invest in what they may see as technologies with unclear returns on investment. In turn, smart and precision farming solutions will take several years to improve social and occupational standard levels in the sector and will not offer an immediate solution to the high accident rate and occupational health challenges.

Digital literacy and training are other two aspects to be seriously addressed to facilitate the adoption of new technologies, which are prominently digitally-based. The need for digital skills among farmers is an urgent issue to ensure that workers know how to use new technologies effectively but also with confidence in order to avoid additional psychosocial pressures related to the introduction of new technologies. Psychosocial challenges such as monotony and stress are both associated with the introduction of new automated technologies in farming. Stress and frustration have been experienced by farmers faced with malfunctioning automated systems during their initial implementation periods, such as false alarms and malfunctions, and older workers have been experiencing more stress related to the introduction of new technology (EU-OSHA, 2020).

The perception of job insecurity resulting from the deployment of technology that can lead to capital-labour substitution can also lead to distrust and scepticism towards technological innovations. Frustration also arises because of reliance on equipment that the operators is unable to fix on their own, making farmers reliant on outside technical assistance, which results in lost production time, additional costs and a feeling of loss of autonomy.

Increased risks of isolation is another aspect to be taken into account in the definition of the social impacts of the uptake of these technologies. Many farm and rural areas are isolated and far away from the nearest help centres. New technologies reduce the workload and the number of workers necessary to carry out certain tasks (and as a result have a direct impact on rural depopulation). This may increase the number of lone workers in agriculture. Legislative and technological measures should be devised to guarantee high standards of protection for workers.

Fragmentation of and lack of standardised safety protocols and certification systems for smart farm technologies can also lead to barriers to the uptake. The application of technology-based on AI systems may imply the risk of malfunction or injury if the various systems do not work effectively together.

Digital data is another significant aspect to be addressed to facilitate the spreading of digitally advanced applications. There are several risks that need to be managed in smart farming, such as the possibility of confidential data being stolen, systems subjected to ransomware, agricultural production disrupted. The fear of data misuse can also hinder the acceptance of new technology, as witnessed by a German survey (Deter, 2020).

As mentioned above under ‘New smart monitoring technologies’, monitoring of workforce performance and pace through new wearable technologies could raise ethical concerns.

4. Labour market trends in agriculture

The importance of the farm workers has lately been highlighted during the Covid-19 pandemic. In response to COVID-19, the EU Farm to Fork Strategy stated that it is ‘particularly important to mitigate the socio-economic consequences impacting the food chain and ensure that the key principles enshrined in the European Pillar of Social Rights are respected, especially when it comes to precarious, seasonal and undeclared workers. The considerations of workers’ social protection, working and housing conditions as well as protection of health and safety will play a major role in building fair, strong and sustainable food systems.’

Labour market in the farming sector is affected by multi-faceted issues which are widely intertwined with each other.

Rural depopulation is one of those horizontal challenges that has having an impact on labour and social dynamics in agriculture. Rural depopulation largely influences the categories of workers in the sector.

According to Eurostat, the share of temporary workers is increasing in the sector (currently about 30% of the farm workers). This brings about negative externalities which are linked to the lower level of knowledge of the workplace and of the working and safety practices in the workplace. In many cases, seasonal workers arrive at the place of work only hours before the official starting date and are unable to receive an appropriate training before starting work. This creates problems for both workers and employers. COVID-19 has highlighted the vulnerability of seasonal workers to health impacts resulting from poor living and working conditions. Adequate training and health monitoring should be provided to fill this gap and smart farming technology may play a key role in the design of online training schemes and health monitoring packages.

Most of the workforce in agriculture is made up of self-employed family labour. Considering the low propensity of self-employed workers to report accidents on the workplace compared to employees, there is thought to be gross under-reporting of injuries. There is thus a need to increase the offer of low-cost smart technologies favouring safe working conditions which is not easy to estimate in quantifiable terms. Self-employed family labour also implies to consider the gender dimension in the labour market. Karttunen et al. (2019) point out that the risk of injuries for male and female workers is virtually equal, given equal work time Therefore, gender is an indicator of different work exposures in farming, rather than a risk factor for injury, in spite of the general perception that indicate that women are less likely to take risks than men.

Nevertheless, there is a need to take account of certain gender aspects in OSH practices in the sector. In terms of exposure to pesticides, maternal occupational exposure (as well as the man's exposure) to chemicals in the workplace before and during pregnancy could lead to the development of congenital anomalies (Snijder et al., 2012; Spinder et al. 2019). EU-OSHA highlights that work equipment, such as machinery and protection devices are still designed for the average-sized male worker and takes less account of the ergonomic needs of women.

Farmers aged over 65 years make up one third of the EU farm workforce. Older farmers tend to invest less in the farm and in new technologies, as well as having significantly lower levels of training in general. According to Eurostat (2018), older farmers are less likely to have any formal agricultural training

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B. Briefing Paper 2 - Compatibility with international ISO standards

1. Interoperability and compatibility of data in precision agriculture

The agricultural sector is faced with several challenges from extreme events to resource scarcity. Technology is providing a unique opportunity to expand yields and mitigate some of the losses related with the various challenges in this sector.

Interoperability is one of the key challenges of the smart and precision technology uptake in agriculture, where interconnection between heterogeneous hardware and software systems plays a key role.

The main problem of the precision farming technologies is then the compatibility between certain machines. Therefore, the main concern of the farmers investing in precision farming solutions is ‘will this new digital and automated technology work with the technique already existing and used in the farm?’

Precision technology providers have to comply with the principle of transparency in their marketing activities and have to develop their production by using the same standards. An already available opportunity and good practice is to check if the tractor and certain machines are compatible on the databank of the AEF. The “Agriculture Industry Electronics Foundation” provides a free databank where farmers can check if their vehicle combinations are compatible. If there is a problem with the compatibility of two machines, which should be compatible according to AEF, the manufacturer of both machines are committed to solve the problem.

At the beginning of the XXI century, ISO 11783, known as Tractors and machinery for agriculture and forestry—Serial control and communications data network (commonly referred to as "ISO Bus" or "ISOBUS") was the first step towards a revolution in the agricultural world. Isobus is a communication protocol for the agriculture industry based on the SAE J1939 protocol.

The goal was to achieve compatibility and standardisation between tractors and agricultural machinery. The Isobus protocol allows standardised communication between different types of tractors and machinery, bringing several advantages, including for example the fact that it is no longer necessary to have a different terminal for each type of machine, but it is possible to use a single universal terminal, which can be connected to several machines. This means that you can connect all the machines to a tractor.

From this achievement, a whole series of applications has expanded from year to year with integrations and unions to GPS systems and increasingly precise sensors that today allow automation and total traceability of every intervention that is done in the field, e.g., virtual terminal (displays showing the information of the connected tools and allowing to control every movement of the tools in the field), task controller (allowing to perform the work in relation to the position of the machines in the field, integrating with the GPS), and Farm Management Information Systems (FMIS).

Isobus offers countless advantages even to small farms, as well as other larger ones: it improves and standardises upwards the quality of products; it increases the efficiency of the production process, with higher yields per hectare and a decisive rationalization of costs; it reduces the environmental impact of fertilisers and pesticides thanks to a targeted use of these products that are all targeted, eliminating waste; it decreases the fatigue of the agricultural operator thanks to the automation of operations and increase his safety at work; It traces the entire production process and documents it with end-of-campaign reports that can be delivered to buyers (stockers, mills, agri-food industries, processors, etc.).

Despite the advantages, challenges exist to the shaping of a harmonised approach in terms of designing common implementation norms and practices. The interconnectivity of information systems suggests the possibility of linking information systems, so that data from one system could be automatically consulted by another system at a central level. This solution requires technical compatibility between the systems, as well as strict privacy safeguards and access control rules. There are different levels of interoperability affecting data, such as technical (the use of data management systems that allows connection with other systems), semantic (the use of metadata and knowledge organisation systems for the description and organisation of data, based on existing standards) and legal (the use of appropriate licences that allow the exchange of data between different systems and providers). Interoperability, being viewed as something more than interconnecting ICT-systems, comes with certain risks that refer to the possible infringement of data protection principles, and in particular of the purpose limitation principle.

Current precision agriculture systems are based and should comply with ISO 11787.3 However, there are still equipment incompatibilities, as well as incompatibilities between owned and contracted farm equipment.

The issue of equipment compatibility is coupled with the problem of data management. As smart machines and sensors appear on farms and farm data grows in quantity and scope, farming processes will become increasingly data-driven and data-enabled. These large amounts of different types of data are collected by drones, robots and sensors in general and include climate information, satellite imagery, digital pictures and videos, transition records or GNSS signals. The complexities arise due to the fact that these technologies support very detailed data capturing, which in principle can be shared (cloud technology) and interpreted with big-data techniques. By linking and combining data from different sources, a farm produces many types of data that can be classified into different categories: agronomic data, financial data, compliance data, metrological data, environmental data, machine data, staff data, personal data, financial data and operational data. Confidential farm-related data concerning particular farming techniques, soil fertility and crop yields, but also certain financial and other personally identifying information that may be subject to legal restrictions, is also collected.

The issue of data management and data compatibility forms one of the main current limitations to the wider spread of common tools and methods to handle data gathered by several sensors, approaches and temporal and spatial scales. In particular, one of the main restrictions for data sharing among institutions, farmers, advisers and researchers is due to non-standard software and data formatting solutions. The challenge is to properly manage the large data sets that are acquired by different sensors, and to enable data sets to be shared easily, irrespective of the sensor model and brand used.

Data management, data storage, data sharing and interconnectivity strategies are urgently needed.

Precision agriculture systems may be placed into farm environments where the connectivity is usually rather poor and may not be able to share data even with other systems on the same farm. Hardware/software providers are not necessarily incentivised to share data with other systems as they strive to offer complete systems of their own. Furthermore, compatibility issues in precision agriculture are limiting the development of technology, as it prevents data exchange between instruments, and interconnection of equipment. There is a lack of, or poor compliance with, standards for software development and data formats, limited data infrastructures on farms that are not designed for data sharing, and extensive brand protection by large companies

The lack of cohesion in data exchange and the vendor lock-in scenario, which occurs even where a standard such as ISOBUS exists, limit the uptake of precision agriculture. Several standards are available, but these have been created by unrelated organisations and they are not centrally indexed.

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C. Briefing Paper 3 - Environmental trade-off

1. Present challenges and sustainable intensification

The scale, scope, and complexity of agri-food systems and their linkages to natural and human systems have tremendously been growing in the last decades. This is leading o inevitable trade-offs among and between the economic, environmental, and social impacts of these systems.

The agricultural sector is supposed to fulfil several vital goals, e.g., increased food production, preserving and developing cultural heritage, biodiversity, mitigating and adapting to climate change, while at the same time being both sustainable and economically viable on a long-term basis.

Being sustainable means fulfilling the needs of the present without compromising the ability of future generations to meet their needs. Thus, sustainability implies a trade-off between the environmental, economic and social domains.

In the attempt to address the challenges of the increasing demand for food, feed and energy from a growing global population, in a world where the natural resources are overexploited and used unsustainably, agricultural sciences have launched the concept of *sustainable intensification*, whose objective is to frame the idea of increasing food production from existing farmland while minimising the pressure on the environment.

The concept underpins the idea of a healthy environment where earth's natural processes carry on meeting ecosystem – including human – needs, not only now but for the future generations. While caring for the environment, sustainable intensification must prove to be economically viable to ensure the producer will put these methods into practice for the long term.

From a global viewpoint, sustainable intensification plays a role in ending hunger and poverty, as it includes better quality of living for both farmers and the community as a whole. As the world's population continues to grow, there is no doubt that sustainable intensification is non-negotiable, but getting farmers to switch to sustainable farming is a real challenge.

The question to addressed is how can farmers be helped to change to sustainable farming and achieve all the above-stated objectives?

The agriculture sector is indeed one of the larger contributors to global GHG emissions both directly and indirectly. The major GHGs produced in the agricultural sector are methane (CH4), nitrous oxide (N2O) and carbon dioxide (CO2).

CH4 is mainly produced from anaerobic decomposition of organic matter during enteric fermentation and manure management. N2O arises from the microbial transformation of nitrogen (N) in soils and manures (during the application of manure and synthetic fertilisers to land) and from urine and dung deposited by grazing animals. CO2 arises from pre-farm and post-farm energy use and from changes to above- and below-ground carbon stocks induced by land use and land use change.

2. Precision agriculture and environmental trade-off

Being precision agriculture, a set of tools, processes and strategies aiming to better manage the uses of data and digital farming technologies to help the producer know precisely what crops need, when they need it, and where, farmers are turning to it for sustainable agriculture, notably for maximising production while reducing the input.

This statement might be considered as a reliable approximation if one considers as farmers only those primary producers in the North of the world, which are quite well integrated in the global supply chain and invest in large-scale farming activities.

Price, production costs, lack of technical skills and social acceptance, reduced investment capacities and uncertain return on investment are all acknowledge barriers to the uptake of precision agriculture technology.

Technology management and transfer are indeed key to pave the way to the application of precision agriculture on a large scale.

Primary producers mastering precision methods become familiar with agricultural products and know the exact combination of pesticides, herbicides, and fertilizers to use on their crops. This results in reduced waste and minimizes environmental externalities. They also reduce the use not necessary input, such as the overuse of water and seeds. Variable-rate application technology allows farmers to disperse fertilizer, water, pesticides, or seed at different rates across a field. Data collected by sensors and maps help farmers determine these application rates. By using all technologies available to them, such as GIS, crop sensors, soil sensors, and yield monitors, farmers can reduce the use of unnecessary input. Precision watering then gives farmers the ability to use the precise amount of needed input directly to the roots. It also prevents the runoff of fertilizer into adjacent water sources, a problem often caused by overwatering.

Variable-rate nutrient application (VRNT) technologies and variable-rate irrigation (VRI) systems are notably considered to have a significant potential for reducing GHG emissions[1]. The former optimises the use of fertilisers, which contribute to GHG emissions by releasing CO2 during their production and transportation. The global warming potential of N-based fertilisers is even much greater, as it also contributes to N2O emissions, being the most influential GHG produced as a result of agricultural activities. Variable-rate irrigation (VRI) systems rank second in GHG emission reduction potential, as they have a dual impact: the reduction in the amount of water needed for irrigation decreases the energy needed for pumping water and transporting it from the aquifer; secondly, an optimal irrigation schedule could prevent extreme soil water availability (which boosts N2O emissions).

These methods of precision agriculture meet its environmental stewardship mission, i.e., protection and wise use of finite natural resources such as water, soil, and phosphorus and minimizing the ecological burden of chemicals used in pesticides are crucial factors behind this technology.

Nonetheless, it is easy to infer the environmental benefits of precision agriculture in qualitative, very few quantitative data are available.

2.1. The study in the US

The American Association of Equipment Manufacturers (AEM), in partnership with the American Soybean Association, CropLife America, and National Corn Growers Association, has recently released a study

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[1] Soto, I., Barnes, A., Balafoutis, A., Beck, B., Sanchez, B., Vangeyte, J., Fountas, S., Van der Wal, T., Eory, V., Gómez-Barbero, M., The contribution of Precision Agriculture Technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-92834-5, doi:10.2760/016263, JRC112505.

quantifying how widely available precision agriculture technology improves environmental stewardship in the United States.

The study identifies five key precision agriculture technology areas (auto guidance, machine section control, variable rate, Fleet analytics and precision irrigation) and five key environmental benefits to be quantified as a result of precision agriculture technology adoption:

1. Productivity: Yield benefit from accurate spacing (pass-to-pass, end/point rows) and population rate;
2. Fertiliser Use: Optimization of fertiliser applications (reduced overlap, avoid skips, best placement and rate of inputs);
3. Herbicide Use: Optimization of herbicide applications (reduced overlap, avoided skips, best placement and rate of inputs)
4. Fossil Fuel Use: Fuel savings from fewer field passes, variable depth of tillage, and/or more efficient harvest;
5. Water Use: Application of water avoided due to remote shutoff of centre pivots, along with selective application.

A model was built for each of the five environmental benefits, capturing data and contributions from each of the relevant precision agriculture technology areas.

According to the study, productivity has increased an estimated 4% as a result of current precision agriculture adoption and has the potential to further increase 6% with broader PA technology uptake. The more efficient use of existing has contributed to avoiding the cultivation of an estimated 10.2 million ha of cropland in the US.

In the area of fertiliser placement, precision agriculture techniques have contributed to improving efficiency by an estimated 7%. The study's forecasts state that this increase could improve by an additional 14% with broader adoption of the above-mentioned technologies. Variable rate technologies support the identification of the right rate and place, along with the contribution from auto guidance and section control technologies.

More specifically, in a pilot farm in the US, researchers have been able to quantify economic and environmental benefits from the application of PA technologies. A reduction by over 15% of CO_2 equivalent GHG emissions was recorded over the transition from the traditional to advanced precision agriculture methods.

The same study reveals that the herbicide use was cut down by an estimated 9%, with a potential of further decrease by additional 15% when precision farming practices are widely adopted.

The use of fossil fuel is another parameter the was considered. It was calculated that the current uptake of precision agriculture techniques has contributed to reduce the use of fossil fuel in agriculture by an estimated 6%. This percentage could reach an additional 16% compared to the current status, if precision agriculture practices were widely adopted. This means that the use of an estimated 38 M litres of fossil fuels was avoided due to adoption of precision agriculture technologies, equivalent to an estimated 193,000 cars off the road annually or 18,000 average flights.

Water Use has also registered an estimated decrease by 4% as a result of current PA adoption, with the potential to further decrease 21% over the widest uptake. 44,667,838 ML was the estimated water application in a world with no precision agriculture technology uptake, 42,775,133 ML is the amount of the current water application levels, thanks to variable rate precision irrigation and soil moisture sensors.

2.2. The study in the EU

In *The contribution of Precision Agriculture Technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU*, Soto, I. *et al*. (2019) selected five case studies for identifying a combination of EU countries, precision agriculture techniques and arable crop types that could realise the maximum potential economic and environmental benefits of adopting precision agriculture techniques. The EU countries selected included Germany, the United Kingdom, Belgium and the Netherlands, since they are countries with large farms, high farm incomes and high levels of GHG emissions, in particular N2O. Greece was also included to represent the heterogeneity of EU environmental and climatic conditions. The selected technologies were MG and VRNT, since they ranked among those with the highest potential to reduce GHG emissions.

The Miterra-Europe model was used to assess the EU-wide environmental impact of MG VRNT, with a focus on GHG emissions, using MG and VRNT under different uptake scenarios (low, medium and high). The results of the analysis showed that GHG savings are higher for VRNT than for MG in all three uptake scenarios. This is because the capacity of VRNT to reduce indirect, but especially direct, N2O emissions associated with the reduced use of N-fertilisers is higher. VRNT also saves fertilisers, and therefore the CO2 emissions associated with the production of these fertilisers are also lowered. The fuel reduction capacity of MG is higher than it is for VRNT, as MG is used for field activities additional to the application of fertiliser. The mitigation potential for MG ranges from 1513 to 2760 Ktonnes carbon dioxide equivalent (CO2-eq) per year. The mitigation potential range for VRNT varies from 3805 to 6567 ktonnes CO2-eq per year. These potential GHG emission reductions represent 0.3–1.5 % of the total EU 2015 GHG emissions of the agriculture sector. Other environmental impacts (such as ammonia emissions and nitrate leaching) can also be reduced. However, the size of this reduction varies locally because of differences in farm size, current fertiliser uses and environmental conditions. Farm size is an especially important factor, as the implementation of PAT on large farms has greater potential benefits: there is a lower investment cost per ha and a greater benefit regarding input reduction.

3. Results from systematic reviews of academic literature

In a recent study by Koutsos T. and Menexes G. (2019)[2], a systematic review was conducted to investigate further the economic, agronomic, and environmental benefits from the adoption of PA technologies, based on the systematic search and evaluation of related eligible academic articles.

A simple yet effective system was developed for grading the quality (level) of evidence and the strength of recommendations of studies included in the systematic review. Four levels of evidence were defined as follows: (1) strong evidence (S1): studies with consistent results of high quality, proven economic, agronomic or environmental benefits from the adoption of the proposed PA technology; (2) moderate evidence (S2): studies with consistent results with rough partial budget analysis or articles that use simulation methods; (3) some evidence (S3): studies with unsubstantiated benefits or recommendations regardless quality.

Against this systematic review, twenty-two articles were assessed as having S1 strength of evidence (20.4%) and seventy-two as having S2 (66.7%) strength of evidence – total N=94 out of the total studies assessed (N = 108) or 87.1%.

It is worth mentioning that only 22 out of the 94 articles included (S1: N = 13 and S2: N = 9 studies) succeeded in reporting monetary gains from the adoption of PA technologies. Similarly, a total of 19 out of the 94 articles included (S1: N = 18 and S2: N = 1 studies) reported tangible agronomic benefits. Unfortunately,

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[22] Koutsos T. & Menexes G. (2019), Economic, Agronomic, and Environmental Benefits From the Adoption of Precision Agriculture Technologies: A Systematic Review. International Journal of Agricultural and Environmental Information Systems, Volume 10 • Issue 1 • January-March 2019.

most of the reports assessed failed to report measurable environmental benefits and only three studies attempted to enumerate the expected benefits (S1: N = 1 and S2: N = 2 studies), proving that it is still difficult to calculate the environmental gains from the adoption of technological innovations in agriculture.

Still, the review implies that all studies included reported positive implications and that the most relevant benefits come from the adoption of precision agriculture technologies for managing the spatial variability and the precise nutrient applications. Based on the strength of evidence of the included articles, the agronomic benefits are more tangible, while the economic benefits cannot always be measurable and the environmental benefits are not always clear in terms of quantitative figures.

4. Conclusions

The environmental benefits of precision agriculture are currently not well assessed. There is a lack of quantitative studies of the environmental benefits of using precision agriculture, which should go beyond the field and farm scale to wider environmental footprint. A study by AEM indicated that the potential for improved environmental quality was a strong adoption motivator across PA technologies and provide some figures linked to specific cases in the US primary sector. The study focusing on the EU countries indicates that the mitigation potential of VRNT is higher than that of MG representing 1.5% and 0.3% of the total EU 2015 GHG emissions of the agriculture sector respectively. There is a general consensus that PA could therefore represent a tool for GHG emission reduction in agriculture. Moreover, those technologies also have positive environmental co-benefits on air and water quality by reducing ammonia volatilisation and nitrogen leaching and runoff.

The studies are nonetheless insufficient and call for more research on the uptake of precision agriculture technology to foster sustainable intensification. Firstly, there is a need to quantitatively assess the current and potential adoption rates of PAT throughout the EU in order to obtain better estimates of the real mitigation potential of these practices. Secondly, there is the potential to further assess the impact of the use of these technologies in the application of manure, which could increase the mitigation potential in the land-based livestock sector. Lastly, farm size is still identified as an important barrier to the technology uptake, and research on assessing the economic impacts might shed some light on making technology more affordable to farmers.