SCOUTING THE AUTONOMOUS AGRICULTURAL MACHINERY MARKET

A study by Fraunhofer IESE and KLEFFMANNGROUP more than facts

Digital Forecast – Science Fiction or Future Reality?

The development and introduction of machines ranging from highly automated to driverless will have a strong impact on global agriculture - there is no doubt about this. Today, fully autonomous tractors or combine harvesters are no longer prototypes, but are already in use in preliminary stages. This inevitably raises the question of how fast and to what extent the new technologies will determine the market in the future.

To examine this question, Fraunhofer IESE in cooperation with the Kleffmann Group conducted this study, which deals with the state of the art as well as the future development of the autonomous agricultural machinery market. Several parallel paths were taken in the study: (1) The first task was to identify and classify the influencing factors related to the market. This is linked to the determination of changes in agricultural work processes within the framework of autonomous agricultural machinery development. (2) These influencing factors in combination with corresponding expert assessments as well as market data on tractor sales were then used within the framework of an empirical modeling approach to develop possible future scenarios up to the year 2045.

Technology Adaptation and Productivity Goals Rule the Market!

Essentially, the study identified two main groups of factors that have an impact on the market development. On the one hand, these are technological influences such as the development of sensor and actuator technology and, on the other hand, market-related influences such as climate change or demography (see Table 1).

Both the research and the experts ultimately prioritized four aspects as being most relevant. These include (1) available technology/ technology adaptation (meaning sensors and actuators, pattern recognition, and decision-making processes), as automation will not happen when the technical implementation is not available. In addition, farm productivity and

Technology-related influence factors	Sensor and Actuator Technology
	Pattern Recognition
	Decision Making Process
	Complexity of Autonomous Actions
	Standards
	Laws and Legislation
	Trust and Acceptance
Market-related influence factors	Change of Climate and Natural Conditions
	Consolidation in the Agricultural Industry and Change of Food Production Systems
	Farm Productivity and Profitability
	Demographic and Social Change
	Political and Economic Framework
	Regulatory and Pest / Disease Pressure

Table 1: Main influence factors

profitability, understood as (2) achievement of increased productivity goals, are also crucial. Particularly against the background of a growing world population, agriculture is simply forced to substantially increase its production - but taking natural resources into account. Ultimately, this can only be achieved by adding automated processes. At the same time, however, the issue of (3) trust and acceptance of autonomous technology by farmers is linked to this, which involves a great deal of uncertainty. Finally, as work has to be coordinated and should enable simultaneous operations, reliable (4) machine-to-machine communication is also regarded as a key factor.

Relevant System Classes

Knowing these influence factors, the question arises which different system classes in agricultural machinery will exist and what their degree of automation may look like. The listed market-related and technical influencing factors describe push and pull factors of autonomous agricultural processes, but also parameters that slow down their development. In the study, four basic autonomy levels of agricultural production were defined in order to predict their future development:

- **Entirely human-driven machines**, i.e., with no or low technological assistance
- **Assisted human-driven machines**, i.e., with technological assistance, e.g. GPS-assisted driving
- **Supervised autonomous machines**, i.e., using autonomous functions that are directly supervised by a human being
- **Entirely autonomous machines**, i.e., without human supervision.

The experts envisioned how they expect technology to evolve within a time frame of 25 years (for the points in time 2025, 2035, and 2045) and describe how the above-mentioned systems would develop during that time. Their opinions regarding the generalt rends were fairly homogeneous.
According to their predictions, in 2045 there will still be tractors on the market worldwide that correspond to today's tractors (entirely human-driven machines). The same applies to assisted human-driven machines driven by a farmer. These machines and implements will be equipped with many sensors that enable site-specific work tasks and reliable assistive technology used for safety features. The experts estimate that in the development towards 2045, supervised autonomous machines will first be controlled by expert operators, but the contact between machine and driver/operator will decrease and their role will change from being expert machinery operators to being system operators, with less qualification required. In addition, entirely autonomous machines will evolve from single, field- and application-specific autonomous tasks towards more complex tasks. In 2045, they are expected to perform multiple process steps autonomously. Machines and corresponding IT systems (e.g., farm management systems) will be able to determine their activities (e.g., when to go out on the field, or which fertilizer to choose) based on defined work plans. Additionally, the machines will be able to handle all implements.

The New Production Cycle

The various agronomic requirements of different crops determine the necessary process steps during a cultivation period. Accordingly, crops and crop rotations determine technical developments and must be taken into account in the autonomous implementation of work steps. Figure 1 shows general work steps during a cultivation period. Today, the central role is assigned to the farmer and tractors (or combine harvesters) that work with appropriate implements.

In the future, work steps with high tractive power, such as tillage or application of organic fertilizers, will be carried out autonomously by existing tractor systems, taking into account the lowest possible soil compaction. A similar development is predicted for transport and logistics tasks such as transport of harvested crops or manure.

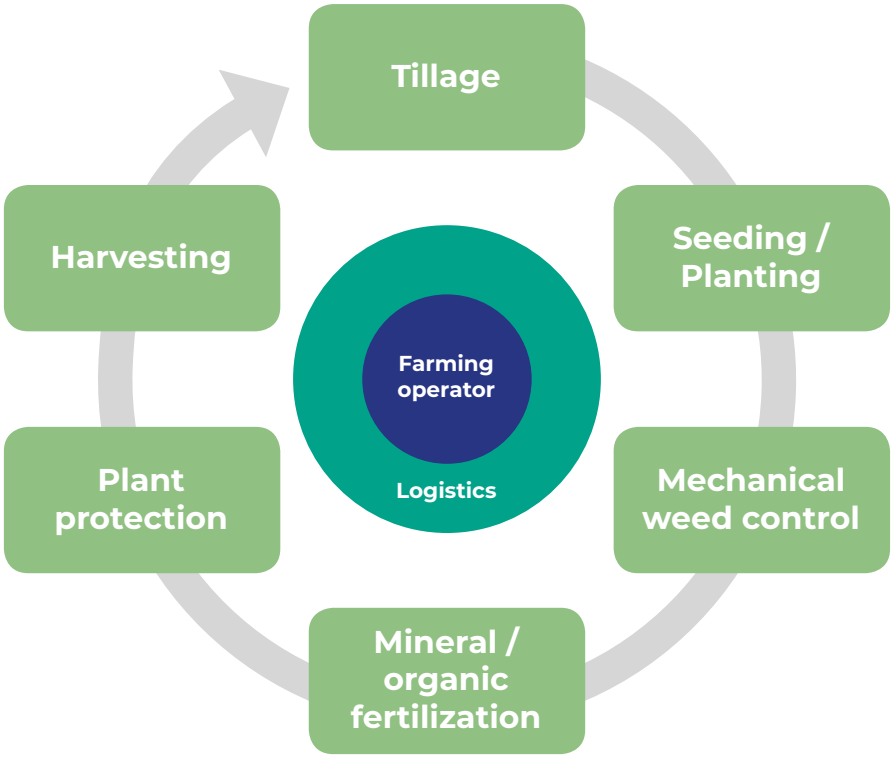

Figure 1: Main work steps of the farm operator during the crop production cycle

The work steps seeding, mechanical weed control, mineral fertilization, and plant protection have high potential to be replaced in the future by autonomous machines or robot swarms. These work steps have the highest potential for increasing efficiency through site-specific applications. Through continuous improvement of the autonomous process flows, the competing factor area performance will be balanced in the future. Especially in row crops (e.g., corn and sugar beets), autonomous approaches already exist, with different robot sizes up to robot swarms.

In the harvesting step, novel approaches are conceivable, such as division into individual work steps. Initially, however, the focus will primarily be on automatic machine optimization during operation.
In summary, the focus will be even more on site-specific applications and work steps around the plant will be increasingly automated due to the potential increase in efficiency achieved through reduced use of resources.

Forecasting the Tractor Market

The study focuses specifically on the global tractor market. On the basis of available tractor sales information as well as projections regarding the development of the tractor market, the development of tractor sales was estimated in decade-splits following technological and structural clusters (see Table 2). The arrows indicate whether the total tractor sales will increase, decrease, or stay flat compared to the previous point in time.

In sum, the conclusion was that the demand for tractors at the global level is expected to increase both in 2025 as well as in 2035, but to remain flat afterwards. This development is mainly driven by the Asian markets, which continue to grow as a whole. A similar picture can be observed in the high-technology large-scale North American market, which is also expected to grow until 2035 but to decrease afterwards. This decrease in demand will set in even earlier in the Western and Eastern European market, which are expefcted to slightly improve until 2025 though. Somewhat surprisingly, the tractor demand in both the low-technology large-scale and the African market is projected to continuously shrink over time.

Development of annual tractor unit sales	Estimated share of global sales (2009-2018)	2025 vs. 10-year average 2009-18	2035 vs. 2025	2045 vs. 2035
High-technology large-scale markets (North America & Australia)	15%	↑	↑	↓
Western European markets	7%	→	↓	↓
Small-scale Asian markets	67%	↑	↑	↑
Low-technology large-scale markets (Latin America)	4%	↓	↓	↓
Eastern European markets	3%	↑	↓	↓
African & Middle East markets	4%	↓	↓	↓
Total global market	100%	↑	↑	→

Table 2: Development of annual tractor sales (in units), own estimation on the basis of historical tractor sales data for the selected countries mentioned above and FAP´s agricultural long-term projections until 2050 based on an empirical model of the Kleffmann Group

Autonomous in 2045?

The study finally focuses on an econometric estimation of how the different types of automation will be distributed in the selected markets. Using the approach of a market- and system-class-specific distribution estimation based on the discussions and agreements of several renowned experts in the field, this study is breaking new ground because to date, projections on the global autonomous agricultural machinery market were always quite vague. Table 3 illustrates the market share of automation types for the year 2045. Whereas in 2035, the classical human-driven machines – either with or without technological assistance – will remain the largest class in all regions, this situation is expected to change in 2045 – mainly in the high-technology, large-scale North American and Western European markets. The majority of agricultural machines in these markets will operate either in supervised mode or entirely autonomously, whereas human-driven tractors and combines will only have a marginal market share. But the exact market share is highly dependent on the laws and legislation in those regions – which will either enable or inhibit the operation of autonomous machines. In terms of automation, the other regions are still expected to lag behind. Although the Latin American and Eastern European markets will also develop in this direction, human-driven machines are still expected to represent a significant market share.

Year 2045	Entirely human driven (no technological assistance)	Assisted human driven (with technological assistance, e.g. GPS)	Supervised autonomous	Entirely autonomous machine
High-technology large-scale markets (North America & Australia)				
Western European markets				
Small-scale Asian markets				
Low-technology large-scale markets (Latin America)				
Eastern European market				
African & Middle East Markets				
Legend				
Market share	> 80%	50 – 80%	10 – 50%	< 10%

Table 3: Market share of automation type for the year 2045, estimation based on interactive expert sessions

What we found out

In sum, the study concludes that (1) entirely human-driven systems will remain similar to the way they are today, but (2) significant changes are expected for the other three classes: Assisted systems will be able to support more complex actions, being equipped with more cameras and more safety features. The class of supervised autonomous machines will evolve with lower demands on supervisor presence and qualification over time, and field- and application-specific autonomous actions will evolve towards more universal actions. The class of entirely autonomous machines will develop from pure demo systems via systems that act autonomously on the field with defined plans once they are there towards systems that receive rough planning via other systems and then act completely autonomously. Regarding the development of the tractor market, it turns out that (3) the demand for tractors will be mainly driven by Asian countries, whereas the uptake of autonomous technology will be led by North America and Western Europe.
All this means that there will be a clear shift towards autonomous agricultural systems in the long run, but the speed at which farmers will adopt autonomous systems will differ substantially between different regions/markets. This is also a result of the different farm and production structures.

The full report can be found on our homepages:

http://s.fhg.de/AutonomousMachinery

https://www.kleffmann.com/de

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