

## Agriculture 4.0 - A state of the art review focused on electric mobility

Agricultura 4.0 - Uma revisão no estado da arte em mobilidade elétrica

Michéle Weisbach<sup>1\*</sup>, Heiko Fechtner<sup>2</sup>, Alexander Popp<sup>3</sup>, Utz Spaeth<sup>4</sup> and Benedikt Schmuelling<sup>5</sup>

**ABSTRACT** - In its endeavor to conserve resources and create a more environmental-friendly agriculture, the 4<sup>th</sup> agricultural revolution now underway needs innovative methods and new technologies to achieve a more sustainable farming industry. In addition to the different methods and applications, subsumed under the term agriculture 4.0, this article focuses on the areas in which the discipline of electric mobility is becoming more and more important. Therefore, the two superordinate categories “family” and “industrial” farming were considered separately to compare technical approaches and solution which are currently in use or conceivable in the future.

**Key words:** Agriculture 4.0. Electric mobility. Smart farming. Family farming. Industrial farming. Sustainability.

**RESUMO** - Em seu esforço para conservar recursos e criar uma agricultura mais ecológica, a 4<sup>a</sup> revolução agrícola em andamento precisa de métodos inovadores e novas tecnologias para alcançar uma indústria agrícola mais sustentável. Além dos diferentes métodos e aplicações, incluídos no termo agricultura 4.0, este artigo enfoca as áreas em que a disciplina da mobilidade elétrica está se tornando cada vez mais importante. Portanto, as duas categorias superordenadas da agricultura “familiar” e “industrial” foram consideradas separadamente para comparar abordagens técnicas e soluções que estão atualmente em uso ou concebíveis no futuro.

**Palavras-chave:** Agricultura 4.0. Mobilidade elétrica. Smart farming. Agricultura familiar. Fazendas industriais. sustentabilidade.

DOI: 10.5935/1806-6690.20200103

Editores do artigo: Professor Daniel Albiero - daniel.albiero@gmail.com e Professor Alek Sandro Dutra - alekdutra@ufc.br

\* Author for Correspondence

Received for publication 22/01/2020; approved on 24/11/2020

<sup>1</sup>Engenheiro, Cadeira de Mobilidade Elétrica e Sistemas de Armazenamento de Energia, Universidade de Wuppertal, Rainer-Gruenter-Str. 21, 42119 Wuppertal, Alemanha, weisbach@uni-wuppertal.de (ORCID ID 0000-0001-5282-8051)

<sup>2</sup>Engenheiro Doutor, Cadeira de Mobilidade Elétrica e Sistemas de Armazenamento de Energia, Universidade de Wuppertal, Rainer-Gruenter-Str. 21, 42119 Wuppertal, Alemanha, fechtner@uni-wuppertal.de (ORCID ID 0000-0002-2132-929X)

<sup>3</sup>Engenheiro Mestre, Cadeira de Mobilidade Elétrica e Sistemas de Armazenamento de Energia, Universidade de Wuppertal, Rainer-Gruenter-Str. 21, 42119 Wuppertal, Alemanha, apopp@uni-wuppertal.de (ORCID ID 0000-0002-9898-9456)

<sup>4</sup>Engenheiro Mestre, Cadeira de Mobilidade Elétrica e Sistemas de Armazenamento de Energia, Universidade de Wuppertal, Rainer-Gruenter-Str. 21, 42119 Wuppertal, Alemanha, uspaeth@uni-wuppertal.de (ORCID ID 0000-0002-4910-5773)

<sup>5</sup>Prof. Ph. D. Engenheiro, Cadeira de Mobilidade Elétrica e Sistemas de Armazenamento de Energia, Universidade de Wuppertal, Rainer-Gruenter-Str. 21, 42119 Wuppertal, Alemanha, schmuelling@uni-wuppertal.de (ORCID ID 0000-0002-1050-5278)

## INTRODUCTION

For more than a century, the global population has been growing rapidly; even minor and major crises in recent history like environmental disasters or worldwide pandemics were not able to stop this trend. Starting with an estimated population of around 300 million in the 1<sup>st</sup> century, a steep increase can be observed since the beginning of the 20<sup>th</sup> century (UNITED NATIONS, 2019). The remarkable growth of the last 150 years is explained by the industrial revolution and all the improvements it brought with it, which made communication, cooperation, and the food production even more efficient.

Besides other fields of application like city planning, traffic infrastructure, or tourism, this article deals with the developments surrounding the current farming revolution often dubbed as agriculture 4.0 and focuses on electric mobility aspects.

To be better equipped for this examination, an overview of the agriculture 4.0 cluster, with its different subtopics is presented to show the sectoral diversity of this field and illustrate that arable farming in the 21<sup>st</sup> century is much more than tractors on fields. This reveals various ways in which electric mobility can find its way into agriculture. To be able to present a differentiated overview which reflects the reality of farming in the modern world, industrial and family agriculture are considered separately regarding their implementation of these new technologies. Finally, a short conclusion and an evaluation of the current developments and research activities concerning electric mobility in the agricultural sector is presented.

## THE 4<sup>th</sup> AGRICULTURAL REVOLUTION

The most important aspects of agriculture 4.0 are summarized and presented in Figure 1 and are shown as an overview. Divided into three different cluster sections, from farming diversity over to increasing food chain efficiency to cross-industry technologies, specific approaches with individual purviews already exist or will be used in the near future (DE CLERCQ *et al.*, 2018).

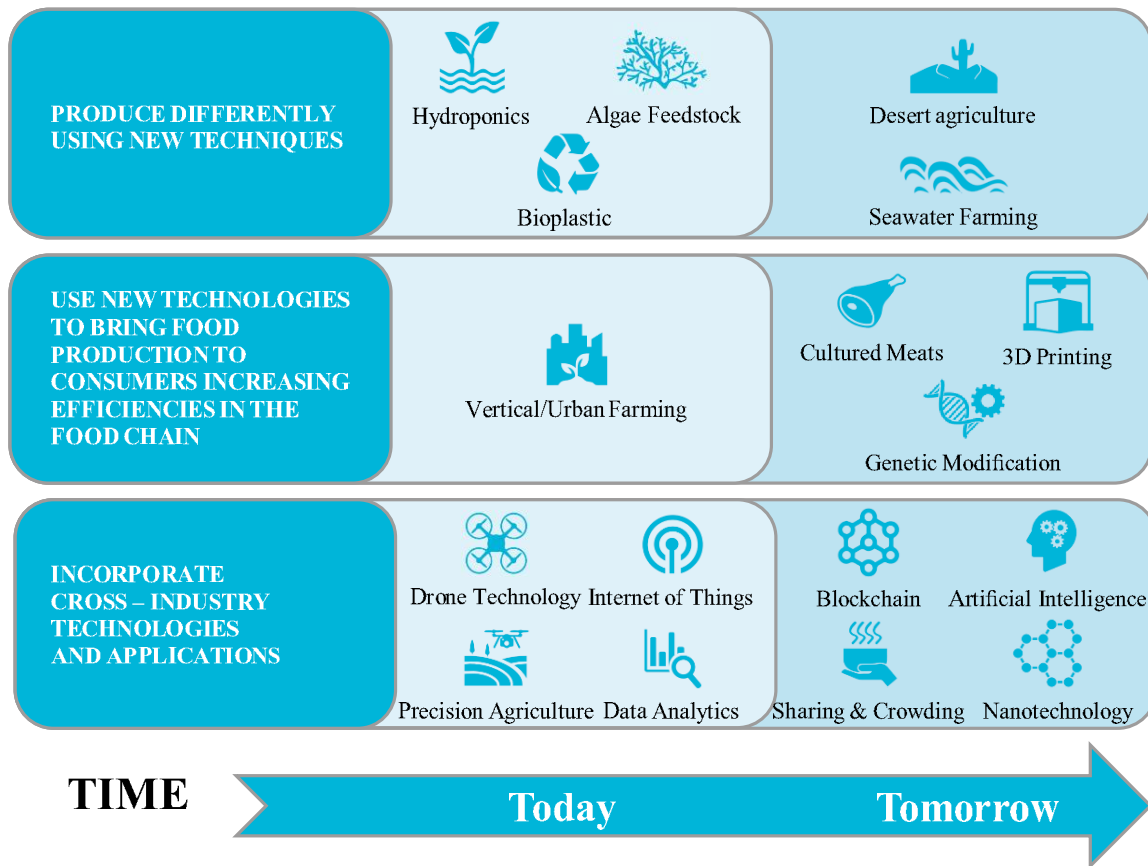
The topics presented in Figure 1 are the result of a long journey that started with humanity's first steps into arable farming thousands of years ago, continued with the early usage of animal power (agriculture 1.0) and mechanical tools (agriculture 2.0) to improve agriculture efficiency until reaching the implementation of monitoring or guidance systems (agriculture 3.0) and the employment of micro-electronics or big data IoT solutions (agriculture 4.0) with the aim of a comprehensive autonomous farming industry (agriculture 5.0) (LIU *et al.*, 2020).

Starting with alternative ways to produce and package food and beverages by using new technologies, hydroponics, algae feedstock, or bioplastics are growing in importance. The first one is a sub-segment of hydroculture, based on the method of growing plants without soil, using mineral nutrient solutions in a water solvent (JENSEN, 1997). A further step in the direction of hydroculture feedstock is the cultivation of algae. With an average cost of around \$500 per metric ton farming algae is a realizable way of producing food for many different regions (DE CLERCQ *et al.*, 2018). However, not only the production but also the packaging is an important issue in the agriculture 4.0 revolution. In response to the maritime pollution by over 250,000 tons of plastic pieces (ERIKSEN *et al.*, 2014), the development of bioplastic has increased significantly in recent years. Even though the idea of a 100% biodegradable packaging material has existed since the end of the 20<sup>th</sup> century, no currently-available product fully meets this requirement (JARIYASAKOOLROJ *et al.*, 2018). Companies like e.g. the startup TIPA Corp Ltd. seek to change this and TIPA® advertises on its website, “[...] we create packaging that behaves just like organic waste, so nature won't even notice we're here.”

(TIPA CORP LTD., 2020), which raises great expectations. While such innovations do harbor great potential, the progressively growing world population means that the competition and scarcity of farmland is becoming more intense. This pushed for the development of agriculture sectors to extend the amount of usable landmass. Desert agriculture and seawater farming might be the answer to the demand for additional agricultural areas by adapting plants to extreme stress conditions using specific microbes (ALSHARIF *et al.*, 2020).

Apart from just using new techniques to implement agriculture, the whole supply chain of food production needs to become more efficient in the future. To achieve this, farming must no longer be the exclusive purview of rural regions, but also be integrated into urban regions. Vertical or urban farming increases the farmable space by using all three dimensions to grow crop plants (AVGOUSTAKI; XYDIS, 2020). Conservatories with vertically stacked layers allow the reduction of water and fertilizer usage and for dispensing with the use of nutritional supplements and pesticides while boosting productivity (DE CLERCQ *et al.*, 2018). While vertical or urban farming is already in use, a look ahead gives an idea of how far removed the future of agriculture could be from the more primitive and arduous manual labor of a thousand years ago. Some of the new technologies presented in Figure 1, like cultured meat (laboratory meat grown in-vitro, (BRYANT; BARNETT, 2018), genetic modification (genome editing to reduce natural weaknesses, (ANZALONE *et al.*, 2020) or 3D food printing (by the usage of microalgae, natural source of

Figure 1 - Agriculture 4.0 - Cluster Overview



Source: Own representation based on (De Clercq, Vats, & Biel, 2018)

protein, carbohydrates, pigments, or antioxidants, (OTCU *et al.*, 2019), are on the threshold of market maturity.

Despite the promising benefits, many critical voices regarding these artificial agriculture technologies are becoming louder and louder. With the aim to continue to use the natural process of plant and animal growing but still increase productivity and reduce costs, cross-industry technologies are being introduced into the agriculture sector. Even today, several applications like big data analytics, IoT (Internet of Things) gadgets, or drone technologies, which are also applied in other industries, are used to improve the farming productivity. Taking a closer look at the use of drones, currently in use for e.g. crop monitoring (e.g. identifying production inefficiencies), soil and field analysis (e.g. planning seed planting), irrigation (dehydration analysis), etc., a first example for electric mobility in agriculture is revealed (MOTTELEONE; ALVES DE MORAES, 2019). The autonomous flying machines are generally battery powered, comparative quiet, equipped with a variety of sensors, and still very

lightweight, which allows an environmentally sustainable, cost-efficient and much more productive cultivation. In this regard, IoT-based D2D-communication (device to device) and big data analytics (ISLAM; DEY, 2019) are necessary to enable the desired autonomy. Moreover, future agriculture systems may also use distributed ledger technologies, like blockchain, to reduce inefficiencies and fraud and improve food safety, farmer pay, and transaction times. Another promising field is that of nanotechnologies which can use nanoparticles delivered to plants and advanced biosensors for precision farming.

## AGRICULTURE AND THE USAGE OF ELECTRIC VEHICLES

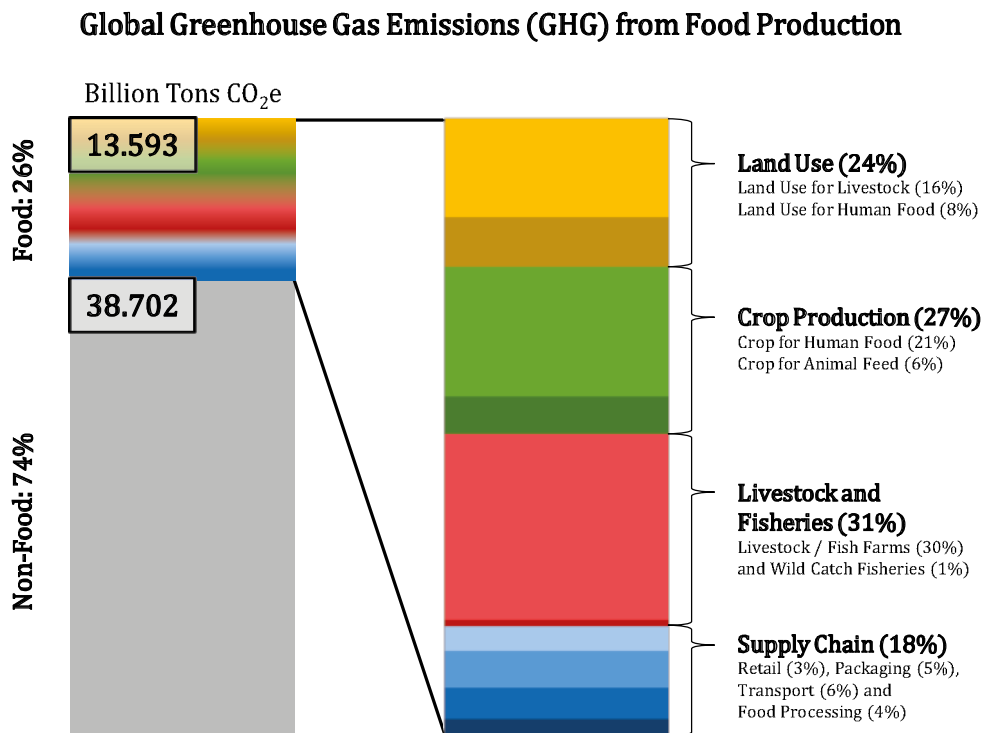
The environmental impact of agriculture, land use and food production to feed over 7.7 billion people (as of mid-2019) (DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS OF THE UNITED NATIONS, 2019)

is far from negligible and especially considering the forecasted population growth. The “World Population Prospect” (DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS OF THE UNITED NATIONS, 2019) of the United Nations (UN) predicts a global population of 8.5 billion in 2030, 9.7 in 2050, and 10.9 billion in 2100. This makes a sustainable and climate-friendly strategy for agriculture sector more and more important to reduce or mitigate effects caused by climate change (e.g. growing number of wildfires, ice melting in the arctic). Climate change also creates challenges for farmers, like increasing temperatures as well as periods of drought, which effect e.g. crop yields (McELDOWNEY, 2020). On the way in which climate change may impact agriculture depends e.g. on regional circumstances. In this context, the Joint Research Centre (JRC) of the European Commission summarized in its final report on climate impact (JOINT RESEARCH CENTRE, 2018) that particularly the countries in the south of Europe will suffer more droughts in the future, making the irrigation of the fields more difficult. Moreover, assuming a 2 °C warming scenario, the JRC predicts a reduction of 20% for irrigated crop yields in Europe (JOINT RESEARCH CENTRE, 2018). This underscores that farmers should have a self-interest in using sustainable technologies.

Poore and Nemecek (2018) emphasize that 26% of the anthropogenic greenhouse gas (GHG) emissions are caused by food production. The global share of food-production-based GHG emissions is presented in Figure 2. An additional 5% of the GHG emissions result from non-food agriculture (POORE; NEMECEK, 2018). Worldwide agriculture activities have a share of 10-14% of the global GHG emission (JANTKE *et al.*, 2020). The majority of these emissions are caused by enteric fermentation, forestry and land-use change, manure, on-farm energy consumption as well as agricultural vehicles (AHMED *et al.*, 2020). This data underlines the importance of a sustainable climate-protection approach.

In 2017, a survey (JANTKE *et al.*, 2020) has been conducted with 254 German farmers participating to identify and evaluate e.g. the interviewees personal attitude regarding GHG emissions caused by agriculture and GHG reduction potential. Over half of the farmers (54.3%) stated that climate change is the greatest threat to agriculture. On the one hand, 44.5% of the interviewees also emphasized that the GHG emissions can be reduced (JANTKE *et al.*, 2020). On the other hand, 37.4% of the farmers see activities for GHG emission reduction to be an economic risk. A different point of view claims that agriculture is essential for food supply as well for food

**Figure 2 - Global Share of Greenhouse Gas Emissions (GHG) from Food Production**



Source: Own representation based on (Poore; Nemecek, 2018)

security and should therefore not be considered for climate protection (ROSIN, 2013). These aspects and different opinions must be considered when changing from conventional agriculture to climate-friendly agriculture.

The implementation of climate-protection measures poses a number of challenges for farmers, like the above-mentioned technical and economic risks as well as restrictions by law. For example, in some countries and regions (like in Sub-Saharan Africa), agriculture has a large share in the gross domestic product (THE WORLD BANK, 2020). Hence, governments are afraid to introduce climate-protection laws because they expect economical disadvantages compared to other countries that implement less or no climate protection measures (WREFORD *et al.*, 2017).

While the use of electric vehicles (EVs) instead of conventional vehicles can be a promising approach to reduce GHG emission from agriculture activities, EVs are faced with prejudices like low range or long charging times, which deter potential buyers from giving these vehicles a chance. For a successful integration of EVs for agriculture work, the advantages of using EVs must be highlighted by policymakers to dispel farmers' fear and concerns. The willingness to make the switch to EVs depends, among other things, on the individual's experience in dealing with EVs. Riedner *et al.* (2019) conducted a survey with 334 farmers which revealed a correlation between satisfaction and experience with EVs. The satisfaction of the interviewed farmers increased with their experience with EVs. In view of this finding, the authors recommend pilot projects to give farmers the opportunity to test EVs (RIEDNER *et al.*, 2019).

The combination of EVs for agricultural work with renewable energy sources to supply these EVs, increases the climate protection potential of the agriculture sector significantly (FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY, 2018). Added to this potential is the interest expressed by farmers in self-sufficient power (RIEDNER *et al.*, 2019). Therefore, one goal of the project presented in the upcoming chapter A) Electric Mobility at Family Farms is the realization of an electric-powered tractor combined with a self-sufficient energy supply network in Brazil with a focus on family farming. Based on an analysis by McKinse (AHMED *et al.*, 2020), the adoption of zero-emissions technologies for farm machinery and equipment has the greatest potential of all 25 analyzed measures (AHMED *et al.*, 2020). An emission reduction of approximately 537 MtCOE by 2050 is feasible by shifting from conventional technologies (e.g. combustion engine) to zero-emission vehicles or machines (e.g. EVs powered by renewable energies). One of the major obstacles to buying an electric tractor are the purchasing costs and the lifetime

of the conventional tractors. Following a survey carried out by Caban *et al.* (2018), the authors summarized that 75% of the interviewed farmers have no interest in buying an electric tractor. The reason cited most often was the investment in traditional machines in the last years, with conventional tractors usually used for over 20 years (AHMED *et al.*, 2020). A policy that supports the purchase of zero-emission tractors may speed up the sales number of zero-emission tractors. A further potential approach is e.g. the support of academic or industrial research projects as well as the foundation of start-ups to develop promising solutions for a sustainable agriculture, and future legislation needs to consider these (STROUD *et al.*, 2018). Beside the emission reduction potential of EVs, there are some further advantages to their use for tasks in agriculture like a precise control compared to conventional tractors, which makes a more productive farming possible (GHOBADPOUR *et al.*, 2019), as well as lower maintenance costs and fewer moving components (QUALMAN, 2019).

Many countries and regions have already introduced regulations intended to combat climate change. For example, the EU aims to become climate-neutral by 2050 (McELDOWNEY, 2020) for which purpose it has elaborated the "European Green Deal" (EUROPEAN COMMISSION, 2019), which considers, among other things, measures for agriculture and transportation. Nevertheless, a growing spread of EVs for agriculture work in the near future can only be achieved by laws and regulations incentivizing farmers to invest in sustainable technologies.

## ELECTRIC MOBILITY IN A BIPARTITE AGRICULTURE SECTOR

Before the integration of electric mobility in the context of agriculture 4.0 can be addressed, a distinction must be made between family and industrial farming. For this purpose, the first step is to create a comprehensive definition of the two terms.

The interchangeable terms family farm and smallholding are often used without a clear distinction or definition, hence there is no existing statistical measurement reflecting the term. This results in an estimate of at least 500 million family farms, accounting for nearly 85% of the world's food production while holding 53% to 75% of all agricultural land out of 570 million farms worldwide, as depicted in Figure 3 (GRAUEB *et al.*, 2016; Food and AGRICULTURE ORGANIZATION OR THE UNITED NATIONS, 2014). Family farming can be seen as one of the fastest-growing segments of food production, providing food security while ensuring

sustainability and socio-environmental responsibility (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2017).

Additionally, smallholding is a complementary activity to large-scale farming and is extremely important in developing countries. In these regions, smallholding leads to the creation of jobs in rural areas and an increase in family income also reducing social inequalities and poverty (SIMA; GUERRA, 2019). Given this context, national authorities take a leading role by juggling food production between large producers and smallholders (SHETE; RUTTEN, 2015).

One popular definition of family farming reads as follows: “Family Farming (which includes all family-based agricultural activities) is a means of organizing agricultural, forestry, fisheries, pastoral and aquaculture production which is managed and operated by a family and predominantly reliant in family and labor, including both women’s and men’s. The family and farm are linked, co-evolve and combine economic, environmental, social and cultural functions.” – definition of the Food and Agriculture Organization of the United Nations (FAO) given as an outline for the international year of family farming (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2014). Another, but more context-based definition is provided by the High Level Panel of Experts on Food Security and Nutrition (HLPE, 2013). While both definitions exhibit a socio-economic point of view, organizations such as The World Bank focus on more quantifiable features (THE INTERNATIONAL BANK FOR RECONSTRUCTION

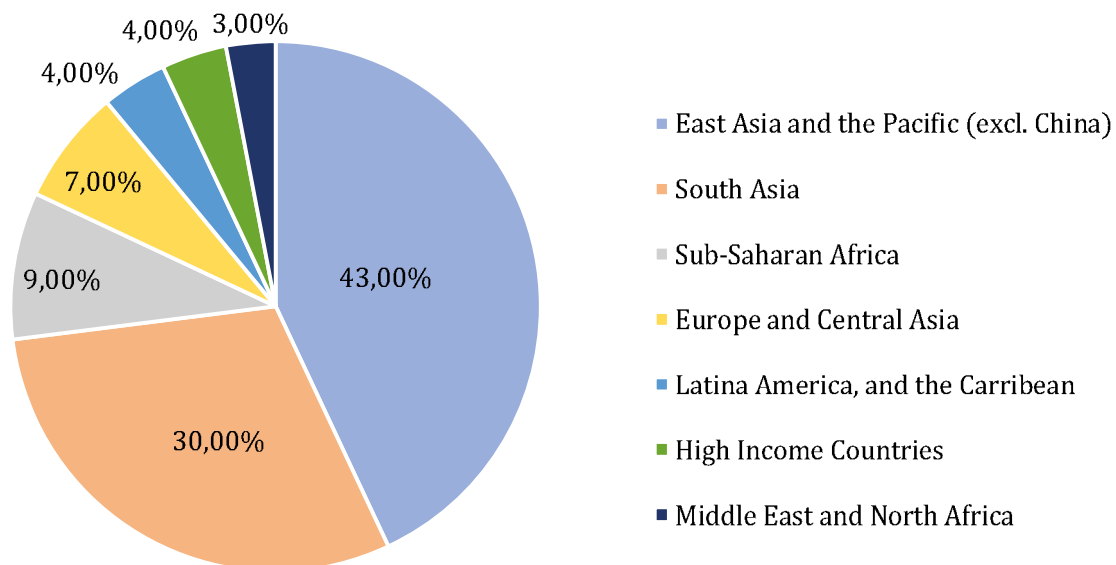
AND DEVELOPMENT/THE WORLD BANK, 2003). According to this approach, a family farm has up to two hectares of cropland. Despite those generalizing definitions, the specialized meeting on family farming (REAF) of the southern common market (MERCOSUR) conceived a more specific definition in its Resolution No. 25/07, resulting in specific criteria for different countries partially included in the following Table 1 (MÁRQUEZ; RAMOS, 2012; OLIVEIRA *et al.*, 2020; BERCHIN *et al.*, 2019).

The lack of a clear definition besides the regional diversity of the agricultural sector in different countries requires varying approaches for different regions, which result in different policies.

Following the international year of family farming (IYFF) in 2014, declared by the international organization, the United Nations Decade of Family Farming (UNDF) aims to achieve the seventeen Sustainable Development Goals (SDG) (United Nations Organization, 2015). Goal number two of the SGD is to end hunger by utilizing family farms, by doubling the agricultural productivity and income. In context of this article, goal number 7.1 “*access to affordable, reliable and modern energy services*” could be supported by electric vehicles combined with bidirectional charging.

Due to the plethora of different influencing factors, arriving at a clear definition of industrial farming is even more difficult. The entities referred to in this article as industrial farms are those agricultural organizations which do not fulfil any of the conditions from Table 1.

**Figure 3 - Worldwide Share of Family Farms**



Source: Own representation based on (Food and Agriculture Organization of the United Nations, 2017)

**Table 1** - Family Farming Criteria for South American Countries

Parameter	Countries				
	Argentina	Brazil	Chile	Paraguay	Uruguay
Permanent Employees (non-family)	<= 2	<= 2	N/S	N/S	<= 2 or 500 days wage
Maximum distance between residence and farm	On-farm or nearby site (no specifications on distance)	On-farm or nearby site (no specifications on distance)	N/S	On-farm or nearby site (no specifications on distance)	On-farm or nearby site (at a distance of ≤ 50 km.)
Maximum size of farm	500 ha	4 fiscal modules (ranging from 20 ha to 440 ha)	12 BRU (may reach up to 750 ha in total)	50 ha	500 ha to 1000 ha
Source of farm in-come/earnings	> 50% derived from on-farm activities)	≥ 70% derived from on-farm activities	> 50% derived from on-farm activities (no cap)	> 50% derived from on-farm activities (no cap)	> 50% derived from on-farm activities (no cap)

Source: Own representation based on (Márquez & Ramos, 2012; de Oliveira, et al., 2020; Berchin, Nunes, de Amorim, Zimmer, da Silva, & Haendchen Fornasari, 2019)

The presented electric mobility solutions (e.g. ideas, research projects, prototypes, or market-ready products) are assessed with regard to their suitability for use in the respective sectors.

## A) ELECTRIC MOBILITY AT FAMILY FARMS

The development of technologies transferable to small farms (e.g. family farms in developing countries) is of great significance considering the large share of small-scale farms in the total number of farms worldwide. Ahmed *et al.* (2020) emphasize that three-quarters of all global farms are smaller than three soccer fields. Thus, the focus on the following pages will be on the presentation of projects for small-scale farming and family farming.

The importance of family farming has been underlined by the IYFF in 2014 (INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT, 2014) discussed above. The goal of the United Nations (UN) was to highlight the great influence of family farming on global food security and e.g. to develop a legal framework for sustainable family farming (INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT, 2014). In 2016, 95.2% of the 10.5 million European farms were family farms (EUROSTAT, 2019). The greatest number of family farms in the EU were located in Romania (3.4 million), Poland (1.4 million), and Italy (1.1 million) (EUROSTAT, 2019). In the United States, the share of family farms in the total number of farms

in 2018 was approximately 90% (UNITED STATES DEPARTMENT OF AGRICULTURE, 2019). 80% of the world's food supply is produced by family farms (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2018). Thus, family farms make a major contribution for food security, which is of vital importance for the growing global population and the vast number of famine-stricken people (821 million) (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2018).

The FAO funds and promotes initiatives and programs worldwide. As an example, the FAO cooperates with the government of Brazil in promoting dialogue and experience sharing in Africa on public policies targeting Africa's Community of Portuguese Speaking Countries (CPLP). The goal is to characterize family farming to frame national agricultural policies resulting in access for farmers to agricultural inputs, agrarian extension services, credit and other resources. In addition, Mozambique has partnered with Brazil in establishing a national land registry system for family farmers. Taking similar approach, other countries in Central America are establishing national strategies for identifying and registering family farmers. Furthermore, the FAO tries to establish a farmers' registry for Near East and North Africa using a comparable approach (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2017). In addition to a more precise definition of who is considered as a family farmer, another objective is the access to suitable technology; one example of this can be the use of internet-enabled cell phones in combination with apps and other tools. With suitable



technology, farmers have access to more data and are enabled to make better decisions based on the available data (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2017).

In an effort to optimize agricultural processes, universities (e.g. (MELO *et al.*, 2019; TRONCON; ALBERTI, 2020) and industrial companies (e.g. John Deere, Fendt (VOGT *et al.*, 2018) are constantly inventing and developing new technologies for farming, like autonomous tractors or zero-emission tractors. These technologies are mainly designed for large-scale farming and are not intended for smaller farms, for example, because the tractors are too cost-expensive or the drive system is too big for smaller applications (MELO *et al.*, 2019). Therefore, reliable but affordable electric tractors could be a solution for family farms. A promising project that can fulfil this expectation is presented in the upcoming section.

To enable even family farmers to use electric mobility applications, the feasibility of an independent and cross-family farming system is to be developed in a research cooperation between the two Brazilian universities UNICAMP (Universidade Estadual de Campinas) and UFC (Universidade Federal do Ceará) and the German University BUW (Bergische Universität Wuppertal). The entire system will be comprised of three main units (Figure 4). The energy supply unit will essentially consist of photovoltaic modules and batteries intended as a buffer. In case of a trailer-based energy distribution, which is one of the imaginable operating modes, the buffer stacks work as a replacement station for empty vehicle batteries. Another way to deliver electric energy over long distances

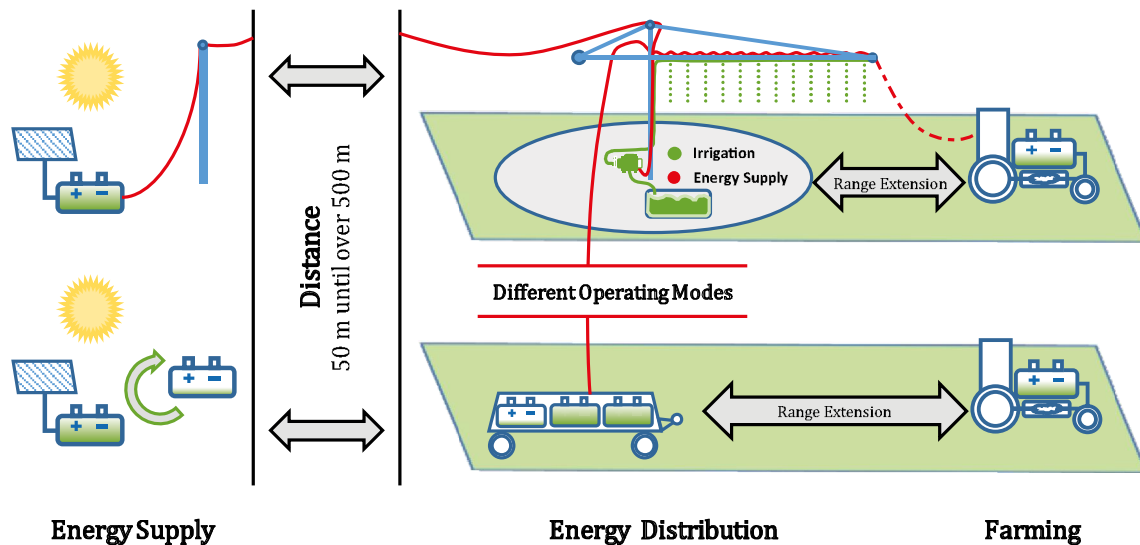
to the area of operation is a cable system, based on a pivot arm that can also be used for additional applications, like irrigation. In some scenarios, it might be useful to connect the battery trailer directly to the cable system. Regardless of the form of energy supply, the mobile part of this farming system is the small-scale electric tractor, which can operate by traction batteries, or a cable-based energy supply. This enables the flexible use of the vehicle, also by several family farms in mutual agreement (VOGT *et al.*, 2018).

One case study presented by Troncon and Alberti (2020) focuses on the electrification of a traditional tractor for vineyards and orchards powered by a 74 kW (99.2 HP) internal combustion engine (ICE). Instead of this ICE, a 100 kW (134.1 HP) hybrid system with a downsized ICE and an electric motor was designed using finite element simulations. The presented results can be a further inspiration for the development of electric drive systems for family-farming applications.

With the aim of improving the climate-friendly management of orchards, the Nelson Mandela University (South Africa) has designed an electrical tractor powered by a 35 kW (46.9 HP) electric motor (STROUD *et al.*, 2018). The tractor has a loading capacity of 1,000 kg and a potential operation time of 5 to 6 hours until the vehicle needs to be charged. The costs for the electrical orchard tractor are between \$25,000 and \$30,000. The Nelson Mandela University recommends the introduction of creative vendor financing schemes to reduce the purchasing costs.

As already mentioned before, the combination of renewable energy sources and electrically-powered

**Figure 4 - Schematic Visualization of the Cross-Family Farming System**



Source: Own representation



tractors can bolster the positive effect of electric tractors on combatting climate change. In an Iranian research project (MOUSAZADEH *et al.*, 2011) a life-cycle assessment was carried out for a solar-assisted plug-in hybrid electric tractor (SAPHT). The comparative analysis between the SAPHT and a diesel-powered tractor (John Deere 3320) shows that there is a great emission reduction potential. In addition, the total cost of the SAPHT over the expected lifetime is significantly lower compared to the conventional tractor. The designed tractor has a power of 12 kW (16 HP) and is thus more suitable for small-scale or family farming.

The presented research projects show different technical solutions for family farming. Despite the immense potential here, most development activities take place in the context of industrial agriculture as well as in the design of tractors for heavy-duty application. More information with regard to industrial agriculture is presented in the next chapter.

Hence, it is recommended to introduce more funding programs for family farming. In addition to direct funding, there is the possibility of an improvement in productivity of smallholding through research specifically aligned with the needs of family farms, like machinery for field operation, food processing and other operations directed towards the value chain (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2014).

## B) ELECTRIC MOBILITY AT INDUSTRIAL FARMS

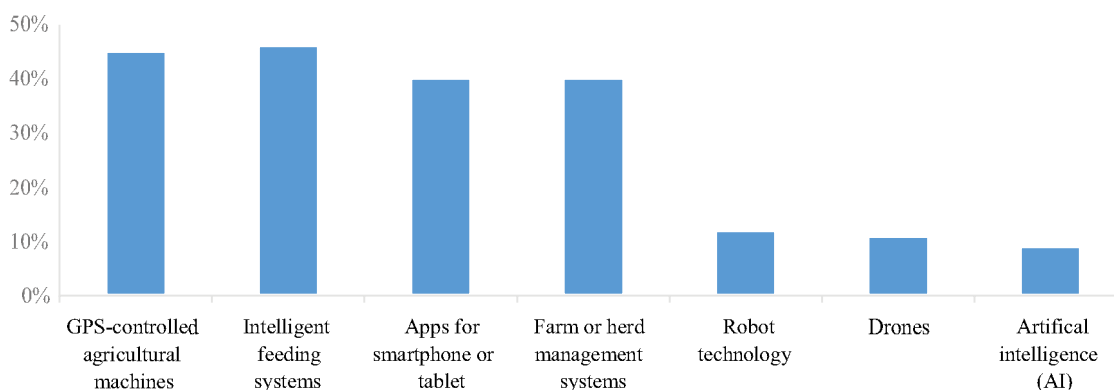
The agricultural sector is expanding its pioneering role in the field of digitization. More than 80% of the

agricultural enterprises already rely on “smart farming” approaches for different sectors like arable farming and livestock breeding. More details about the specific digital technologies used and their market shares can be taken from Bitkom (2020). GPS-controlled machines, intelligent feeding systems, apps for smartphones or tablets and farm or herd management systems are used by more than 40% of the farmers and can therefore be assumed as state of the art technologies. In contrast, drones, robotics, and artificial intelligence (AI) are only used by a mere 10% and can thus still be regarded as a future technology (BITKOM, 2020).

The combined use of the above-mentioned technologies for the optimization of precision agriculture goes by many names, one of these is the already-mentioned smart farming, and others are digital farming or agriculture 4.0. The basic principle is to use data collection and processing to enable automated strategical and operational decision-making instead of the farmer physically going to the fields, checking the status of the crop, and making decisions based on their own experiences. Unmanned operations and autonomous decision-making support systems enabled by the use of robotics and AI are the main steps still required for the transition to agriculture 5.0 (SAIZ-RUBIO; ROVIRA-MÁS, 2020). It should be noted in regard to agriculture 4.0 and 5.0 that Bosch has recently launched NEVONEX, a manufacturer-independent system for smart, digital agriculture. But even if such fully autonomous systems seem to be very promising, it is clear that the high acquisition costs due to the current development status are a significant entry barrier for smaller farms (ROBERT BOSCH GMBH, 2020)

Whereas most tractors are still powered by combustion engines, but electric mobility in agriculture can be observed in the air above the fields in the form

**Figure 5 - Digital Technologies used by Agricultural Enterprises**



Source: Own representation based on (Bitkom e.V., 2020)

of unmanned aerial vehicles (UAVs), better known as drones. These drones are used for many different tasks with solely information gathering character, like soil and field analysis over to crop-monitoring to irrigation control but also for more active use cases like crop spraying or aerial planting. The key limiting factor for the, at least for the time being, niche use of drones despite the significant potential is, as always, the difficult financial situation of many farms. Of course, this barrier is smaller for large industrial farms where increasing usage is expected and contracting forms for drone services may grant access to the benefits of these services even to small family farms (EUROPEAN COMMISSION, 2018).

Electric tractors have not yet found common in agriculture, but the number of available models and manufacturers is growing, and more and more farms are at least testing the integration of such models into their operations. Increasing pressure in forms of environmental requirements becoming stricter promise to further accelerate the transition from fossil fuels to full or at least hybrid electric drive systems. Their advantages are evident and include, emissions-free operation fulfilling local regulations and less vibration and noise to allow usage at night and in residential areas. Of course, the overall higher efficiency and the longer service life and lower maintenance costs of electrically operated machines must also be mentioned. Besides the higher acquisition cost, another reason for the rare use of electric tractors is their short travel range because of their batteries. Improvements in cell technology alone probably cannot overcome this limitation. More likely, with the integration of AI and the aim of determining perfectly balanced duty and rest cycles for the machines and maybe battery changing stations or wired power supply could help achieve the goal of a fully electrified agriculture fleet with high efficiency and minimum downtimes (CABAN *et al.*, 2018).

A pilot project seeking to do precisely that, called GridCON, is already underway. The main innovation in the project is a fully electrified tractor with 290 kW (400 HP) supplied by cables to allow for a high continuous power output of more than 1 MW without downtimes. The fully electric tractor is combined with a semi-stationary battery system to reduce, or at least ensure a consistent load on the power grid. This system also facilitates the integration of renewable energy generation systems. The project summarizes the benefits and proves the basic feasibility of fully-electric tractors. Semi-electric tractors are already being produced by the project partner John Deere (TARASINSKI *et al.*, 2018).

Another noteworthy, yet more futuristic project currently being developed for future agriculture is swarm robotics. Simply put and as the projects name suggests,

an army of small robots swarms around the field and, at a later stage fully autonomously, takes care of the full process of ploughing, seeding, irrigation, fertilizing and harvesting (ANIL *et al.*, 2015).

## CONCLUSION

1. This article attempted to clarify how the field of electric mobility has already found its way into the agriculture 4.0 revolution currently changing the agricultural landscape. For this purpose, a short overview of different subsections was presented and followed by a conclusive analysis of the necessity of electric mobility in the agricultural industry. After a qualitative distinction between family and industrial farming, different examples for innovative technologies, focused on electric mobility, were given and assigned to the respective subsections;
2. In principle, it is evident that many approaches to integrate new technologies into the agricultural sector are designed for the use on larger farms. Most of the presented prototypes or products are not suitable for family farming, or suitable only to a limited extent due to the expected higher acquisition costs and the required minimum size of the cultivated area. Although there are also research projects with a clear objective of addressing especially smaller farms, these purposes are often confronted with the problems of long-term financing. Considering the share of family farming in the global food chain, as presented in the beginning of this article, a stronger focus should be set on such research projects, especially with the aim of cross-family farming concepts. By realigning the focus of research, the development of both branches can be put on equal footing, thereby paving the way for a geared, intelligent, and autonomous agriculture 5.0.

## REFERENCES

- AHMED, J. *et al.*, 2020. Agriculture and climate change: Reducing emissions through improved farming practices, McKinsey&Company.
- ALSHARIF, W.; SAAD, M. M.; HIRT, H., 2020. Desert Microbes for Boosting Sustainable Agriculture in Extreme Environments.
- ANIL, H., NIKHIL, K. S., CHAITRA, V.; GURU SHARAN, B. S. 2015. Revolutionizing Farming Using Swarm Robotics. Kuala Lumpur.
- ANZALONE, A., KOBLAN, L.; LIU, D. 2020. Genome editing with CRISPR-Cas nucleases, base editors, transposases and prime editors.

- AVGOUSTAKI, D. D.; XYDIS, G. 2020. Indoor Vertical Farming in the Urban Nexus Context: Business Growth and Resource Savings.
- BERCHIN, I. I. *et al.*, 2019. The contributions of public policies for strengthening family farming and increasing food security: The case of Brazil. **Land Use Policy**, Issue 82, p. 573-584.
- BITKOM, V. 2020. Digitalisierung in der Landwirtschaft.
- BRYANT, C.; BARNETT, J. 2018. Consumer acceptance of cultured meat: A systematic review.
- CABAN, J. *et al.*, 2018. Analysis of the market of electric tractors in agricultural production. MATEC Web of Conferences.
- DE CLERCQ, M., vats, A.; BIEL, A. 2018. Agriculture 4.0: The Future of Farming Technology.
- OLIVEIRA, A. L. *et al.*, 2020. Revisiting the concept of “fiscal modules”: implications for restoration and conservation programs in Brazil. *Land Use Policy*.
- DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS OF THE UNITED NATIONS, 2019. World Population Prospects 2019, New York, USA: United Nations.
- ERIKSEN, M., LEBRETON, L. C. M.; CARSON, H. S., 2014. Plastic Pollution in the World’s Oceans.
- EUROPEAN COMMISSION, 2019. The European Green Deal, Brussels, Belgium: European Union.
- EUROPEAN COMMISSION, 2018. Digital Transformation Monitor - Drones in agriculture.
- EUROPEAN PARLIAMENTARY RESEARCH SERVICE, 2020. EU agricultural policy and climate change, European Union.
- EUROSTAT, 2019. Agriculture statistics - family farming in the EU. [Online] Available at: [https://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture\\_statistics\\_-\\_family\\_farming\\_in\\_the\\_EU#Structural\\_profile\\_of\\_farms\\_-\\_analysis\\_for\\_the\\_EU](https://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_statistics_-_family_farming_in_the_EU#Structural_profile_of_farms_-_analysis_for_the_EU) [Accessed 28 October 2020].
- FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY, 2018. ICT for Electric Mobility III, Berlin, Germany.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2014. International Year of Family Farming 2014 - Master Plan. [Online] Available at: [http://www.fao.org/fileadmin/user\\_upload/iyff/docs/Final\\_Master\\_Plan\\_IYFF\\_2014\\_30-05.pdf](http://www.fao.org/fileadmin/user_upload/iyff/docs/Final_Master_Plan_IYFF_2014_30-05.pdf). [Accessed 27 October 2020].
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2014. The State of Food and Agriculture 2014: Innovation in family farming. Rome.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2017. Information and Communication Technology (ICT) in Agriculture, A Report to the G20 Agricultural Deputies.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2018. FAO’s Work on Family Farming: Preparing for the Decade of Family Farming (2019-2028) to achieve the SDGs.
- GHOBADPOUR, A. *et al.*, 2019. State of the art of autonomous agricultural off-road vehicles driven by renewable energy systems. *Energy Procedia*.
- GRAUEB, B. E. *et al.*, 2016. The State of Family Farms in the World. *World Development*.
- HLPE, 2013. Investing in smallholder agriculture for food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.
- INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT, 2014. The International Year of Family Farming: IFAD’s Commitment and Call for Action, Rome, Italy.
- ISLAM, M. S.; DEY, G. K., 2019. Precision Agriculture: Renewable Energy Based Smart Crop Field Monitoring and Management System Using WSN via IoT.
- JANTKE, K. *et al.*, 2020. Agricultural Greenhouse Gas Emissions: Knowledge and Positions of German Farmers. *MDPI Land*.
- JARIYASAKOOLROJ, P.; LEELAPHIWAT, P.; HARNKARNSUJARIT, N. 2018. Advances in research and development of bioplastic for food packaging.
- JENSEN, M. H. 1997. Hydroponics.
- JOINT RESEARCH CENTRE, 2018. Climate impacts in Europe: Final report of the JRC PESETA III project, European Union.
- LIU, Y.; MA, X.; SHU, L.; HANCKE, G. P. 2020. From Industry 4.0 to Agriculture 4.0: - Current Status, Enabling Technologies, and Research Challenges.
- MÁRQUEZ, S.; RAMOS, Á. 2012. Differential Policies for Family Farming in MERCOSUR, Contribution of Political Dialogue in the Design of Public Policies and Institutionalization. [Online] Available at: [http://fidamercosur.org/claeh/images/BIBLIOTECA/FaseIII\\_2012/DocumentosFaseIII\\_2012/Paper\\_Differential%20Policies%20for%20Family%20Farming%20in%20MERCOSUR.pdf](http://fidamercosur.org/claeh/images/BIBLIOTECA/FaseIII_2012/DocumentosFaseIII_2012/Paper_Differential%20Policies%20for%20Family%20Farming%20in%20MERCOSUR.pdf) [Accessed 27 October 2020].
- MELO, R. R.; ANTUNES, F. L. M.; DAHER, S.; VOGT, H. H.; ALBIERO, D.; TOFOLI, F. L. 2019. Conception of an electric propulsion system for a 9 kW electric tractor suitable for family farming. *IET Electric Power Applications*, Monaco.
- MONTELEONE, S.; ALVES, E. M. 2019. Analysis of the variables that affect the intention to adopt Precision Agriculture for smart water management in Agriculture 4.0 context.
- MOUSAZADEH, H. *et al.*, 2011. Life-cycle assessment of a Solar Assist Plug-in Hybrid electric Tractor (SAPHT) in comparison with a conventional tractor. *Energy Conversion and Management*.

- OTCU, G. B., RAMUNDO, L.; TERZI, S. 2019. State of the Art of Sustainability in 3D Food Printing.
- POORE, J.; NEMECEK, T. 2018. Reducing food's environmental impacts through producers and consumers.
- QUALMAN, D. 2019. Tackling the Farm Crisis and the Climate Crisis: A Transformative Strategy for Canadian Farms and Food Systems, discussion document, Saskatoon, Canada: National Farmers Union.
- RIEDNER, L. *et al.*, 2019. E-mobility in agriculture: differences in perception between experienced and non-experienced electric vehicle users. *Clean Technologies and Environmental Policy*.
- ROBERT BOSCH GMBH, 2020. Nevonex. [Online] Available at: <https://www.nevonex.com/> [Accessed 29 October 2020].
- ROSIN, C., 2013. *Journal of Rural Studies*.
- SAIZ-RUBIO, V.; ROVIRA-MÁS, F. 2020. From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management. *MDPI Agronomy*.
- SHETE, M.; RUTTEN, M. 2015. Impacts of large-scale farming on local communities' food security and income levels - Empirical evidence from Oromia Region, Ethiopia. *Land Use Policy*.
- SIMA, M.; GUERRA, J. B. S. O. A. 2019. The contributions of public policies for strengthening family farming and increasing food security: The case of Brazil. *Land Use Policy*.
- STROUD, T. *et al.*, 2018. Farm Torque: electric orchard tractors, South Africa: World Wide Fund for Nature.
- TARASINSKI, N.; KEGEL, V.; DAUBERMANN, J., 2018. GridCON - Development and Testing of a Cable-fed, Full Electric and Autonomous Agricultural Machine. Leinfelden-Echterdingen, VDI Verlag GmbH.
- THE INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT/THE WORLD BANK, 2003. Reaching The Rural Poor, A Renewed Strategy For Rural Development.
- THE WORLD BANK, 2020. Agriculture, forestry, and fishing, value added (% of GDP). [Online] Available at: [https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?end=2019&most\\_recent\\_value\\_desc=true&start=2019&type=shaded&view=map&year=2019](https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?end=2019&most_recent_value_desc=true&start=2019&type=shaded&view=map&year=2019) [Accessed 28 October 2020].
- TIPA Corp Ltd., 2020. Overview. [Online] Available at: <https://tipa-corp.com/about/overview/> [Accessed 29 October 2020].
- TRONCON, D.; ALBERTI, L. 2020. Case of Study of the Electrification of a Tractor: Electric Motor Performance Requirements and Design. *MDPI Energies*.
- UNITED NATIONS ORGANIZATION, 2015. Transforming Our World: The 2030 Agenda For Sustainable Development.
- UNITED NATIONS, 2019. World Population Prospects 2019 - Methodology of the United Nations population estimates and projections.
- UNITED STATES DEPARTMENT OF AGRICULTURE, 2019. Most farms are small, but most production is on large farms. [Online] Available at: <https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=58288> [Accessed 28 October 2020].
- VOGT, H. H., ALBIERO, D.; SCHMÜLLING, B. 2018. Electric tractor propelled by renewable energy for small-scale family farming.
- WREFORD, A.; IGNACIUK, A.; GRUÈRE, G., 2017. Overcoming barriers to the adoption of climate-friendly practices in agriculture. *OECD Food, Agriculture and Fisheries Papers*.



This is an open-access article distributed under the terms of the Creative Commons Attribution License