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Status Quo of China's Drone Industry

Market Development, Regulation and Application

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Sino-German Cooperation on Mobility and Fuels Strategy (MFS) as a Contribution to the Mobility and Transport Transition

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Beijing, 2022

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Content

Abbreviations

AGV	Automated Guided Vehicles
AMI	Air Mobility Initiative
BDS	BeiDou Navigation Satellite System
BMDV	German Federal Ministry for Digital and Transport
BMVI	German Federal Ministry of Transport and Digital Infrastructure
BVLOS	Beyond Visual Line-of-Sight
CAAC	Civil Aviation Administration of China
CAIG	Chengdu Aircraft Industry Group
CAGR	Compound Annual Growth Rate
CCTV	China Central Television
CNY	Chinese Yuan Renminbi
DFS	Deutsche Flugsicherung GmbH
EASA	European Union Aviation Safety Agency
EU	European Union
EUR	Euro
eVTOL	Electric Vertical Takeoff and Landing
GACC	General Administration of Customs of the People's Republic of China
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HHLA	Hamburger Hafen und Logistik AG
ICE	Internal Combustion Engine
LGV	Laser Guided Vehicles
Li-Ion	Lithium-Ion
Li-Po	Lithium-Polymer
MARA	Ministry of Agriculture and Rural Affairs of the People's Republic of China

MFS	Mobility and Fuels Strategy
MIIT	Ministry of Industry and Information Technology of the People's Republic of China
MoT	Ministry of Transport of the People's Republic of China
MPS	Ministry of Public Security of the People's Republic of China
PEMFC	Polymer Electrolyte Membrane Fuel Cell
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
R&D	Research and Development
UAM	Urban Air Mobility
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UOM	Unmanned Aerial Vehicles Operation Management System
USD	US Dollar
U-Space	Term for UTM used in Europe
UTM	Unmanned Aircraft Systems Traffic Management
UTMISS	Unmanned Traffic Management Information Service System
uTM-UAS	urban Traffic Management of Unmanned Aircraft System
VLOS	Visual Line-of-Sight

»China« and »Germany« are used as short forms for the People's Republic of China and the Federal Republic of Germany.

Executive Summary

The deployment of private and commercially operated drones in the airspace is rapidly increasing worldwide. Aerial drones are used in a wide range of applications, such as surveillance and inspection of infrastructures, delivery of medical supplies in cities, and logistics and distribution tasks in inaccessible rural areas. Developments in the Chinese drone market are particularly significant, as it is one of the world's dominant markets in terms of technology and innovation and is home to the most influential drone companies and start-ups. At the same time, pilot initiatives supported by the Chinese government are integrating unmanned aerial systems into transport and logistics on a large scale. To better grasp the developments in the Chinese drone market and industry, as well as the regulatory framework, to trace different approaches to implementing pilot projects, and to be able to assess the future potential of this sector, an analysis of the Chinese drone market is needed.

Supportive policy and regulatory frameworks at national and local levels, China's technological leadership in unmanned aerial concepts, and the consistent rise in domestic demand for drones are strongly driving the growth of the Chinese drone industry. At present, China is the second largest drone market in the world after the United States, with a projected revenue of around EUR 13.5 billion in 2024. The province of Guangdong and the Greater Bay Area (Guangzhou, Shenzhen, Macao, and Hong Kong) play a particularly important role as leading regions of the drone industry, where companies such as DJI, High Great or EHang – which are among the largest and most important players in the Chinese (and to a certain extent the global) drone business – are based, working on new propulsion technologies (e. g. hydrogen and fuel cell solutions) and initiating pilot measures. Shenzhen-based global player DJI alone is responsible for more than 70 % of the global consumer drone market.

China's policymakers have taken further steps to open up the airspace and accelerate the development and implementation of drone-related policies by establishing a suitable regulatory framework. By publishing a set of normative documents and proposed administrative provisions at national and local levels for drone operations (e. g. requirements for pilots or certification of commercial drone activities in delivery services), Chinese aviation authorities are addressing the challenges the dynamic development of the drone market poses for the existing regulatory system. The entire regulatory environment is subject to continuous optimisation to keep up with the high rate of development and innovation. In its published drone guideline, the Ministry of Industry and Information Technology refers to more than 200 rules to be created and revised in the areas of research, production, application, and safety regulations for civil drones.

The recent developments in new technologies such as 5G and big data are leading to a vast increase in commercial drone applications in the Chinese low-altitude airspace, especially in urban areas (e. g. for express delivery services). To integrate all these new unmanned aerial vehicles safely, efficiently, and flexibly into the airspace, while considering manned aviation, China is applying the »Unmanned Aerial Vehicles Operation and Management System« (comparable to »U-Space« in Europe), which has already been demonstrated in national pilot projects. The system creates a unified mechanism to manage information synergies through industry management, airspace control, government coordination and social services. By 2030, the system is expected to be mature enough to cover the entire life cycle, all-weather conditions, and all-directional and all-visual monitoring of drones at low altitudes.

Chinese manufacturers have been among the early adopters of autonomous aerial systems in transportation and logistics: As early as 2017, JD.com began building China's largest low-altitude drone logistics network in the Shaanxi Province, operating several hundred routes and drone bases within in a 300 km radius to provide cost-effective, scalable, safe, and reliable delivery options in remote rural areas. Following the outbreak of the COVID-19 pandemic in early 2020, Antwork conducted its first delivery of medical samples and quarantine materials between hospitals and disease control centres in the Zhejiang Province. This system-based drone transport has established itself as a safe and reliable, cost-effective, and contactless means of transport for pandemic response in China, reducing delivery times by more than 50 % compared to road transport. In 2019, DHL Express and manufacturer EHang partnered to run drones in a demonstration project carrying shipments between DHL's service centre in Liaobu (Guangdong Province) and a DHL customer's site on a daily basis. By using drones, the delivery time is reduced from 40 minutes on the road to eight minutes in the air. In addition to reducing energy consumption and CO_2 emissions, there are also cost savings of up to 80 %.

The insights into the Chinese drone market (including key players, the regulatory framework and pilot projects) underscore China's role as one of the leading nations in the development and application of drones. The lessons China is learning from the adopted measures, ranging from the Chinese government's high investments into the drone industry, over the high pace of adoption of innovative technologies and the implementation of pilot projects, to the creation of favourable regulatory frameworks in selected pilot regions (»Real Laboratory« Shenzhen), will significantly influence the shaping of innovative aviation in the future. Against the backdrop of the advancing digitalisation of transport and mobility worldwide, notably in China, increased attention must be paid to the rapid developments in the future topic of drones. In mutual dialogue, potentials for possible cooperation between China and Germany may be explored and mutually beneficial learning strengthened.

1 Introduction

Sustainable transport and mobility planning and the use of renewable energies are becoming increasingly important in the wake of the transformation of the transport and energy sectors worldwide. The development and implementation of corresponding strategies and measures in the realm of sustainable and intelligent technologies, standards and regulations at national and global level represent a major challenge for the international community.

To meet the requirements of the Paris Agreement from 2015, Germany and China have set themselves long-term energy and climate targets in the course of the energy and transport transition: According to the new Federal Climate Change Act of 2021, carbon neutrality must be achieved in Germany by the year 2045 [1]. In this context, it is essential that transport as a key sector, which was responsible for around 20 % of national greenhouse gas (GHG) emissions in Germany in 2019, reduces its GHG emissions quickly and drastically in the coming years [2]. This is also the case for China, which aims to peak its GHG emissions by 2030 and, after a stabilisation phase, initiate continuous emission reductions. By 2060, complete carbon neutrality and a sustainable circular economy should be established [3]. The share of transport in the total carbon emissions in China is currently around 10 % [4].

To sustainably reduce emissions in the transport sector, a wide range of measures need to be taken across all modes of transport. With a share of well over 80 % of transport-related CO_2 emissions, road transport in particular plays a central role in China's climate protection roadmap [5]. However, the use of innovative aviation concepts, namely unmanned aerial systems (UAS), unmanned aerial vehicles (UAV) or drones (these terms are used synonymously in this report), for instance, can also be an important component in reducing mobility-related emissions, as many areas of application for drones are still being taken over by modes of transport that are equipped with internal combustion engines (ICE). These include, for example, the use of helicopters for monitoring infrastructures, the delivery of parcels by trucks in cities and in rural areas, or the supply of remote islands by ships [6].

Both China and Germany are investigating the opportunities and challenges of drone use in pilot and demonstration projects and are working intensively on innovative solutions to integrate unmanned aerial concepts into transport in the future. The German Federal Government's Action Plan [6], as an example, aims to promote research and development (R&D) as well as further innovations and new economic fields with drones [7]. Since 2019, the German Federal Ministry for Digital and Transport (BMDV) has approved more than 40 different projects from industry and science on unmanned aerial applications and individual air mobility solutions [8]. China's 14th Five-Year Plan for the Development of Civil Aviation also shows how the innovative development of drones will be advanced in the future. The primary targets of this new development plan are [9]:

- Active expansion of service areas: promoting the development of drone applications; supporting drone services in postal express logistics, urban public services, emergency rescue and public health; promoting drone applications and integration in urban, rural, and remote areas to modernise agriculture and rural regions.
- Improvement of regulation and standardisation system: establishment of drone regulations, classification and management methods, management platforms and guiding mechanisms, and a sound industry management system; formulation of (international) group standards for drone application areas and involvement of private enterprises.
- Innovation of UAV industry ecology: continuous promotion of pilot regions, research activities, risk assessment and technology verification; construction of innovative platforms and agglomerations focusing on the development of the entire drone industry chain.

This report aims to describe the importance and role of UAV in the Chinese transport sector, and to look at the innovative developments and approaches to integrating drones into the transportation and mobility system in China. At the same time, the overview of the drone sector in China presented in this article allows initial assessments of the possible significance of this transport segment for the future transport cooperation between China and Germany.

In a first step, the essential key terms in the subject area of drones are defined, different areas of application of UAV are described and the European, German, and Chinese understanding of drones is delineated (Chapter 2). Chapter 3 presents the current and future developments in China's drone market, looking at, for example, the latest figures in the market, the main stakeholders (mostly manufacturers), the drone classifications as well as the propulsion technologies currently used in the drone business. The political and regulatory framework prevailing in China for drone deployment is discussed in Chapter 4. Against the background of China's importance for the global drone industry (also as a »Real Laboratory«), this section creates an understanding of the direction of future legislation, the handling of drone licensing in China and the different drone management systems that China has set up to smartly monitor and control the already large number of UAV in operation throughout China. Several years back, China began to implement first pioneering pilot and demonstration projects for the innovative use of drones (with the involvement of the private sector) in various fields of application. Chapter 5 therefore looks at the use of drones in selected case studies (focusing on transport and logistics) by describing the potential of UAV use for the integration into existing transport solutions and for opening up new opportunities as well as the framework conditions, results and challenges of conducted pilot and demonstration projects in China. A short insight into pilot projects from Germany and Europe is also included in this chapter. This report ends with a summary of lessons learned and includes an outlook on the role that drones could play in the future for use in the transport and logistics sector. As machine-building technology continues to evolve, new internet services emerge, and potential areas of use for drones expand, UAV have become a hot topic for policymakers and transport planners worldwide.

This report was conducted within the framework of the project »Sino-German Cooperation on Mobility and Fuels Strategy (MFS) as a Contribution to the Mobility and Transport Transition«, which is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the BMDV (formerly German Federal Ministry of Transport and Digital Infrastructure (BMVI)) in cooperation with the Ministry of Transport of the People's Republic of China (MoT). The project activities carried out strive to intensify the bilateral Sino-German policy and technical expert dialogue on the energy transition in the mobility and transport sector. Furthermore, the project supports bilateral formats of implementation in key issues such as sector coupling of the transport and energy sector, integrated mobility concepts or, as in this article, the deployment of drones in the transport sector. The project thus contributes to the debate on innovative and sustainable logistics and feeds this topic into the bilateral policy dialogue between China and Germany.

2 Definition of Terms and Drone Application Fields

When it comes to the terminology of unmanned aerial objects, there is a large variety of terms that many experts use interchangeably, under the assumption that the different names or acronyms describe the same object. Apart from the notion of aerial drones, these include terms such as UAV, UAS or remotely piloted aircraft systems (RPAS), which are considered to be the most common acronyms. In addition, there are national definitions, where the name is translated into the respective national language [10].

However, a detailed examination shows that there are in fact specific differences in the definition of the aforementioned terms. In contrast to a UAS, the term UAV in its most basic form refers only to the autonomous flying object itself and not the entire system [11]. The Commission of the European Union (EU), in its Commission Implementing Regulation EU 2019/947 [12], defines the concept of UAS as »… an unmanned aircraft and the equipment to control it remotely«. Such equipment may include a ground control structure, a communication infrastructure required to send, relay, and receive data, as well as image and video analysis components [11, 12]. In analogy to the European understanding of drone-related terms, Chinese regulators use the terms UAS and UAV in their normative documents, with UAV in the Chinese definition denoting an aircraft managed by a control station (including remotely piloted and autonomous concepts, but not radio-controlled model aircrafts), also referred to as a remotely piloted aircraft (RPA). The UAS concept (also called RPAS in China), refers to the unmanned aircraft, the associated control station, the required command and control data connection and the approved system, consisting of all other components specified in the type design [13]. This report uses the terms drone, UAV and UAS synonymously.

In recent years, UAV have become of pivotal importance to many individuals, businesses, and government organisations. It has been realised that drones have many useful capabilities and since the physical limits in the ultra-low- and low-altitude airspace provide great flexibility for the use of UAV, these aerial vehicles cover a multitude of areas in which they can be applied. At the same time, this diversity of possible applications is leading to a large complexity of the drone market, especially with the introduction of new innovations that continuously unlock more fields of UAV use.

Table 1 shows a selection of drone applications in today's UAV market according to their general purpose. For instance, drones are deployed for camera recording (e. g. in archaeology or agriculture), for entertainment purposes in the film industry or in private contexts, for risk mitigation and avoidance (e. g. during maintenance work, fire-fighting operations, etc.), to enhance accessibility in, for example, rural or inaccessible areas (e. g. rural and express deliveries) or to increase efficiency and productivity in mobility, disaster control or agriculture.

Table 1: Deployment of UAV in Different Application Areas (Data: [14, 15])

	Purpose of Application	Example Areas of Application
1	Camera	Disaster Rescue, Agriculture, Archaeology
2	Entertainment	Videography, Lightshows, Private Use
3	Risk Avoidance	Infrastructure Inspection (e. g. High Voltage Power Lines), Firefighting, Emission Level Measurement, Military Use
4	Accessibility	Rural Delivery, Express Delivery, Congested Streets, Usable 24/7
5	Efficiency	Agriculture, Port Operations, Emergency Services

This presentation of applications is non-exhaustive and not free of overlaps between the individual categories (e. g. a drone can be used for risk prevention, but at the same time also reach inaccessible regions by means of cameras).

Based on the above definitions of terms and different drone application areas, this report is mainly addressing the Chinese civil UAV industry and UAV market and a limited subset of its application scenarios, especially in the transport and logistics sector (along the application areas of accessibility and efficiency).

As the statistics on civil drone market applications (on an industrial scale) in China in 2020 in **Figure 1** illustrate, only roughly 1.2 % of all UAV implementations in China are operated for transport and logistics purposes (express logistics). The lion's share, however, is accounted for by applications in geographical surveying and mapping (29.3 %), followed by agriculture, forestry, and plant protection (24.9 %) and inspection tasks with a share of 14.2 % [15].

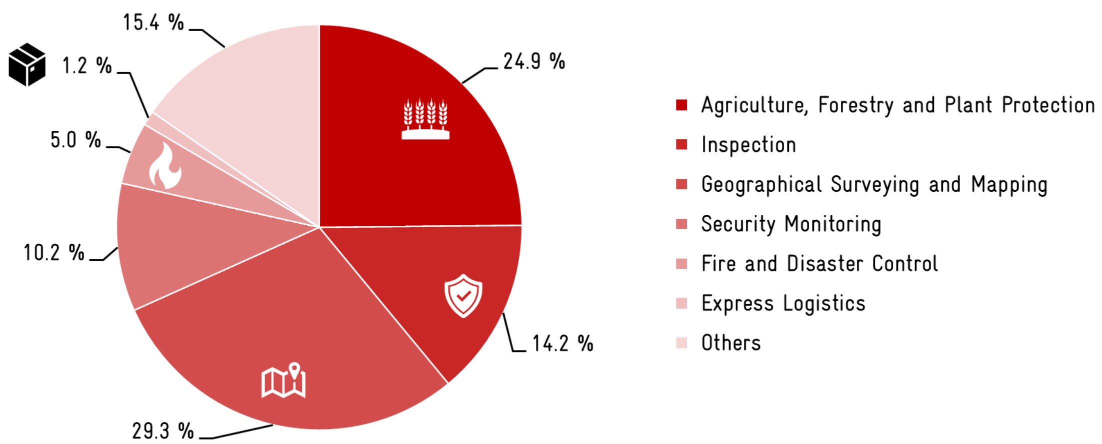

Figure 1: Application Areas of Industrial Drones (as per Scale) in China in 2020 (Data: [15])

3 Development Status of China's Drone Industry

3.1 Market Development

The Chinese drone industry is in the stage of a very dynamic and rapid development, driven by, among other things, the maturity of satellite positioning systems, the continuous improvement of electronic and radio-controlled technologies and innovations in UAV multirotor development. In recent years, there has been a proliferation of innovative companies and start-ups in the Chinese UAV market producing drones and components for commercial, industrial, and military purposes. China's technology leadership, alongside rising domestic demand and a supportive policy and regulatory framework is strongly propelling the growth of the drone industry in China [14, 15].

Figure 2 describes the size of drone markets worldwide in terms of revenue generated and provides a forecast for 2025.

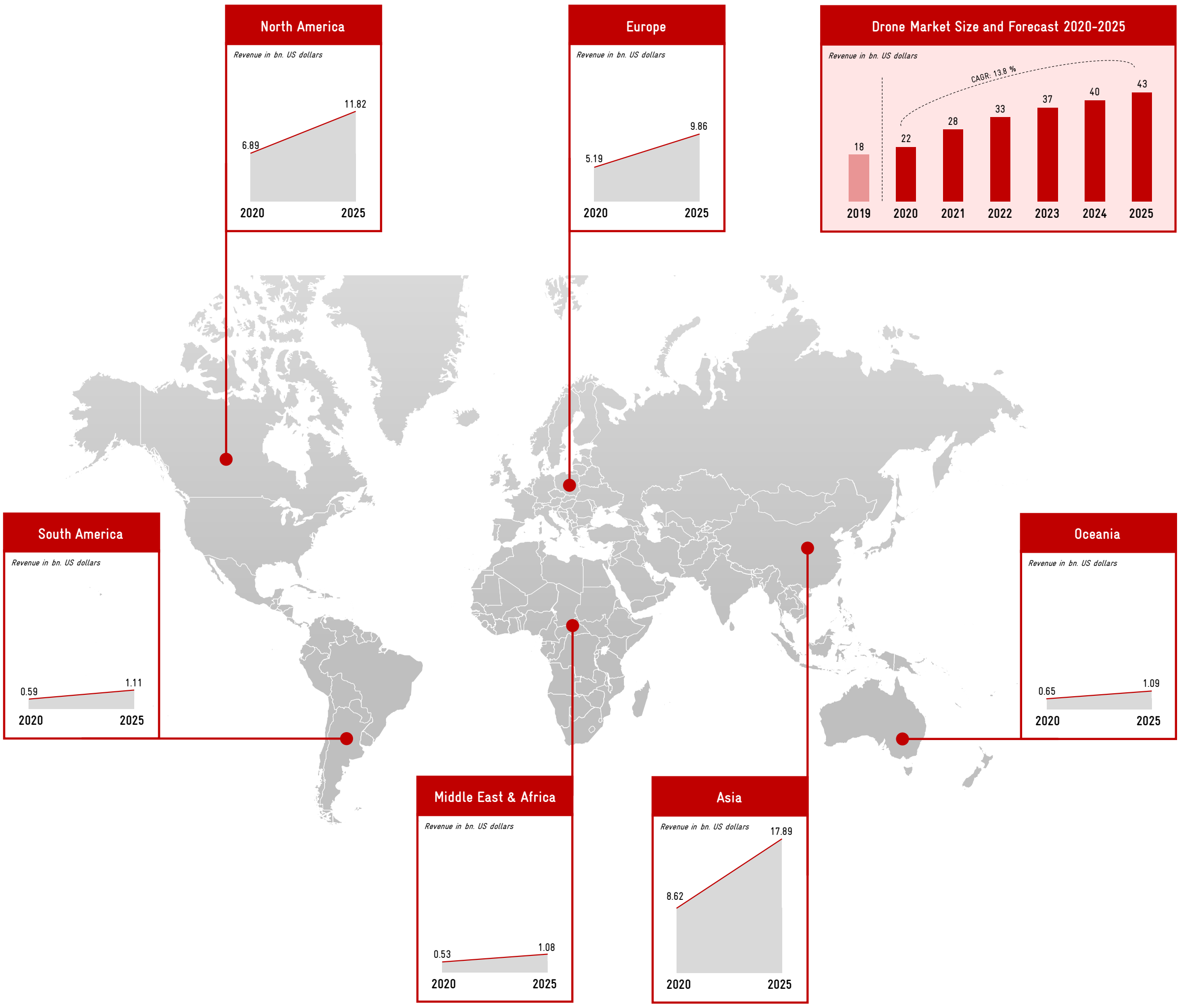

Figure 2: Drone Market Size and Forecast from 2020 to 2025 (Own Illustration based on [16])

Looking at Asia as a whole, the market is projected to grow strongly in the coming years with a Compound Annual Growth Rate (CAGR) of approximately 15.5 % between 2020 (revenue of USD 8.62 billion (EUR 7.55 billion)) and 2025 (revenue of USD 17.89 billion (EUR 15.13 billion)). By 2025, the CAGR of the European (revenue of USD 9.86 billion (EUR 8.34 billion)) and North American market (revenue of USD 11.82 billion (EUR 9.99 billion)) will be 13.5 % and 11.3 %, respectively. Forecasts show that the global UAV market will also register a strong growth with a CAGR of 13.8 % between 2020 and 2025. The total revenue of the entire drone industry in 2025 is estimated at more than USD 40 billion (EUR 33.8 billion) [16].

China alone is currently the second largest drone market in the world, behind the United States as the leading market (Europe in third place). It is expected to close the gap with the United States by 2024 and generate a revenue of around USD 16 billion (EUR 13.5 billion[1] [14, 16]. Initially, drones in China were mainly used for military purposes. However, in recent years, the development of the UAV industry has accelerated and gradually extended from the military to the civilian sector (consumer and industrial UAV). In the field of civil drones, China is the world leader and the most important industrial base globally. China's UAV research and development enterprises have developed rapidly over the years and have taken a better competitive position in the international market [15, 17]. The total volume of drones in China is expected to increase to more than three million units by 2025 [14]. As the biggest manufacturer in the global drone industry, China is also the world's largest exporter of civil consumer drones by revenue generated and export levels have steadily grown over the past few years. According to data released by the General Administration of Customs of the People's Republic of China (GACC) in 2021, the export of civil consumer drones from China in 2020 amounted to about CNY 23.7 billion, or EUR 3.0 billion (CNY 18.7 billion (EUR 2.4 billion) in 2017) [17].

3.2 Drone Industry Stakeholders and Manufacturers

China's UAV sector is shaped and influenced by a wide range of stakeholders. These include policymakers, the industry and private sector, as well as drone users. Policymakers, legislators, and decision-makers in authorities at national and local levels are setting the appropriate policy and regulatory frameworks to ensure that drones can be operated properly and safely and to promote the overall development of the Chinese UAV industry. The private sector is engaged within the established framework, producing drones, components, and software

1 Exchange rates can be found in the appendix.

solutions for distinct user groups, including individuals, enterprises, institutions, and governmental organisations. This section will mainly focus on the industrial environment and the major players in the drone sector.

The Chinese drone industry comprises numerous companies and start-ups pushing innovative UAV technologies with the aim of evolving China into a lead market and leading supplier. While the drone market in China is dominated by only a limited number of (also globally significant) manufacturers, industry estimates point to around 70,000 registered companies in China manufacturing UAV, producing components, and offering drone software solutions [18].

As shown in **Figure 3**, from the perspective of regional distribution, the provinces of Guangdong, Jiangsu, Beijing, Shanghai, Sichuan, and Jiangxi have the most representative enterprises in the UAV industry chain in China. Zhejiang, Henan, Chongqing, Jiangsu, and Shandong are also home to a large number of UAV industrial parks. Furthermore, in 2021, the Chengdu Aircraft Industry Group (CAIG), which is a subsidiary of the state-owned Aviation Industry Corporation of China, has also signed an agreement with the provincial government of Sichuan to jointly invest approximately USD 1.55 billion (EUR 1.3 billion) in the construction of a UAV industrial park in the region [14].

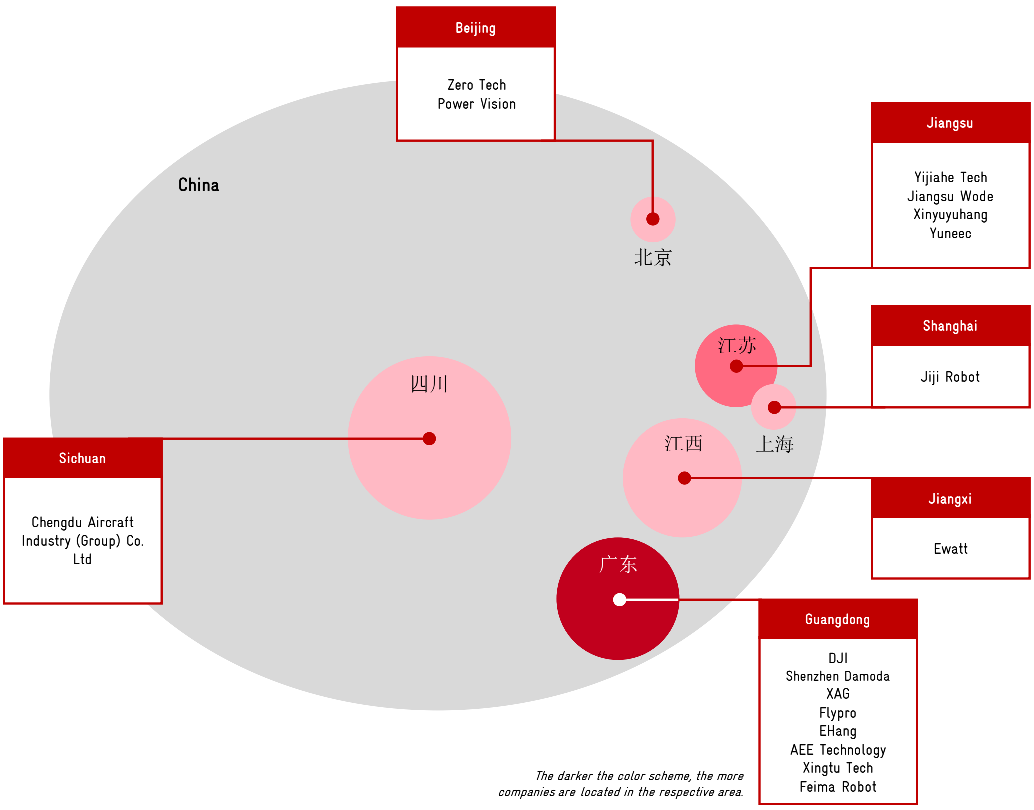

Figure 3: Geographical Distribution of Civil Drone Industry in China (Own Illustration based on [15])

In particular, Guangdong and the Greater Bay Area (Guangzhou, Shenzhen, Macao, and Hong Kong) are the leading regions of the drone industry in China, with Shenzhen-based companies DJI or Dajiang Innovations (Chinese: 大疆创新), High Great (Chinese: 高巨创新) and Shenzhen Damoda (Chinese: 深圳大漠大), and their Guangzhou-based neighbour EHang (Chinese: 亿航), among the largest and most significant players in the Chinese (and to some extent the global) UAV industry [15, 18].

Located in the Greater Bay Area, Shenzhen stands out as the true »Capital of Drones« in China [18-20], with Shenzhen-based global player DJI responsible for more than 70 % of the world's consumer drone market, ranking first among civil drone manufacturers worldwide [15]. Shenzhen, which has hosted the annual Drone World Congress since 2017, also appears to be a highly favourable location for UAV enterprises in China due to its early adoption of regulations to promote an attractive regulatory environment that supports innovations in the UAV industry. Such measures include, for example, the adoption of a local legal framework for mini and light civil drones, as well as special funding schemes that stimulate emerging UAV companies through direct support and risk compensation [21-23]. Through these programmes, the local government supports more than 200 drone-related initiatives every year [21]. Moreover, companies can benefit from partnerships with various stakeholders, such as scientific institutes, the military or energy companies. At the same time, Shenzhen not only provides easy access to drone suppliers and raw materials, but also opens up a pool of creative talents to companies [18]. This creates cross-cutting value, consolidates Shenzhen's position as a UAV knowledge centre and creates major industry players, which are briefly described below.

DJI is currently the leading company in drone manufacturing with a global consumer and commercial drone market share of more than 70 %, ahead of Intel (United States) with 4.1 % market share and the Chinese manufacturer Yuneec (Chinese: 昊翔), which has a 3.6 % share of the global market [14]. DJI continues to set global technological standards with the introduction of highly innovative drone products that combine compact weight and high-end features. This can be attributed to, among other things, the company's innovation-driven R&D strategy (25 % of all employees are working in R&D), low production costs, skilled personnel, and the ability to quickly respond to market needs [14, 21]. In 2012, the company launched its first consumer drone, making its UAV, previously exclusively available to professional users, accessible to the public [24]. This and the introduction of more advanced drones in the following years (e. g. with high-resolution camera systems) allowed the civil drone market to expand enormously. DJI's flight control systems, stabilisers and UAV cameras are all developed and produced by the company in-house. By the end of 2019, the company had filed over 11,300 patents [21]. From 2013 to 2017, sales doubled almost every year, and its industrial output exceeded USD 3.8 billion (EUR 3.4 billion) in 2019 [14]. In the future, the company plans to set another focus on electromobility and intelligent and automated driving with the foundation of the separate automotive division DJI Automotive [18].

Another global player, mainly in logistics and passenger transport, smart city management and entertainment (photography and media), is Guangzhou-based EHang. Valued at around USD 7 billion (EUR 5.9 billion) in February 2021, the company is working on battery-powered autonomous aerial vehicles (for electric vertical takeoff and landing (eVTOL)) for use in smart cities. EHang became the first listed passenger drone company in December 2019 [18, 25]. EHang's mission is to make safe, autonomous, and environmentally friendly aerial mobility accessible to all by providing end-to-end solutions including hardware and software configuration, takeoff and landing platform set-up, and other operational services. In addition, considering rising personnel costs and the rapid development of smart logistics, EHang is working on ways to meet the different requirements of various application scenarios in terms of flight range, loading, takeoff and landing methods, helping to create a more open, intelligent, and efficient air logistics platform [26].

EHang, which competes with companies such as Munich-based Lilium, Airbus, Boeing, Hyundai, and General Motors, has already completed a number of demonstration flights. For example, in January 2021, EHang successfully carried 36 passengers through a test area in Guangdong with its first autonomous passenger UAV EH2016. In February 2021, the first test flights were conducted in the Chinese capital Beijing [18, 27]. With the formal adoption of the »Special Conditions for EH216-S AAV Type Certification« by the Civil Aviation Administration of China (CAAC) in February 2022, another milestone was reached. These special conditions form the basis for the compliance and safety of EH216-S drones, including flight performance, structures, design and construction, propulsion systems, systems and equipment, data link and ground control stations [28]. Nevertheless, regulatory hurdles, R&D costs and lagging infrastructure will continue to pose challenges for EHang in the future [18].

In parallel to the above-mentioned drone players active in the transport and mobility segment, there are several other important companies in China that develop drones mainly for use in the entertainment sector. The two companies High Great and Shenzhen Damoda (together with EHang) are among the big three Chinese companies in the entertainment sector [18]. High Great was founded in Shenzhen in 2014 and is, among others, Audi's partner for vehicle presentations. With fleets consisting of several thousand drones, High Great has already performed over 1,000 light shows in more than 200 cities worldwide [18, 29]. Shenzhen Damoda's headquarters are also located in Shenzhen. The company was founded in 2016 and focuses on the research and development of drone flight control systems and cluster formation technology. Shenzhen Damoda, which offers its light shows mainly for festivities, theme parks, advertising, and marketing, also features prominently at the most significant event in China, the annual nationally broadcasted Spring Festival Gala of China Central Television (CCTV). The company works closely with the two other Shenzhen-based enterprises BYD and Huawei on aerial advertising [18, 30].

Given the large number of players involved in the UAV supply chain and the size of the Chinese drone market, the rapidly growing UAV industry in China creates significant value for the Chinese economy. Against this backdrop, China has taken a strong interest in recent years to establish a well-functioning framework at the regional and national levels. This is to ensure the proper operation of UAV in China's airspace and thus enable the sustainable expansion and healthy development of this industry and market.

3.3 Drone Classification System

Drones are configured very differently in the industry depending on the platform and task. As for any aircraft, there are different classifications for drones or UAV based on corresponding parameters. In general, drones can be classified according to their performance characteristics. Key parameters for differentiating and classifying drones include, for instance, weight, wingspan, wing loading, range, maximum altitude, speed, endurance, degree of operational autonomy, propulsion type (see Chapter 3.4) or operational costs. Furthermore, civil aviation authorities of different countries also use their own classification systems [31].

Table 2 shows the classification established by the CAAC. A distinction is made according to classification level, empty weight and maximum takeoff weight. Depending on the operational risk, civil drones in China are divi-

Table 2: Classification of Drones in China according to CAAC (Data: [32, 33])

Classification Level		Empty Weight W_E [kg]	Takeoff Weight W_T [kg]
I	Micro Drone	$0.0 < W_E \leq 0.25$	-
II	Light Drone	$0.25 < W_E \leq 4.0$	$1.5 < W_T \leq 7.0$
III	Small Drone	$4.0 < W_E \leq 15.0$	$7.0 < W_T \leq 25.0$
IV	Medium Drone	$15.0 < W_E \leq 116.0$	$25.0 < W_T \leq 150.0$
V	Large Drone	Agricultural / Plant Protection Drone	
XI		$116.0 < W_E \leq 5{,}700.0$	$150.0 < W_T \leq 5{,}700.0$
XII		$W_E > 5{,}700.0$	-

ded into micro, light, small, medium, and large drones.

Micro drones (classification level I) are designed with an empty weight of less than 0.25 kg and a maximum air speed of not higher than 40 km/h and a flight altitude of not more than 50 m. The radio transmission equipment meets the technical requirements of the micro-power short-range radio transmission equipment of remotely piloted aircrafts [32].

Light UAV (classification level II) are drones with a maximum empty weight of 4 kg. With a maximum takeoff weight of 7 kg, light drones achieve a maximum flight speed of 100 km/h. In addition, light drones are capable of maintaining their position (altitude) in the airspace and being continuously and reliably monitored. At the same time, the technical requirements for remote-controlled aircrafts must be met [32].

Classification level III refers to small UAV with a maximum empty weight of no more than 15 kg or a maximum takeoff weight of no more than 25 kg (micro and light UAV are excluded). Medium UAV (classification level IV) are limited to a takeoff weight between 25 kg and not more than 150 kg and an empty weight of not more than 116 kg. Large UAV, which include agricultural drones and plant protection UAV (classification level V), are allowed to have a takeoff weight between 150 kg and 5,700 kg with an empty weight of maximum 5.700 kg (classification level XI). Classification level XII drones are designated as having an empty weight of more than 5.700 kg [32].

The classification system presented is based on the latest CAAC documents, regulations, and guidelines for differentiating drone classes. Previous documentation published by the CAAC may also be based on other classifications (e. g. with a higher number of classification levels).

3.4 Drone Propulsion Technology

Drones can also be classified according to their type of propulsion system. The Chinese drone industry makes use of a whole range of propulsion technologies that are currently on the market or still in development. A brief discussion of the propulsion technologies listed in **Figure 4** follows, which primarily includes three types of drive systems for UAV: fuel (combustion engine), hybrid fuel-electric and pure electric propulsion systems [34].

Of the different technologies used in unmanned aviation today, ICE, both petrol and diesel powered, have the longest standing and are still among the preferred power supplies for most military and commercial UAV [35]. The fuel propulsion system of a drone usually consists of a fuel supply system, an engine, a mechanical transmission, and a propeller. Fuel engines can mainly be divided into piston and turbine engines (e. g. turbojet, turboprop). In the case of the piston engine, mainly 2-stro-

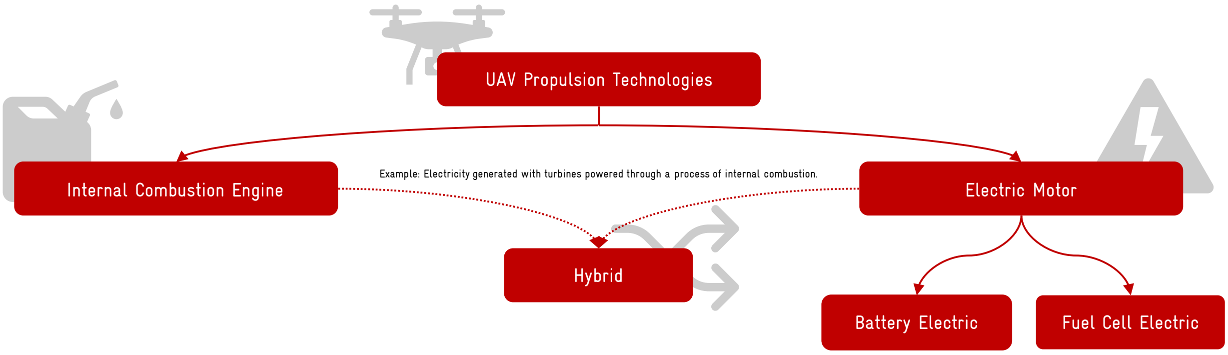

Figure 4: Simplified Schematic Overview of UAV Propulsion Technologies (Own Illustration based on [34])

ke, 4-stroke or also Wankel engines are used, whereby the 2-stroke engine (which operates in two strokes and the four stages intake, compression, power, and exhaust) is the most widely used internal combustion engine. Because a lot of air must be inhaled during the combustion process, piston engines are often only applicable for drones operating at low speed and low or medium altitude [34, 35]. Overall, engines deployed in UAV must have many characteristics, including long lifespan, low volume, high power-to-weight ratio, robustness, and maintainability [34]. This leads to advantages of UAV equipped with ICE: longer flight times, robustness, small size, low specific fuel consumption and quick refuelling. The disadvantages are that they require more maintenance and, in some cases, may be even heavier compared to battery-powered drones [34, 35]. In addition, the use of internal combustion engines (e. g. gas engines) is often not practical for multirotor drones, as drones with multiple rotors require fast and high-precision throttle changes to keep them stabilised, which an ICE is not capable of [36]. With increasing environmental concerns and the depletion of fossil fuels, the energy supply of aircrafts has become an ongoing challenge. Therefore, hybrid and purely electrically powered drones are now the focus of interest.

The electric powertrain of UAV usually involves a power source, an electric motor, and a control system. Power sources for UAV cover a wide spectrum with the use of, for example, lithium batteries, fuel cells, solar photovoltaic or supercapacitors. By using electrical energy as a power source, UAV with electric powertrains are more environmentally friendly, reducing fuel consumption, pollutant emissions and noise [34]. Additionally, compared to fossil fuel drive systems, electric propulsion systems offer greater potential for more diversified applications. For example, more versatile and sophisticated designs can be built with distributed electric propulsion systems and multirotors to improve flight characteristics. At the same time, electric-powered drones are technically simpler in design, and easier to repair and maintain compared to ICE drones. However, due to insufficient adaptability to the environment, use in poor weather conditions or in complex electromagnetic environments is often problematic [34, 35].

At present, the most mature drone technology is certainly the battery electric propulsion. There are many different types of batteries with their respective advantages and shortcomings that can be considered for drone applications. However, the most common batteries for drones are lithium-polymer (Li-Po) and lithium-ion (Li-Ion). Li-Ion batteries feature both high energy as well as high power density. They are also lighter and more compact than other rechargeable batteries. High energy efficiency, no memory effect and a relatively long cycle life can be seen as further advantages in drone use. The major disadvantage, though, lies in the high battery costs. Li-Po batteries are preferred in portable devices and electric transportation due to their superior energy density, power-to-energy ratio, and long cycle life [35]. Battery-powered drones can also be recharged almost anywhere by replacing the battery pack [35], and as innovative approaches show, this can also be basically automated without interrupting the flight [37, 38].

Other innovative drone propulsion concepts being worked on both in China and Germany involve the use of hydrogen and fuel cells (e. g. Polymer Electrolyte Membrane Fuel Cells (PEMFC)) as alternative source to batteries [34, 35]. A hydrogen fuel cell operates with the two reactants hydrogen as fuel and oxygen as oxidant, producing water and air as by-products. Due to the high energy density of these fuel cells, which is up to 150 times higher than that of a Li-Po battery [35], extended UAV flight times can be achieved. Other major advantages of fuel cells in drones include no direct pollution, no noise, and rapid refuelling. On the downside, they are much larger than conventional battery-powered drones, operating costs depend on the availability of hydrogen and the size of the hydrogen tank limits the drone's design. As the drone weight declines when the hydrogen tank is emptied during the flight, the tank must also be considered when balancing the drone. The application of hydrogen fuel cells in vehicles also requires high power density, rapid response to loads, and a hydrogen supply infrastructure [35]. Although their use in drones seems promising, fuel cell powered UAV concepts are still considered an immature technology in terms of volume, weight, and costs.

One solution to balance the strengths and weaknesses of different UAV propulsion technologies lies in the use of hybrid systems. Hybrid systems rely on two or more types of power sources, generally using one to generate the other, or preferring one and using the other at certain times to improve efficiency. The respective advantages of the energy sources used can thus be exploited at specific operating points. This helps to improve the energy and fuel efficiency of the overall system. Some of these hybrid power systems, which are not discussed in detail here, include solar hybrids, gasoline-electric hybrids, plug-in hybrid electric systems, and hybrids that incorporate supercapacitors [35]. A hybrid propulsion system, for example, consisting of an internal combustion engine and an electric motor that together generate the power required for flight can save about 30 % of fuel compared to conventional fuel propulsion [34]. Research continues in this area [39, 40].

Finally, there are other power sources in the context of UAV propulsion, such as tethered power systems or in-flight battery charging with laser beams, that are not considered here.

4 Political and Regulatory Framework for Drones in China

4.1 Development of Regulation

The progressive uptake of drones in China in recent years requires systematic management at the national (and provincial) level. **Figure 5** depicts the general drone regulations that have been issued in China since 2013 (not complete).

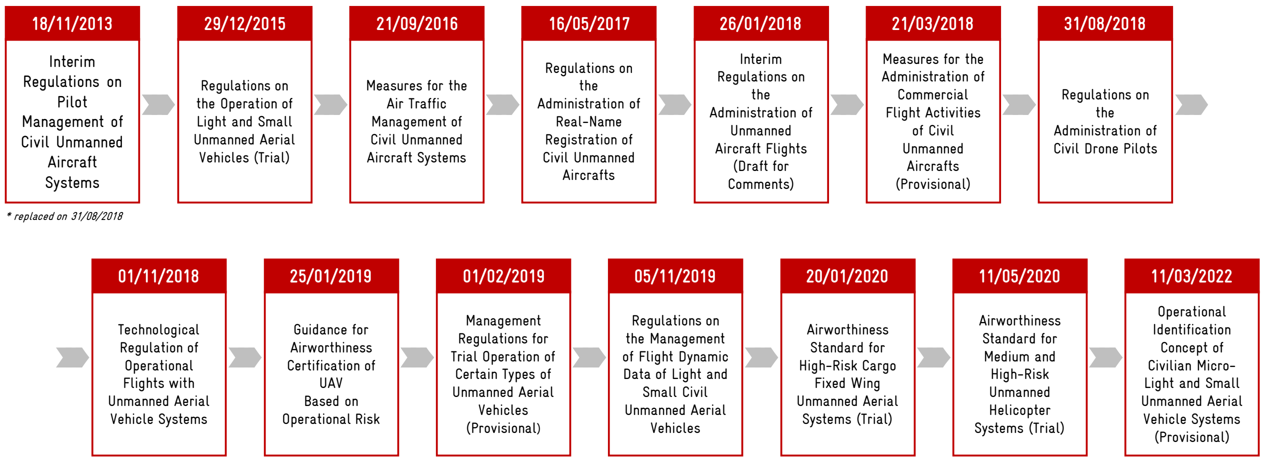

Figure 5: UAV Policy Regulation System in China (Selected Regulations) (Data: [13, 32, 33, 41-51])

Through the development and publication of a set of normative documents and an administrative regulation proposal (in January 2018) for the operation of UAV in the Chinese airspace, the CAAC and other aviation administration bodies and authorities at the local level aim to address the challenges that the dynamic development of the UAV market poses for the existing civil aviation regulatory system. There are currently no comprehensive laws or strictly legally binding administrative regulations for UAV at the national level in China [52, 53].

The regulatory system is currently based on five fundamental normative documents (consisting of Advisory Notices, Management Documents and Aviation Procedures) that have been published nationally by the CAAC and, although the CAAC is a state body, are not easily enforceable nationwide and can in principle be questioned in court [52]:

- Advisory Notice »Regulations on the Operation of Light and Small Unmanned Aerial Vehicles (Trial)« – published on 29 December 2015 [13].
- Management Document »Measures for the Air Traffic Management of Civil Unmanned Aircraft Systems« – published on 21 September 2016 [42].
- Aviation Procedure »Regulations on the Administration of Real-Name Registration of Civil Unmanned Aircrafts« – published on 16 May 2017 [43].
- Management Document »Measures for the Administration of Commercial Flight Ac-

tivities of Civil Unmanned Aircrafts (Provisional)« – published on 21 March 2018 [44].

- Advisory Notice »Regulations on the Admimistration of Civil Drone Pilots« – published on 31 August 2018 [33].

The regulatory document published in 2015 focused primarily on regulating increasing numbers of light and small drones with low flight altitude and speed in China. In June 2017, it was introduced for the first time that civil drones with a maximum takeoff weight of 250 g or more (not micro drones) must be registered through China's Real Name Registration System for UAV. Owners or rights holders of such drones must register and update both their personal data and information about their UAV through this system, including the owner's or holder's name, personal ID or passport number, mobile phone number and email address, and the drone's model and serial number [53]. Further regulations issued in 2018, for example, specified which drones of different classes are allowed to be operated up to certain flight altitudes without approval. In 2019, the CAAC began piloting certain drone operations (for instance, in unmanned short-distance delivery). In 2020, the CAAC published two airworthiness standards in a row, indicating that large-scale unmanned delivery and logistics applications in China will become more important in the future.

In addition to drone regulation at the national level, local governments also promulgate rules and notices on the use of drones at certain times or in certain areas. In Beijing, for example, the Public Security Bureau usually issues official public notices banning the flying of drones throughout the Beijing metropolitan area during important events (e. g. the annual National People's Congress meetings in March). For the remaining part of the year, drones are banned within Beijing's Sixth Ring Road, which encompasses the entire city centre within a 30 km radius of Tiananmen Square [52]. Less stringent and less restrictive UAV regulations apply in other parts of China outside the capital city. Most provinces and cities have not yet released formal public notices or issued local regulations on the use of drones. However, some local authorities have enacted several, albeit often very vague, local laws and published flight restriction zones (for areas around airports, or military bases) following several UAV incidents. Also, some drone manufacturers implement their own area restrictions, such as setting own flight zones for their users to prohibit movements in sensitive areas [52].

Although China's drone regulation may seem somewhat multi-layered due to the complexity of government regulations at the national and local levels, China has managed to drive the growth of the drone industry (especially in the areas of transport and logistics, agriculture, and environmental protection) through favourable regulations and measures related to innovation and technology. In addition, it can be observed that regulators are continuously making changes and adjustments to the overall administrative system, thus cleaning up regulatory actions. In recent years, policy makers have taken a positive approach to opening up low-altitude airspace and have accelerated the development and implementation of drone-related measures. Optimising the regulatory framework will positively influence this fast-developing market and further accelerate the development of the drone industry in China.

4.2 UAV Licensing

In China, the operation licensing and requirements for pilots and certification of commercial drone activities (for instance, for use in entertainment or delivery activities or for training purposes) are mainly regulated in the normative documents [33] – »Regulations on the Administration of Civil Drone Pilots« – and [44] – »Measures for the Administration of Commercial Flight Activities of Civil Unmanned Aircrafts (Provisional)«.

To ensure an orderly and safe deployment of UAV despite the complexity caused by the variety of drone classes and systems and the greater flexibility in the applicable airspace compared to manned aviation, the implementation of a classification/licensing system for UAV pilots is required. The relevant regulations specify the following [33]:

- The UAV pilot is responsible for the following cases without having to hold an operating licence:
  a) Drones operated indoors.
  b) Drones in classes I and II (see Table 2 for drone classification). If required for operation, the pilot may file an entry in the UAV Cloud Exchange System. The record should include the pilot's real identity information, the drone model used, and the pilot should pass the online regulation test.
  c) Drones for testing in sparsely populated, open, or non-densely populated areas.
- Pilot licences for UAV other than classification levels I and II operating in segregated airspace (specifically allocated for UAV operations) and integrated airspace (where other manned aircrafts are operating simultaneously) shall be managed by the CAAC. Pilots operating UAV within the visual line-of-sight (VLOS) must hold a VLOS licence with the appropriate category and classification level issued in accordance with these regulations and carry the licence when exercising the appropriate rights. The same applies to drone pilots who wish to obtain a licence for operating UAV in beyond visual line-of-sight (BVLOS) mode.
- Special requirements for agricultural and plant protection drones (classification le-

vel V): Pilots responsible for operation and safety of the UAV system shall hold a classification level V licence, or a pilot licence approved by the Ministry of Agriculture and Rural Affairs (MARA) and other bodies that meet the qualification requirements. Companies manufacturing drones for crop protection are independently responsible for the training and assessment of plant protection drone operators.

According to the Management Document [44], the use of UAV with a maximum empty weight that is equal to or surpasses 250 g to carry out commercial activities such as aerial spraying, aerial photography, and aerial performance flights, etc., or for pilot training, requires an application for an operating licence issued by the CAAC. These measures do not apply to UAV for commercial air transport of passengers and cargo. In order to obtain an unmanned aircraft business licence, the following basic conditions must be met [44]:

- The main enterprise conducting the business must be a legal entity and the legal representative has to be a Chinese citizen.
- The enterprise must own at least one drone registered in the real-name registration system of the CAAC.
- The training capability must be recognised by the relevant industry department or an authorised institution (only applicable to the conduct of training-type business activities).
- Hold ground liability insurance for UAV.

The application for the UAV operating licence is made online via the »Civil Unmanned Aircraft Operating Licence Management System«. The following information is required: basic information about the enterprise; registration number of the UAV; certification number of the drone pilot training institution (applicable to training business only); evidence of a ground liability insurance; UAV business activities to be carried out by the enterprise [44].

For UAV activities in the transport and mobility sector, for example, for the transport of cargo and passengers by drones, the CAAC uses an accreditation approach. Depending on the complexity of the aviation activities carried out and the differences in the scope of operation, the CAAC has formulated distinct validation rules and issued different operating certificates. For example, public air transport carriers for large aircrafts [54] and commercial transport operators for small aircrafts [55] are validated in accordance with the appropriate provisions of China's civil aviation regulations.

In the future, automated and digital management systems will play an increasingly important role in managing the rising number of drones in China's ultra-low airspace. Through the real-name registration system and management platforms like the »Unmanned Aerial Vehicles Operation and Management« (UOM) and the »Unmanned Aircraft System Traffic Management Information Service System« (UTMISS), air traffic control authorities can better monitor and control drone activities. At the same time, the public can also use these platforms to operate their drones legally and reasonably.

4.3 Drone Management Systems

With the rapid penetration of drones and the advancement of new technologies such as 5G, commercial drone applications in the low-altitude airspace, especially in urban areas (e. g. for express delivery services, infrastructure inspections or disaster control), have increased significantly worldwide. Yet, major challenges and technological difficulties remain in the context of drone surveillance and UAV communication in the limited low-altitude airspace. For example, the locations of small and light drones cannot be reliably detected by the traditional radar surveillance systems, normally in place for the medium- and high-altitude airspace. These challenges need to be addressed globally by air traffic authorities, which are often subject to a complex structure of regulatory units and procedures with multi-layered administrative and legislative processes, with effective management measures to ensure the safety and efficiency of drone flights [56, 57].

In an effort to promote the development of resources for the already crowded low-altitude airspace and to standardise the operation and management of UAV in urban regions, regulations, and laws as well as key technologies have been introduced for the use of UAV in the low-altitude airspace in cities [56]. As Chapters 4.1 and 4.2 show, the CAAC in China has already specified regulations on, for example, maximum flight altitudes for light and small drones in the low-altitude airspace or no-fly zones in sensitive areas (geo-fencing) to maintain the efficiency and safety of UAV flights. To further optimise the management of drones against the background of increasing application scenarios, some countries and regions have developed traffic management systems for UAV, such as the »Unmanned Aircraft Systems Traffic Management« (UTM) in the United States, »U-Space« in Europe, the »urban Traffic Management of Unmanned Aircraft System« (uTM-UAS) in Singapore, or the UOM in China, whose basic structure and embedding in China's overall drone management is displayed in **Figure 6** [56].

Spearheaded by the CAAC and kicked off in January 2019, the UOM project aims to create a multi-management and multi-service framework for the safe, efficient, flexible, and scalable operation of light and small drones below 120 m in China [56].

For this purpose, the system, through the UTMISS flight information management subsystem, which is the core component of UOM, comprises four platforms or modules, including connections to the Flight Data Transfer and Flight Data Source layers, and fully integrates the need for information interaction between different administrative departments [56, 57]:

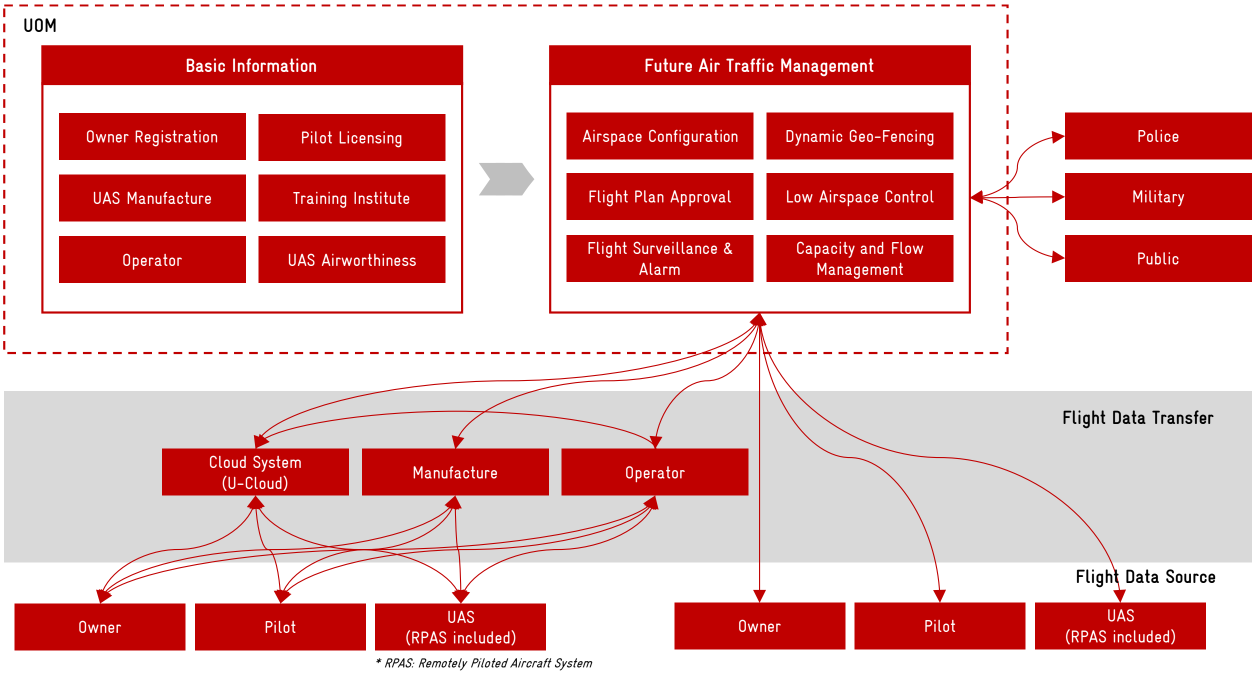

Figure 6: UOM Structure and Embedding in China's Overall Drone Management (Own Illustration based on [57])

- Management Administration Platform: This module is for information filing and registration, airworthiness certification (for manufacturers and R&D companies), real-name registration (for owners), flight licence application and management, business and operation licence approval and issuance (for operators) and certification of cloud business qualification (for cloud providers).
- Operation Management Platform: This module mainly covers air traffic operation management of civil UAV, including air traffic surveillance, flight data collection, air traffic services, flight plan management based on operational safety risks, etc.
- (Intergovernmental) Collaboration Platform: This module mainly consists of government business collaboration management and government information sharing and consultation services. It offers a unique nationwide comprehensive management information interface and industry information inquiry service for ministries and commissions related to the management of specific industries (namely the Ministry of Industry and Information Technology (MIIT), the Ministry of Public Security (MPS) or the Air Traffic Control Committee).
- Public Service Platform: This module comprises qualification verification (qualification inquiry of UAV pilots and training institutions) and information retrieval service (used to share public information, such as pilot and operator credit record, related laws, and policy announcements).

UTMISS was developed to provide a unified mechanism for managing information synergies through industry management, airspace control, government coordination, and social services and to promote the development and application of low-altitude drone pilot operations [56]. It was first launched in late 2018 through a pilot project in Shenzhen [58] for drone air traffic control information services (as well as in the Hainan Province [59]). Its objective is to provide an information-based system to build a set of efficient management practices between UAV users and management departments (for example, to communicate the management requirements of relevant departments to users and to report drone operation information to air traffic control and relevant security departments) [56]. The pilot phases in Shenzhen and Hainan laid a solid foundation for the development of UOM through the optimisation of UTMISS, such as data interaction between the management system and a UAV Cloud Exchange System.

The Chinese UAV cloud-based system requires that drones of classification levels II and IV must be connected to the cloud system if they are operated in sensitive areas and in airport clearance areas. The cloud features a dynamic database system for the operation of light and small civil drones and provides users with navigation and meteorological services and carries out real-time monitoring of civil drones (including information on position, altitude, speed, etc.). In addition, it is mandated that UAV connected to the cloud must upload their flight data immediately, and that the UAV cloud system must trigger an alarm in the event of a drone entering a geo-fenced area [56].

The development plan for the UOM system follows three phases: The first phase (Basic Support Construction) from 2018 to 2020 had the goal of building a national unified comprehensive platform for the operation and management of civil drones. The second phase from 2021 to 2025 (Specification and Integration) is intended to specify aspects of industrial management, air traffic control, government cooperation and social services and to integrate the regulatory framework (standards and norms). In the third phase (Inosculation and Development), planned for 2025 to 2030, a fully mature management service system, including the entire life cycle, all-weather conditions, all-directional and all-visual supervision of low-altitude UAV, should be established [57].

The demonstration and subsequent introduction of UAV management systems in China is an important step in the further advancement of domestic drone management. This can create a clearly defined, formalised system and minimise grey areas of unclear competences and responsibilities. The establishment of a suitable legal and regulatory framework is intended to create an environment in which innovative drone projects and applications can be further developed in the future.

5 Pilot and Demonstration Projects

The above findings lead to the assessment that China is already one of the leading countries in the use of drones, which will have a significant influence on the shaping of innovative aviation in the future. It can be observed that Chinese manufacturers are evincing an enormous speed of innovation and are thus far ahead of their competitors in the development, piloting, and introduction of autonomous systems (e. g. in the field of transport and (personal) mobility). This is due in no small part to China's unique economic and political environment and the government's support in selecting suitable test sites. This chapter describes several Chinese pilot projects from the transport and mobility sector and briefly discusses the situation regarding demonstration projects in Germany and Europe.

5.1 Rural Delivery in Shaanxi

The Chinese province of Shaanxi is located in the centre of the country. It covers an area of roughly 205,600 km² [60] with a population of 39.5 million [61]. Due to its geographical location in the heart of northwest China, Shaanxi is of central importance for the transport and logistics sector as a transport hub. As the numbers in **Figure 7** indicate, the logistics demand in Shaanxi has continued to surge every year since at least 2007.

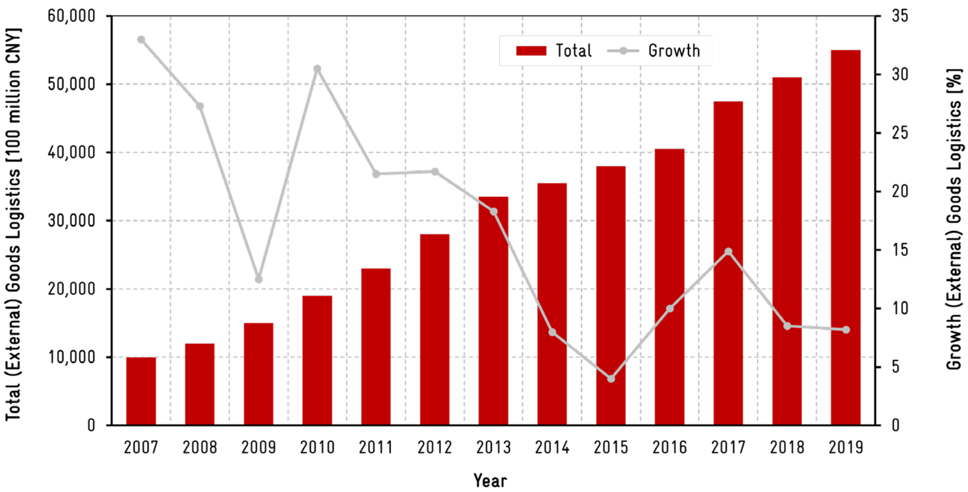

Figure 7: Total Amount and Growth of (External) Logistics in the Shaanxi Province (Own Illustration based on [62])

Due to the importance of the region, China's e-commerce giant JD.com (Chinese: 京东) announced already in 2017 that it would cooperate with the Xi'an National Civil Aerospace Industrial Base in establishing a research and development campus in the provincial capital of Xi'an to develop, manufacture and pilot drone systems. In addition, the campus will incorporate a global logistics headquarter, an unmanned systems centre, and a hub for JD.com's big data and cloud computing activities [63]. The company has earmarked an invest-ment of CNY 20.5 billion (EUR 2.7 billion) by 2022 to expand business operations into Shaanxi [64].

With the decision to move key business activities to Xi'an in 2017, JD.com concurrently began building up China's largest low-altitude drone logistics network under an agreement with the provincial government of Shaanxi. This network operates within an area of a 300 km radius. The operations will eventually include several hundred different routes and UAV airbases throughout the province, where the terrain is complex, and the logistics infrastructure is yet insufficient. The goal is to provide cost-effective, scalable, safe, and reliable delivery options in remote rural areas that are currently not sufficiently connected to the delivery network. Heavy-load drones with a capacity of more than one ton will distribute e-commerce deliveries (e. g. fresh foods, electronics, etc.) and agriculture products to remote regions and cities [63, 65].

The network works by first routing orders from regional delivery stations to JD.com's network of dedicated »village promoters« in each village (currently 300,000 village promoters in entire China). These promoters then distribute the orders directly to customers, significantly shortening delivery times and reducing logistics costs [65]. This solution can be referred to as a delivery hub-and-spoke model, where the UAV takes the place of, for example, conventional delivery vehicles that would normally have distributed orders to the village promoters. This approach allows the use of UAV for delivery to avoid higher costs of transport on rural roads, which typically show poor infrastructure and accessibility. Constructing such a delivery concept is an initial low-threshold entry point for testing the deployment of drones, as the drone replaces an existing link in the delivery chain (delivery vehicle) rather than being added as an additional component to an existing delivery concept. This allows the operators to run their systems nearly unchanged, but more efficiently. In the long term, such a network could be expanded and eventually developed into an intelligent logistics system that integrates air and ground transportation to realize a logistics cycle across provincial or even national borders.

JD.com's Xi'an-based drone delivery unit is the first company in China to be awarded a licence from the CAAC Northwest Regional Administration in 2018 to use logistics drones at the provincial level [66]. Competitor SF Express (Chinese: 顺丰) also received a commercial licence in 2018 to legally deliver goods to customers using drones [67]. In pilot applications in the capital Xi'an alone, JD.com completed more than 800 operational flights from June to July 2017, covering more than 4,000 km with its drones [68].

Based on the experience of these pilot applications in Shaanxi, the Northwest Regional Administration of the CAAC published the »Measures for the Administration of Logistics and Distribution Business Activities of Civil

Unmanned Aircrafts in Northwest China (Trial)« in 2019 [69]. This regulation specifies that civil drones with a maximum empty weight of no more than 250 g and a maximum takeoff weight of not more than 150 kg can undertake commercial cargo transportation and distribution flights in the provinces Shaanxi, Gansu, Ningxia, and Qinghai, subject to obtaining the relevant licences in advance [69]. The issuance of this regulation by the CAAC underscores the success of JD.com's pilot project, which will extend its experience to a wider area. The programme now already covers more than 100 rural villages in China [18].

5.2 Urban Delivery in Zhejiang

Hangzhou is the largest city in the eastern Chinese Zhejiang Province (about 12 million inhabitants [70]) and at the same time the provincial capital, which also functions as the centre of the Hangzhou metropolitan area. In the west of Hangzhou's Yuhang District lies the Hangzhou Future Sci-tech City, an industrial platform and innovation and venture complex for global technology entrepreneurship. This development zone has emerged from a partnership between the Yuhang District Government and China's tech giant Alibaba (Chinese: 阿里巴巴), with the aim of creating an international innovation ecosystem where local players can establish and expand their business activities. Geared towards the integration of industry and city, this high-tech centre, one of several new suburban cities in Hangzhou, is intended to combine high quality of life, mobility, and sustainability [71]. Optimised transport and mobility services, responsible and sustainable urban development and mixed land use are key aspects that represent a great opportunity for innovative developments of, for instance, integration of urban short-distance drone delivery services.

A variety of enterprises and innovative technology actors and institutions have settled in Hangzhou and its Future Sci-Tech City – where there is a high availability of well-trained and experienced technology workforce – including Zhejiang University, Alibaba Taobao City and other e-commerce and internet start-ups. Moreover, the local government has created a business and start-up support network that provides a comprehensive package of assistance services such as patent applications, business registration, cloud processing services at Alibaba and fully equipped laboratories for prototyping and development [71].

Hangzhou's advanced digital infrastructure and digital technology systems (supported by 5G technology and China's independently developed BeiDou Navigation Satellite System (BDS)[2] [72]) provide an excellent environment for companies in the drone industry to develop and demonstrate pilot UAV applications (e. g. in logistics, medical supply distribution, and emergency security). As early as 2020, Hangzhou has been included in the first group of 13 CAAC-designated pilot zones for civil unmanned aerial vehicles [73]. Hangzhou's Yuhang District, which has allocated 25 km^2 of land as a special area for drone experimentation [74], will carry out pilot testing of unmanned aviation in its Future Sci-Tech City [73]. Since October 2020 (until January 2022), over 46,000 unmanned drone trials have been conducted in the logistics, medical care, emergency rescue and city patrol sector in Hangzhou, where the 5G signal facilitating drone deployment already covers over 1,600 km^2 [74].

This innovative development zone is home to the headquarters of Antwork (Chinese: 迅蚁), a Chinese technology and UAV start-up founded in 2015. Antwork's mission is to design and develop drones, unmanned stations and cloud-based UAV traffic and operation management systems. Through these efforts, the company strives to contribute to its goal of building safe and efficient urban air cargo networks with autonomous air delivery services for businesses and consumers in 100 cities worldwide in the next three to five years. The company intends to make a significant contribution to the development of urban air mobility (UAM) [75].

Antwork started in the mail and postal business in rural areas and set up China's first drone mail delivery route with China Post in the Zhejiang Province in 2016. The deployed UAV, which can carry between 5 kg and 7 kg and fly up to 30 km, contributed to a massive reduction in transport time and costs [75, 76]. In 2018, Antwork transitioned to offering food delivery services, with the start-up setting up five drone landing sites in the Hangzhou Future Sci-Tech City, making nearly 10,000 food deliveries via Tencent's WeChat mini programme »Antwork Bar« (Chinese: 迅蚁送吧) [77]. The following year, Antwork launched its Drone Medical Delivery Network, occupying a niche in China with this new core business [75, 78]. In the same year, the project was further advanced with the granting of a drone delivery licence in urban areas by the CAAC, the award of a medical hygiene certificate and the permission to fly through certain areas of airspace [78].

The experience acquired in previous years by delivering food and medical supplies with low weight over short distances benefitted the company during the restrictions imposed by the COVID-19 pandemic in China. In early 2020, after the outbreak of the COVID-19 pandemic, Antwork carried out its first relay delivery of medical supplies (medical samples and quarantine materials) between hospitals and disease control centres at the request of

2 The BDS has been independently developed, implemented, and operated by China. As a temporal-spatial infrastructure of national significance, the BDS is capable of providing users worldwide with all-time, all-weather, and high-precision positioning, navigation, and timing services. The BDS is widely used in transportation, agriculture, forestry, fisheries, hydrologic monitoring, weather forecasting, communications, power distribution, disaster response, public security, and other sectors, and serves nationally important infrastructures. BDS-based navigation services have been widely adopted by e-commerce companies, smart mobile device manufacturers, and location-based service providers [72].

the People's Hospital of Xinchang in Shaoxing, Zhejiang Province [78, 79]. The flight time efficiency of UAV deployed by Antwork had increased by more than 50 % compared to conventional road transport, making systematic drone shipments based on the developed Drone Medical Delivery Network a safe and reliable, cheap, efficient, and contactless means of transportation for epidemic prevention and control in China [79, 80].

Including 2020, Antwork's drones have flown at least 60,000 km, with a maximum flight range of 15 km in urban areas and a maximum load capacity of 5 kg [78]. The medical pilot project in Zhejiang alone has used its drones to transport more than 10,000 medical samples within one year (since the outbreak of the COVID-19 pandemic until January 2021), covering more than 30,000 km [80]. In the future, the focus of Antwork's business activities will be increasingly on the medical logistics sector, especially on medical quarantine deliveries as well as inspections and first aid services [77]. These solutions help to address the challenges of effective and timely provision of resources to relevant medical sites and the hurdles of timely availability of first aid at locations that are difficult to access.

5.3 Express Delivery in Guangdong

In May 2019, DHL Express announced the formation of a strategic partnership with the globally significant Chinese drone manufacturer EHang. With this Sino-German collaboration, the two industry giants aimed to develop innovative and fully automated and intelligent drone delivery solutions to tackle last-mile express deliveries in metropolitan areas in China (e. g. in the Guangdong-Hong Kong-Macao Greater Bay Area). A fully autonomous loading and unloading of parcels and mail should increase the profitability of express delivery processes [81].

In the first stage of the partnership, daily shipments were supposed to be transported by drones between the DHL service centre in Liaobu (Dongguan) in the Guangdong Province and the location of a DHL customer eight kilometres away (Songsanhu Area) in a pilot project. The UAV operated by EHang for this task were tailored to the customer's requirements. They can take off and land vertically and have a high-precision navigation and positioning system, intelligent fully automatic flight route planning and a real-time network connection. Each drone can carry a weight of up to 5 kg and dock with intelligent parcel boxes, which usually function similarly to a conventional parcel station for the customer. The key advantage of these innovative platforms, however, is that the goods delivered by UAV are seamlessly integrated into the sorting, scanning and storage automation of the express delivery. To further increase the service level for the customers in the future, the smart platforms will also include other innovative technologies such as facial recognition and ID scanning [81, 82]. **Figure 8** shows the express delivery system and its drones used in this application.

In this project, the use of drones reduced the delivery time from 40 minutes on the road (in difficult road conditions and traffic jams) to a total of eight minutes in the air. According to DHL, this not only reduces energy consumption and CO_2 emissions during delivery, but also enables cost savings of up to 80 % [81, 82]. As a result, the drones in this demonstration project offer a monetary incentive for their users in addition to a higher level of service. This clearly demonstrates the potential of UAV to make a positive contribution to the traditional urban delivery market, as their deployment can help avoid congestion, symptomatic of large cities and metropolitan areas.

Figure 8: DHL's Fully Automated and Intelligent Urban Drone Delivery Service [81]

DHL is the first international express company to offer such a service in China. Through this innovative drone delivery technology, the company seeks to expand its services in the country, where direct business relationships between private customers and companies continue to surge due to the growing e-commerce sector. Thus, innovative, and automated parcel delivery solutions are on the rise. In addition to the establishment of the first pilot delivery route, DHL intended to further develop and expand its innovative delivery solution with improved drone technology (range, cargo capacity) and rapid development of new routes [81, 82].

Surprisingly, Deutsche Post DHL Group announced in August 2021 the early drop-out from its parcel drone development projects in Germany and abroad. As a consequence, no further pilot projects with parcel delivery drones will be developed in the future and regular operations of delivery with parcel drones will not be pursued, particularly in Germany. Key reasons include regulatory challenges and high costs. Due to the greater potential for drone use in China, the customer-oriented express delivery route launched in 2019 in the Guangdong Province is not affected by this adjustment. The pilot project has now entered regular operation [83].

5.4 German and European Initiatives

There are numerous pilot projects trialling UAV applications in logistics and mobility environments outside of China. European countries are currently working across the entire spectrum of drone technologies to develop innovative solutions and best practices to make use of the great economic and environmental potential of drones in a European operational framework. This chapter briefly looks at selected German and European example applications and initiatives involving UAV technologies.

A comparatively simple but efficient use case is the application of drones to carry out inventories in the logistics industry. Large high-bay warehouses can reach heights of up to 50 m, making drones an effective tool for warehouse management. Suitable solutions have already been developed and used by large logistics players such as the forklift manufacturer Linde Material Handling (now KION Group) or FIEGE Logistics [84, 85]. The system works with UAV that are coupled with autonomous laser guided vehicles (LGV) or automated guided vehicles (AGV) and are supplied with electricity via these vehicles. As the vehicles pass through the warehouse, the camera-equipped drones can scan each pallet location in the warehouse racks vertically up to the ceiling and capture barcodes. This data is fed into the warehouse management system. The coupling of drones with autonomous vehicles enables an uninterrupted power supply, even during long hours of operation, so that the required tasks can be carried out fully automated by UAV, e. g. at night [86].

Outside controllable environments, several players in Germany and Europe are working on unmanned aerial vehicles for use in medical deliveries, partly supported by corresponding government funding programmes. One prominent application in Germany is the pilot project Medifly, which is already in its second phase, funded by the BMDV with several project partners, including Lufthansa Technik AG, FlyNex GmbH and Hamburg Aviation e. V. [87]. The project idea is based on the problem that patients often need urgent medication during operations or that biopsies must be examined during medical interventions in external laboratories. Important time can thus be lost due to road transport over long distances in the city. With the help of the transport of medication and medical samples by UAV in urban areas, it is demonstrated how transport times can be reduced and operations can be carried out more efficiently for the benefit of the patient, considering the corresponding legal and technical framework conditions [87, 88]. Following successful test flights between two municipal hospitals in the city of Hamburg at the beginning of 2020 [89], the drone network is now to be automated and implemented in BVLOS mode between several hospitals in the city, with the aim of regular operation [87]. Another test project in drone logistics for laboratory diagnostics was launched in 2020 by the Swiss company Matternet in cooperation with Labor Berlin Charité Vivantes in Berlin. The established BVLOS drone delivery network is expected to increase timeliness (up to 70 % faster) and efficiency of sample transports between three locations in Berlin [90].

Drone applications (and BVLOS cases in particular) are subject to strict regulations and safety requirements in Germany (e. g. regarding evasive manoeuvres of drones in oncoming traffic) and require corresponding management systems to ensure the operational safety and integration of UAV into the regular airspace. The European system currently being developed for this purpose is based on the U-Space concept and consists of specific services and processes (e. g. network identification, geo-awareness, or traffic information) that are intended to enable drones to access airspace safely and efficiently (see also chapter 4.3). With the participation of member states, the U-Space regulatory package was approved by the European Union Aviation Safety Agency (EASA) Committee in February 2021 and subsequently adopted and published by the European Commission in April 2021. The three implementing regulations of the U-Space regulatory package will apply from 26 January 2023 [91].

Germany's envisaged integration of UAV into existing airspace structures through U-Space airspaces is intended to advance automated and connected aviation while protecting private data and the environment. To this end, Germany is currently establishing a U-Space Real Laboratory (»U-Space Reallabor«) to ascertain potential obstacles and challenges. The cooperation to establish the U-Space Reallabor at the national level focuses on bringing together relevant administrations of the German federal states, the drone industry and research institutions [91]. With the launch of the first U-Space Reallabor in 2021, a groundbreaking project has been initiated and an important undertaking from the German Federal Government's Drone Action Plan on unmanned aerial systems and innovative aviation concepts has been implemented [6].

Funded by the BMDV, the Deutsche Flugsicherung (DFS) as air navigation service provider and its subsidiary Droniq GmbH, together with the Hamburg Authority for Economy and Innovation and other partners, have set up the first German U-Space test field in the airspace above the port of Hamburg. For the first time in Germany, coordinated flight operations between unmanned and manned aviation can take place at this location [92]. Findings from this pilot project will serve as a blueprint for further implementation of the concept in Germany and Europe (in terms of the construction of regular drone airspaces) [93]. Drone flights with a flight altitude of up to 150 m in a spatially delimited airspace element (U-Space) are carried out. Among other things, automated communication between drones and other air traffic participants, the organisation of airspace and automated flight permits for drones are being tested. The drone traffic management system developed by DFS serves as a basis for the implementation of the Reallabor [92, 94, 95]. In addition, other companies such as the Hamburger Hafen und Logistik AG (HHLA) are working on using UAV for tasks such as safety checks, inspection of loading cranes and intralogistics transport within the port [96].

The Port of Rotterdam in the Netherlands is also demonstrating the ecological and economic potential of drone systems in pilot projects and is attempting to integrate the previously separated sectors of aviation and shipping more closely. At the end of 2021, autonomous long-range drones were used to monitor port activities and inspect port facilities (e. g. quay walls, bunker storage, water and air pollution) in the port area. The tests carried out in the port of Rotterdam are part of the innovation programme »Drone Port of Rotterdam«, in which UAV systems of different types are used for distinct purposes. The initiative aims to test new technologies that make the port safer, smarter, and faster [97]. The »Drone Port of Rotterdam« will look at the use of drones under five different headings: (1) Rotterdam, the Safest Port to Fly; (2) Drones for the Port of Rotterdam Authority; (3) Drone Services Port; (4) U-Space Airspace and (5) The Mobile Port [98].

Another application area of drones, which they can cover time- and cost-efficiently in the future, is the aerial collection and recording of traffic data. Traffic data is essential as a basis for transport planning, traffic forecasts and analyses, traffic control, calculation of route options and the subsequent development of transport management measures. In a pilot project of the BELLIS GmbH, UAV have been used since 2020 to record traffic data in city areas in Germany. Test flights show that around 99 % of the data recorded by drones matches the manually counted values. Compared to other counting methods, such as detector counting, UAV can even achieve higher accuracy. In addition to conducting and evaluating pilot flights, the demonstration project will also discuss the legal and regulatory framework and education and training measures for drone pilots [99, 100].

Finally, there are research and pilot initiatives that focus on UAM and the transport of people within cities by means of drones. One example of a promising demonstration project in Germany is the Air Mobility Initiative (AMI), which was founded under the lead of Airbus together with other companies, universities, and the city of Ingolstadt. The project, which is one of Europe's largest initiatives in this field with around 30 partners (including Deutsche Bahn, the German Red Cross, the Technical University of Munich, and the Deutsche Telekom), aims to advance the development of electric air transport. For the first time, taxis are supposed to transport up to four people electrically at a speed of up to 120 km/h over a distance of about 80 km in 2023 (certification begins in 2024). As a first step, the AMI partners will address the technological, infrastructural, legal, and social prerequisites for future urban air transport [101]. In Paris, there are plans to use air taxis on a pilot basis as part of the Olympic Games in 2024. One possible use of drones for passenger transport could be the connection of the city's airports with sports venues. The German start-up Volocopter is working together with the French Civil Aviation Authority on a multi-stage test and market development programme (the company is also aiming to start commercial flights in Singapore). However, the flight taxis still require certification before they can begin trial operations and flights with passengers [102]. Another company working on sustainable urban and regional air mobility and involved in German and international pilot projects is Lilium Air Mobility, a start-up founded in 2015 in Germany [103].

The pilot projects carried out in Germany, especially the described U-Space project in the port of Hamburg, have contributed to prepare the establishment of the first regular drone airspaces in Germany from 2023 onwards. This should further increase safety in German airspace and enable more innovations in unmanned aviation [104].

6 Conclusion and Outlook

As a globally dominant market for consumer and commercial drones and home to the most innovative UAV companies and start-ups, China, with its important centre Shenzhen, is at the forefront of technological maturity of the drone industry. At the same time, digitalisation in the Chinese transport sector is well advanced and, moreover, the entire drone supply chain is integrated at the domestic level. Some globally significant companies such as DJI are setting the pace in the global market through their high speed of innovation, leading to a technological advantage over their competitors. This indicates that the current rapid industry growth will be maintained in the future and may be further accelerated by disruptive technological innovations combined with a rising domestic demand for drones (especially driven by the logistics and delivery sector). This trend is complemented by the Chinese government's political and regulatory support and substantial investments into the drone industry [14].

It is apparent that Chinese drone manufacturers have started to integrate new unmanned aerial systems into transport and mobility (for people, goods, and services) at a very early stage via large pilot and demonstration projects to gain valuable operational experience. The findings from the pilot projects described in China and Europe show that UAV hold great potential for taking over tasks originally performed by combustion-engine-powered vehicles. This is particularly evident in the context of urban mobility (e. g. avoiding traffic jams) as well as in rural applications (e. g. accessibility of remote areas). Delivery by drones offers the advantage of fast delivery speeds at low operating costs and is independent of road conditions. Drone usage enables the application of unmanned aerial concepts for first/last mile and urban short-distance express deliveries or the execution of logistics tasks in rural areas. However, like any technological innovation, an economically and technologically viable and sustainable use of UAV in the future will initially require high investments in hardware and in technological improvements, for example, regarding longer battery life or research on new propulsion systems for drones (e. g. hydrogen and fuel cells).

Despite the multi-layered and complex nature of China's drone regulation with sometimes unclear responsibilities, the country has managed to drive the growth of the drone industry especially in the areas of transport and logistics, agriculture, and environmental protection. Major reasons for this can be found in the favourable regulations and policies related to innovation and technology. In addition, regulators are continuously adjusting and optimising the entire administrative system to keep up with the challenging pace of development and innovation. This is especially important in the light of the rapid diffusion of drone applications and the resulting potential threats to public safety. In its published UAV guideline, the MIIT states that it will create and revise more than 200 rules for research, production, application, and safety regulation for civil drones [14]. To make the use of UAV in transport and logistics future-proof, a comprehensive and efficient administrative system must be put in place to manage the increasing number of drones. At the same time, high-quality and wide-ranging communication must be ensured through 5G and big data technologies. With the support of these technologies, drone management systems will achieve full integration of manned and unmanned aviation. China has already taken an important step in the further development of domestic drone management with the demonstration and deployment of such systems.

In recent years, both Chinese and German policymakers have reaffirmed their positive stance on opening up the low-altitude airspace to unmanned aerial systems (including by increasing support for pilot projects and initiatives to integrate drones into transport) and accelerating the development and implementation of drone-related policies. Digital infrastructure development, regulation and standardisation, technology development and user acceptance are important factors that will influence the dynamic drone market in the future and accelerate the development of the UAV industry in both countries. In this promising field of transport and key industrial technology, China, Europe, and Germany can certainly derive positive results from a joint dialogue both at the technical and political level.

Appendix: Exchange Rates

Table 3: Euro Foreign Exchange Reference Rate of the European Central Bank for CNY and USD (Data: [105, 106])

Year	Exchange 1 EUR = … CNY	Exchange 1 EUR = … USD
2017	7.6290	1.1297
2018	7.8081	1.1810
2019	7.7355	1.1195
2020	7.8747	1.1422
2021	7.6282	1.1827

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