



Department of Infrastructure, Transport, Regional Development and Communications

Economic Benefit Analysis of Drones in Australia

Final Report

Deloitte Access Economics, 23 October 2020

23 October 2020

Re: Economic Benefit Analysis of Drones in Australia, *Final Report*

Deloitte Access Economics was commissioned by the Department of Infrastructure, Transport, Regional Development and Communications (DITRDC) to investigate the economic benefit of drones in Australia. This *Final Report* details the findings of this Study. Outlined in this Report is findings and analysis of use cases for drones over the medium to long term as well as cost savings from the application of drones across different sectors in the Australian economy. Economy-wide modelling is used to estimate the broader economic impacts of uptake of drone technology on the Australian and regional economy in terms of jobs and output. The regulatory environment is also briefly considered in terms of its importance in achieving the potential economic benefits estimated.

Restrictions on report use

This report may be relied upon by the DITRDC in describing market analysis for drones, use cases for drones and economy-wide modelling of drone uptake scenarios conducted for the Department. Deloitte disclaims all liability to any party other than DITRDC for all costs, loss, damage, and liability that the third party may suffer or incur rising from or relating to or in any way connected with the provision of deliverables to a third party. If others choose to rely on the report in any way they do so entirely at their own risk.

Basis of our work

We have based this work on our economic research and analysis of publicly available data as well as our own economic analysis. To the extent that these key information and data change, the results of the economic analysis are likely to change.

For all enquiries on this Report please contact Steve Kanowski - skanowski@deloitte.com.au or 0477 727 754.

Kind regards,



Steve Kanowski

Partner, Deloitte Access Economics

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Executive summary

Key findings 'at a glance'



The global drone industry is estimated at \$100b total addressable market (2016-21)

Source: Drones reporting for work, 2016

Overview

Drones have significant potential to boost the Australian economy and its regions over the next 5, 10 and 20 years. This is through both the growth of the drone industry itself and the cost savings and broader productivity benefits uptake of this technology and use of its services could generate for a range of sectors in the nation.

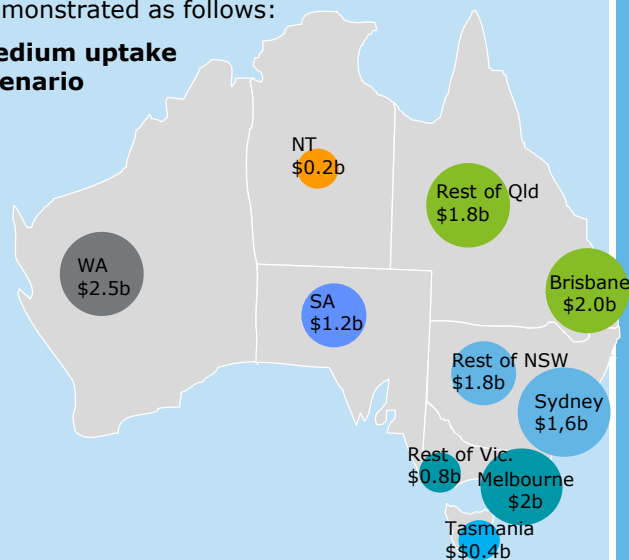


Drones

Regions

The economic potential of drones is estimated to be significant across Australia's states and territories as well as major cities. The present value of the deviation in real GRP (at a 7% real discount rate) over 2020 to 2040 is demonstrated as follows:

Medium uptake scenario



Source: Deloitte Access Economics (DAE), medium uptake scenario

Economic scenario modelling

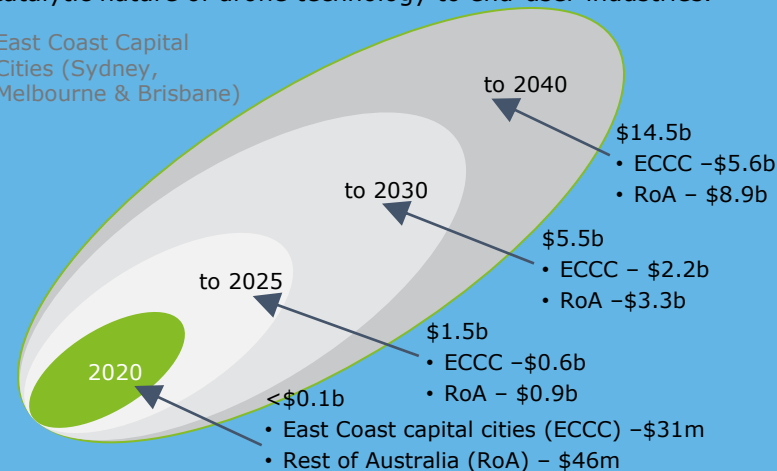
The future economic potential of the drone industry is uncertain. As such, this study applies a scenario-based economic modelling approach to estimate the size of the future 'economic dividend'. Scenarios are not predictions about what will happen. They are hypotheses about what could happen, designed to open our eyes to new opportunities or hidden risks. The impacts of **economic scenarios presented in this report** are modelled relative to a 'baseline forecast'. This is an underlying rate of economic growth in the Australian/regional economy and drone production/uptake.

To provide a range of potential outcomes low, medium and high scenarios have been analysed. However the focus of the report is the medium uptake scenario or 'most likely' scenario. The medium uptake scenario represents an increase in the uptake rate in existing sectors (e.g. agriculture, mining, construction) as well as growth in new use cases. The modelling highlights the impact on Australian GDP could range from **\$9.4 billion to \$20.7 billion in the low to high scenarios (present value at 7% real discount rate)**. The results of the low and high uptake scenarios are summarised in **Appendix A**.

Economic impacts (medium uptake scenario)

The size of the economic dividend for Australia (**Australian GDP**) is estimated to accelerate from 2025-2030 onwards to circa **\$15 billion** by 2040 in line with the assumed increase in uptake rates across a variety of compelling use cases (see overleaf). There are expected to be positive impacts experienced across major capital cities as well as other parts of the nation. This highlights the catalytic nature of drone technology to end-user industries.

East Coast Capital Cities (Sydney, Melbourne & Brisbane)

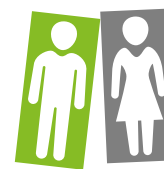


Source: DAE

Medium uptake scenario



Australian real GDP is predicted to expand
\$14.5b



Growth in the uptake of drones is expected to support jobs across the economy

5,500 full time equivalents (FTE) jobs on average per annum (2020-2040)

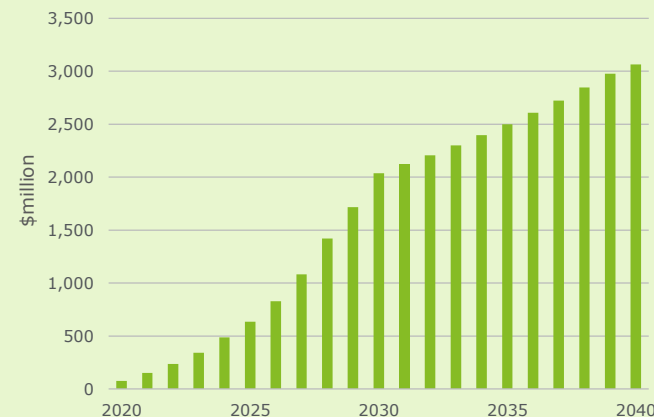


Direct cost savings at 7% real discount rate
\$9.3b

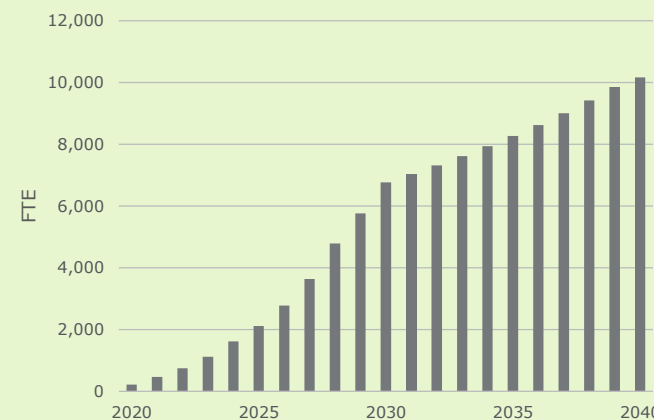
Source: DAE

Value of drones to Australia, present value @7%, 2020 to 2040

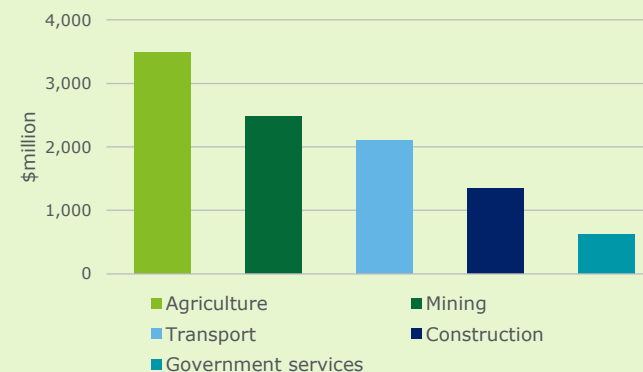
Economy-wide impacts, Australia, 2020 to 2040



Job creation potential, Australia, 2020 to 2040



Industry impacts, Australia, 2020 to 2040



Source: DAE



There is a wide range of ‘compelling use cases’ for drones in the nation

Use cases

This report presents the findings of research and analysis to estimate the size of the total addressable market (TAM) for the major uses for drones. This includes urban/regional air mobility, E-commerce and deliveries and the uptake of drones in a range of industries including agriculture, mining, construction, government, defence and recreational use.

Summary findings of compelling use cases including market analysis (medium uptake scenario)

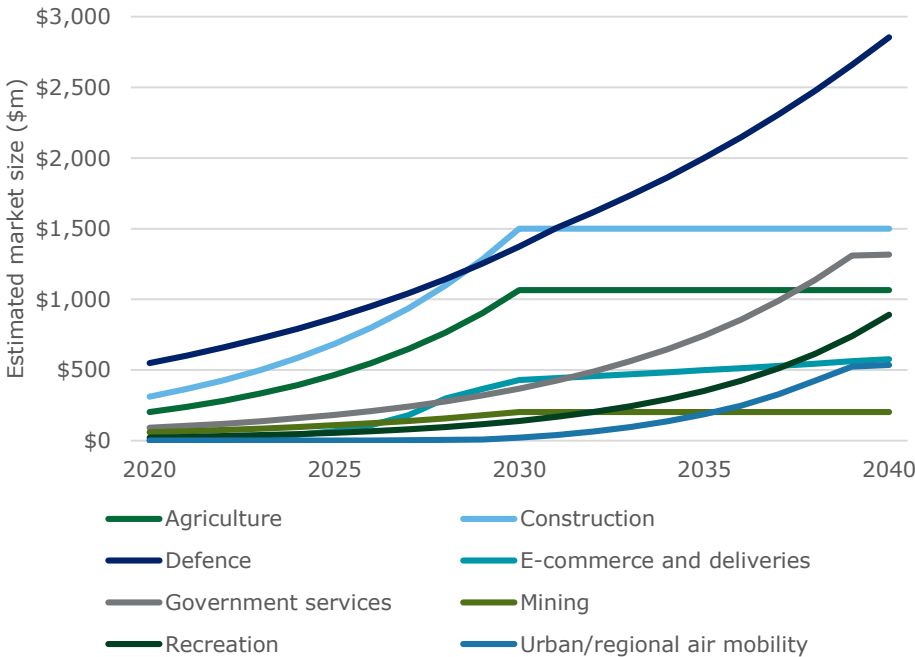
Use cases		TAM	Market penetration – 2040 (%)	Est. market size – 2040 \$m
Urban / regional air mobility	Airport taxi trips	Airport taxi passengers	1.5% to 25%	\$285m
	Point-to-point trips	Other taxi trips	0.1% to 3%	\$234m
	Regional air mobility	Short route domestic aviation	0.1% to 3%	\$74m
E-commerce and deliveries	Express parcel deliveries	Express parcels	13% to 22%	\$223m
	Food deliveries	Food deliveries	53% to 75%	\$264m
	Regional and remote pathology deliveries	Pathology tests	4% to 9%	\$88m
Agriculture, forestry and fishing (AFF)		AFF businesses	27% to 67%	\$1,066m
Construction (Con.)		Con. businesses	41% to 75%	\$1,501m
Mining (Min.)		Min. businesses	41% to 75%	\$202m
Government services		Government spend	17% to 67%	\$1,316m
Defence		Defence spend on surveillance	75% to 95%	\$2,855m
Recreational		Population	2.5% to 40%	\$891m

Source: DAE

The potential for drones to achieve cost savings and other benefits will ‘drive’ the use cases

The anticipated growth in the uptake of drones will create new opportunities for industry by improving/automating some production processes and leading to cost savings over the medium to long term. It could also lead to new transport services such as urban/regional air mobility along with E-commerce and delivery services. The estimated market size for each of the major compelling use cases over the next 5, 10 and 20 years is provided in the following chart. This highlights the estimated different stages of maturity of each of the markets and indicative growth profiles based on research conducted for drones in Australia.

Estimated market size by compelling use cases, 2020 to 2040 (medium uptake scenario)



Source: DAE

Estimated cost savings, present value @7%, 2020 to 2040

	Estimated cost savings
Agriculture, forestry and fishing	\$2,950m
	E-commerce and deliveries
	\$1,875m
	Construction
	\$1,340m
	Mining
	\$2,395m
	Government services
	\$620m
	Urban/regional air mobility
	\$100m

1. Overview

The structure of the report addresses each of the areas the Department of Infrastructure, Transport, Regional Development and Communications (DITRDC) is interested in with respect to drone technology. It provides the level of rigour, research and quantitative analysis to inform the issues paper recently drafted by the Department as well as future policy directions.

The structure of report is as follows:

- **Overview** – The overview gives a brief background and context to the report.
- **Chapter 2: Market analysis of drones** – This analyses the characteristics of the drone market including current and emerging trends.
- **Chapter 3: Analysis of use cases for drones** – This focuses on compelling use cases in Australia from industry use to recreational use. The use cases quantify the initial uptake into the Australian/regional market and rate of adoption over time. To account for uncertainty a scenario based approach is used.
- **Chapter 4: Analysis of cost savings from drone technology** – This estimates the potential cost savings associated with the use of drones across industries in the Australian economy.
- **Chapter 5: Economy-wide impacts of uptake of drone technology** – This presents the results of economy-wide modelling of the impacts of the medium drone uptake scenario at the Australian and regional level. The focus of this chapter is presenting the results of the medium uptake scenario.
- **Chapter 6: Regulatory considerations**– This briefly discusses the current regulatory environment and the importance of regulation in achieving the potential economic benefits as outlined in Chapter's 4 and 5.

Appendix A: This appendix provides further technical detail on our in-house economic model used to estimate the economy-wide impacts presented in this report. The appendix also gives summary results for the low and high drone uptake scenarios.



The report analyses the benefits of drones to the Australian and regional economy by quantifying the uptake and use of drones across multiple users and industries. Drones carry out a variety of different tasks allowing automation of activities (i.e. capital replacing labour) and potentially lead to cost savings, safety benefits and other benefits.

Overview

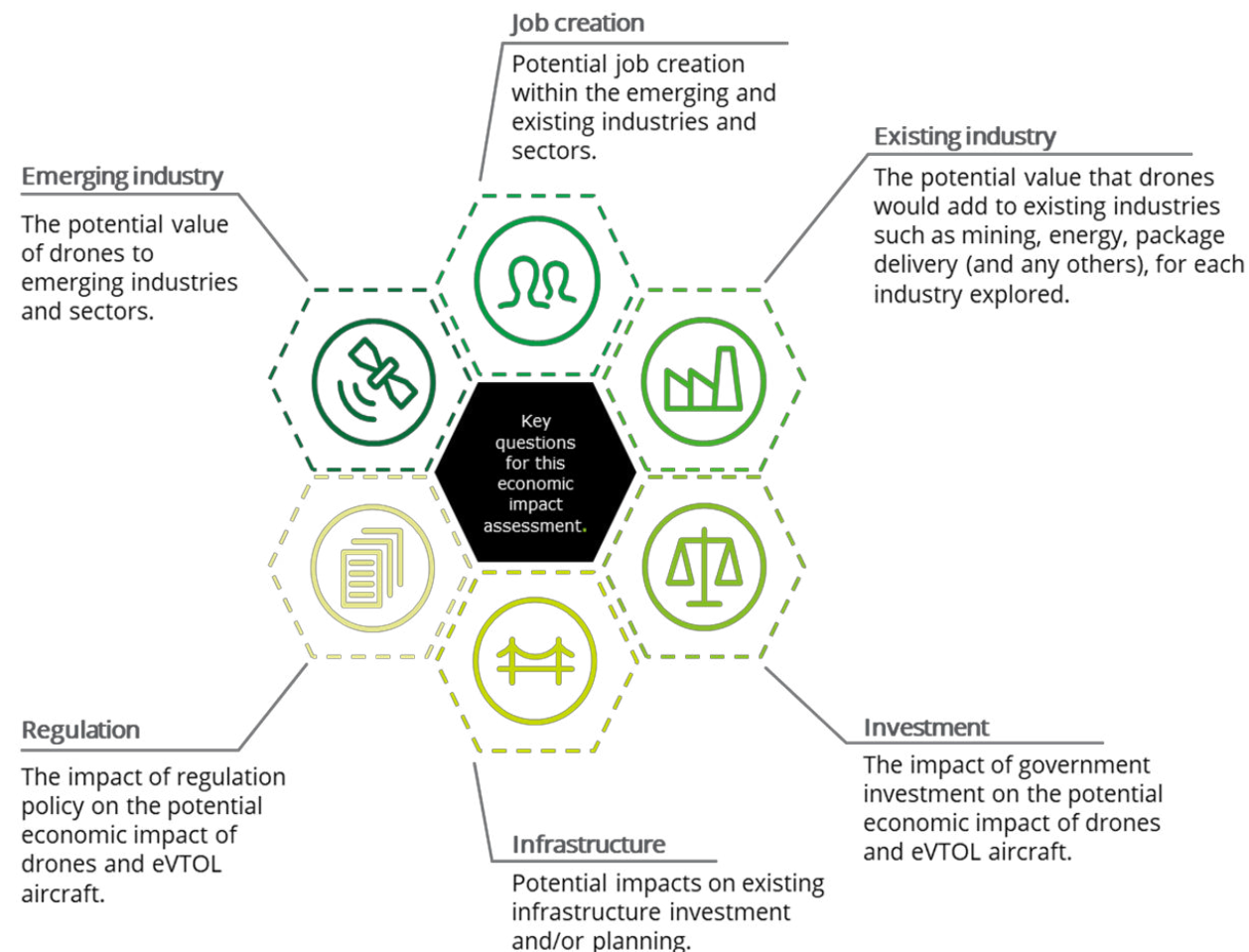
The DITRDC engaged Deloitte Access Economics to estimate the potential economic impacts (benefits, uptake and savings) of the broader adoption and use of drones to the Australian economy. The analysis includes examination of the potential benefits of electrical vertical take-off and landing (eVTOL) aircraft.

In addition to the economy as a whole, the report analyses the value of drones at an industry level including agriculture mining, energy, construction, other industries and end users.

In this report the terminology 'drones' is used to refer to unmanned aerial vehicles (UAV), remotely piloted aerial systems (RPAS) and unmanned aerial systems (UAS).

A bespoke partial economic model has been developed to estimate the potential timing and uptake of drone technologies. The Deloitte Access Economics Regional General Equilibrium Model (DAE-RGEM) is then used to estimate the economy-wide impacts of productivity enhancements and job-creation potential. This model uses the outputs of the partial model that estimates uptake rates and costs savings.

Figure 1: Implications of the emergence of drones technology



2. Market analysis of drones

There are two main categories of drones, namely rotary wing and fixed wing drones. They have different characteristics making them suitable for a range of commercial applications and consumer uses. The emergence of the drone market has been rapid since 2015 with investment by venture capital firms resulting in improved technology and lower production costs.

Defining drones

Drones can take many forms with two major categories namely rotary wing and fixed wing (refer to Table 1 for characteristics of each type).

Fixed wing drones have a similar look to regular aircrafts. The simpler structure and more efficient aerodynamics allows for higher speeds and longer flights, which is ideal for mapping of large areas. Rotary wing drones (helicopter, quadcopter, hexacopter and more), in comparison, are more complicated in mechanical structure and have a shorter range and flight times. However, rotary wing drones do not require runways, are more agile in the air, and are able to hover in the same place for extended periods. The definition of drones includes aircrafts that carry human passengers such as eVTOL aircraft.

Market developments

The accelerated development of the drone market started around 2015 with venture capital investments in UAV manufacturers and UAV application developments tripling compared to 2014.¹ This trend has continued with drones having higher functionality and reaching a broader range of market segments. The level of technology embedded in drones will continue to improve. Unit prices are also likely to fall with drones being produced in higher volumes resulting in economies of scale. The demand for drones is also projected to grow rapidly as the technology has many end-use applications. This is likely to increase demand both across industry uses and by households globally.

¹ Oppenhiemer, Drone Industry Report, Equity Research, Industry Update, February 2016

Table 1: Rotary wing and fixed wing drones

	Fixed wing	Rotary Wing
		
Applications	Land surveying (rural) agriculture, GIS, mining, environmental management, construction, humanitarian	Inspection, cinematography/videography, real estate, surveying (urban), construction, emergency response, law enforcement, passenger movement
Cruising speed	High	Low
Coverage area	Large	small
Object resolution	cm/inch per pixel	mm per pixel
Take-off landing area	Large	Very small
Flight Time & Wind resistance	High	Low

Source: Oppenhiemer, Drone Industry Report, Equity Research, Industry Update, February 2016

The market for drones is at the early stages of development with future growth characterised by an 's-curve'. However with new technologies there is a range of possible paths from the stage of early adoption to more mature technology. Past innovations have been characterised by a fast rate of uptake till they reach a stage of maturity.

Path of new technologies

The broad consensus across different forecasts is that the market for drones will experience rapid growth and will become a multi-billion dollar industry.² The state of drones prior to 2010 is said to have been characterised by the early PC: costly, cumbersome and difficult to operate, with adoption mainly limited to government agencies, the military, academic communities and 'hobbyists'.³ There was no universal design, consolidation of global conglomerates or integration of technologies towards major applications, with limited exceptions such as widespread use of drones in Japanese precision agriculture.⁴

Acceleration in technological development has occurred since 2010, with the integration of drones with smart phone technology, as well as camera and global satellite positional technology and technology for consumer (leisure) market drones (e.g. the 'A.R drone' in 2010 and the 'phantom' drone in 2012). The pace of market development further increased in 2015, with new market entry and a tripling of investment resulting in greater sophistication of drone functionality and a wider range of market segments.⁵ A summary of drones market tiers is provided in Figure 2.

Figure 2: Market tiers and characteristics

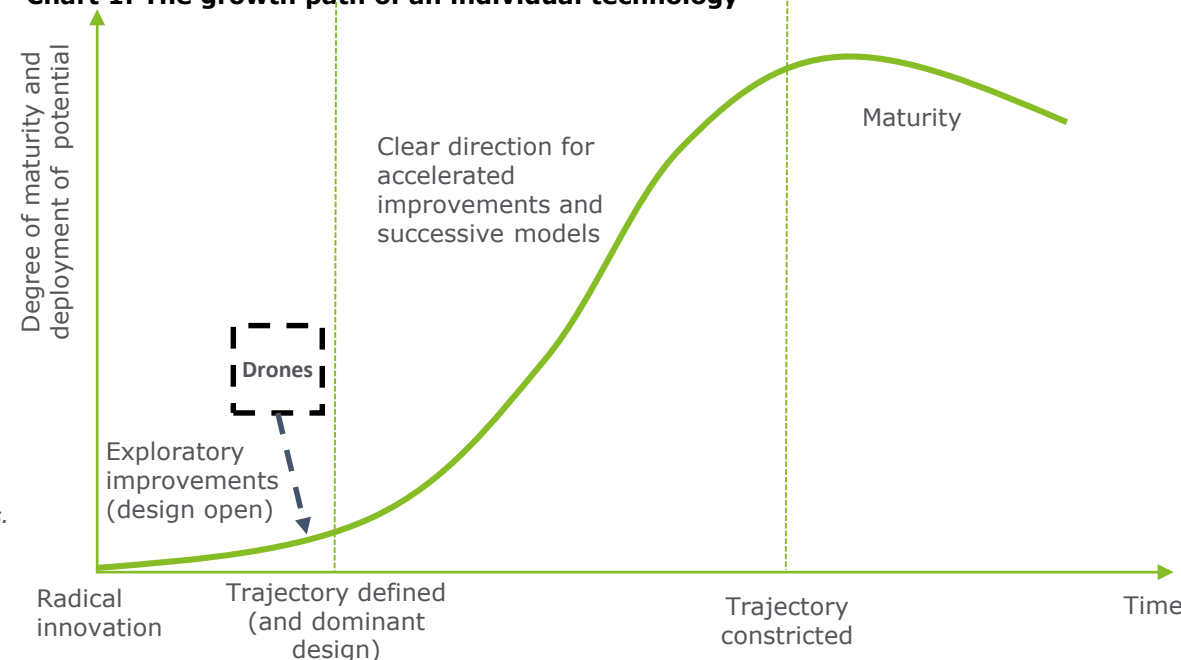
Leisure	'Prosumer'	Professional
High definition/full high definition video, basic flight control software. Premium specs brought down to mass market price points. -	Gimbal, (detachable) full high definition/ultra high definition camera, range sensors. Most rapid innovation: machine vision, image processing, range sensors, and robotics (autonomous control systems).	Large payload, extended range and flight time, advanced sensors. End-to-end solutions to customer, from drone design to software and cloud-based services. Greatest variation in look, price and specification.

Source: Concepts from Oppenhiemer, 2016

Characterising the technology

Globally, it is considered that drones are still in the earlier stage of development, which provides the potential for rapid growth in the future. The capability to successfully move up the 's-curve', that is used to depict the stages of development of a new technology, will depend on multiple factors including technology, regulatory and social factors.⁶

Chart 1: The growth path of an individual technology



Source: Adapted from Oppenhiemer, Drone Industry Report, Equity Research, Industry Update, February 2016

² International Transport Forum, 2018. (Un)certain Skies? Drones in the World of Tomorrow. OECD.

³ Oppenhiemer, 2016. Drone Industry Report, Equity Research, Industry Update, February 2016

⁴ Ibid.

⁵ Ibid

⁶ Ibid

In many sectors commercial drone applications are still in the early to middle stages of development suggesting significant potential for market sales in the future along with the benefits drone technology can bring through increasing efficiency of production and increased safety as drones take over higher risk tasks previously done by workers.

Technological progress⁷

Prior to reaching maturity, technological advancement phases include instalment and then deployment. The early 'instalment' phase of drones has been facilitated by the progress in both smartphones and cloud computing, with smartphones approaching the end of its high growth phase. Communication systems are already characterised as in the late stage of development (refer to Table 2), with smartphones and tablets providing a universal, intuitive, and flexible user interface for all drone users.

Further development is required in 'batteries and other power', and 'detect, sense and avoid capabilities' which will be particularly important in applications such as air transportation and freight/parcel delivery. In addition, the deployment phase is expected to be undertaken through application developers and software upgrades across smartphones, smartphone-connected devices (drones), cloud-based services and smartphone-enabled services.

Commercial use

The success of the professional and commercial segments will be crucial to determine whether UAV will reach maturity as a major technology category. As clusters of sensors, drones are mobile, intelligent, and connected, ranging from basic (GPS sensor, inertial sensors, image sensors, and range sensors) (ultrasound-based) to more specialized drones with thermal sensors, hyper-spectral and multispectral sensors.

Drones are increasingly being 'packaged' with both cutting edge sensors and image processing software, to provide better data acquisition, and better analysis and decision making. Oppenhiemer remarks⁸ that 'drones are essentially nodes in the 'internet of things' that can be deployed on-demand to situations too dangerous or too difficult for humans to access' The applications are widespread, at varying stages of commercial maturity and technological development, with many industries able to take account of benefits from improved efficiency (productivity), greater cost effectiveness, and improved safety (refer to Table 3).

⁷ Oppenhiemer, Drone Industry Report, Equity Research, Industry Update, February 2016

⁸ Ibid.

Table 2: Maturity of commercial drone applications and technology

Category	Early stage	Middle stage	Late stage
Advanced manufacturing			
Batteries and other power			
Communication systems			
Detect, sense, avoid capabilities			
GPS			
Lightweight structures			
Microprocessors			
Motors			
Engines			
Sensors			

Table 3: Maturity of commercial drone applications and technology

Category	Stage of development
Aerial photography	Late stage
Aerial patrol (e.g. border control and public safety)	Late stage
Precision agriculture	Late stage
Emergency management	Middle stage
Construction/real estate images and monitoring	Middle stage
Infrastructure monitoring	Middle stage
Film making and other media uses	Middle stage
Oil and gas exploration	Middle stage
Weather forecasting and meteorological research	Middle stage
Mail and small package delivery	Early stage

Source: Oppenhiemer, Drone Industry Report, Equity Research, Industry Update, February 2016

Passenger and delivery drones will become increasingly important in Australia in a range of applications. Investment in research and development by venture capital firms and large corporations including aerospace companies is accelerating the development of this technology. There could be a number of 'compelling' use cases for Australia in the medium term to longer term.

Lower Level Airspace vehicle market in Australia

Passenger and delivery drones, and other Lower Level Airspace (LLAS)⁹ vehicles have the potential to address today's challenges such as road congestion, improved logistics, and to generate new products, services and markets. Traditional aerospace companies, automobile manufacturers, logistics providers, multinational technology conglomerates and start-ups are investing billions of dollars in LLAS passenger and delivery vehicles (also referred to as drones), eVTOL aircraft, UAS, Unmanned Aircraft Traffic Management (UTM) systems and other parts of the LLAS value chain.¹⁰ Australian authorities are anticipating, in the long term, the integration of manned and unmanned aviation, although regulatory hurdles remain.¹¹

Investors aligned to compelling uses

Many different LLAS vehicle designs are being refined and prepared for certification with over 100 projects announced and multiple vehicles in testing phases.¹² Partnerships between the world's largest brands, such as Google founder and former Alphabet CEO Larry Page and Boeing have taken place to create a vehicle start-up called Kittyhawk. Kittyhawk provides solutions for insurance, public safety, construction, media and entertainment, oil and gas, and utilities requirements, offering security and compliance management tools for Enterprise UAS Operations, as well as integrated software, data storage and flight management software. Uptake is already extensive, in the United States (US), where Kittyhawk estimates that utility customers provide energy services to over 50 million homes and businesses.¹²

⁹LLAS is a commonly used international term generally understood to refer to all airspace below circa below 5 kilometres.

¹⁰ SESAR, "European Drones Outlook Study - Unlocking the value for Europe," 2016.

¹¹ NASA, "Urban air mobility study," NASA, Houston, 2018.

¹² <https://kittyhawk.io/solution/utilities/>

¹³ Boeing, "Cargo Air Vehicle Completes First Outdoor Flight," 2 May 2019. [Online]. Available: <https://www.boeing.com/features/2019/05/cav-first-flight-05-19.page>

¹⁴ Airbus, "Skyways: urban air delivery explored," 26 November 2017. [Online]. Available: <https://www.airbus.com/newsroom/news/en/2017/11/skyways-urban-air-delivery-explored.html>

¹⁵ Embraer, "EmbraerX and Elroy Air Sign Agreement to Collaborate on Unmanned Air Cargo," 8 January 2020. [Online]. Available: <https://embraer.com/global/en/news?slug=1206682-embraerx-and-elroy-air-sign-agreement-to-collaborate-on-unmanned-air-cargo>

¹⁶ Bell Helicopter, "Bell Unveils Full-Scale Design of Air Taxi at CES 2019," 7 January 2019. [Online]. Available: <http://news.bellflight.com/en-US/170543-bell-unveils-full-scale-design-of-air-taxi-at-ces-2019>

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Boeing is also prototyping a cargo air vehicle, known as a heavy-lifter carrying up to 225kg.¹³ Airbus has also been working on multiple vehicle demonstrators, two passenger drones (the Vahana and the City Airbus) and a commercial parcel delivery drone (Skyways).¹⁴ Embraer (the Brazilian airplane manufacturer) is developing a passenger drone EmbraerX and is prototyping a delivery drone in collaboration with Elroy Air.¹⁵ The American helicopter manufacturer Bell is also developing a passenger drone (Bell Nexus) and a delivery drone (Bell APT).¹⁶

Hyundai recently unveiled a LLAS vehicle concept (Hyundai S-A1), with the view of supporting an air taxi network, which was created in partnership with Uber Elevate.¹⁷ Boeing, Embraer, Bell and Pipistrel are also Uber Elevate vehicle partners.

Compelling uses for drones in the Australian market

Areas which could be compelling for future use, such as **by late 2020s**, include:

- *Urban mobility*, including airport tax trips, other taxis and inter-city trips
- *E-commerce and deliverables*, including the delivery of express parcels, food deliveries, imported pharmaceutical deliveries (with high value/low weight), regional and remote pathology drone deliveries, medical deliveries in remote areas and some cargo-airfreight
- *Government and community services*, including emergency ambulance responses, fire response, search and rescue, border patrol, local law enforcement, disaster management and monitoring, conservation management, mapping and research.

Those already in place to an extent, although lower than potential, include:

- *Agriculture*, including crop, livestock and large land monitoring, and crop spraying/ pellet application
- *Mining and resources*, including stockpile measurement /geotechnical modelling, blast and mine reclamation monitoring, and equipment inspection
- *Defence*, including direct warfare and surveillance activities
- *Inspections across the construction and infrastructure sectors*, including power lines, bridges and rail
- *Other*, such as recreational flights, photography and filming.

¹⁷ Hyundai, "CES 2020 Hyundai Unveils UAM S-A1," 8 January 2020. [Online]. Available: <https://www.hyundai.com/worldwide/en/company/news/news-room/news/ces-2020-hyundai-unveils-uam-s-a1-00016375>

A series of investments have been made into the software market to increase the capacity of LLAS users to safely fly, to enable the integration of traditional and UAV traffic, and to support the annual growth of the industry. Drone technology has the potential to provide more time and cost effective solutions through reduced labour and risk, particularly in infrastructure, agriculture, transport and security.

Investment in the unmanned aircraft systems traffic management (UTM) software market

Supporting this potential is a large series of investment made in to the broader UTM software market. Thales is investing in developing an 'ECOsystème' together with Unifly¹⁸, who have raised ~\$40 million, although mainly from the German ANSP Deutsche Flugsicherung GmbH DFS (responsible for air traffic control in Germany) and Belgium's federal investment fund.¹⁹ Thales will leverage this expertise in air traffic management, system integration and cyber security, aiming to provide the leading UTM application. The solution will incorporate Unifly's validation engine, a sophisticated software application that conducts real-time validation of drone flight plans, into Thales ECOsystem and a decision support platform for improved aviation operations.

AirMap, provides mission planning, flight and capture, and dataflow automation solutions to enterprises and third-party solution providers, for both commercial and national defence use in the low altitude air space. AirMap's UTM and U-space products are deployed in the Czech Republic, Japan, Singapore, Switzerland, the United States, and available in over 30 countries, serving over 300,000 registered operators. AirMap was supported by Microsoft, Airbus and Sony as major investors, through market raising of ~\$65 million.²⁰ Others, such as Altitude Angel, have raised lower contributions (~\$7 million).

¹⁸ Unifly NV, "Thales launches ECOsystem UTM and joins forces with Unifly to facilitate drone use," 2017. [Online]. Available: <https://www.unifly.aero/news/thales-launches-ecosystem-utm-and-joins-forces-with-unifly-to-facilitate-drone-use>

¹⁹ Deutsche Flugsicherung (DFS), "DFS invests in Unifly NV," 21 December 2018. [Online]. Available: https://www.dfs.de/dfs_homepage/en/Press/Press%20releases/2018/21.12.2018.-%20DFS%20invests%20in%20Unifly%20NV/

²⁰ Airmap, Inc., "What AirMap's Series A Financing Means for the Drone Ecosystem," 7 April 2016. [Online]. Available: <https://www.airmap.com/airmap-series-a-for-drone-ecosystem/>

²¹ 'Clarity from above: Global report on the commercial applications of drone technology'.

Ibid

Current industry adoption, innovation and outlook

In rural areas of Australia, the LLAS is already being used by mining companies, and is expected to offer greater operational efficiency in agriculture and to improve deliveries and services to those remote areas. Many new possible applications, particularly in agriculture, infrastructure, security, transport, media & entertainment, telecommunications, mining and insurance have been recently achieved through significant progress in technological capabilities and regulatory accommodation.

As detailed in the report *Clarity from Above*, 'the application of drone technologies in existing business processes is allowing companies from those industries to create new business and operating models', with drones creating a market from the labour and services that have a high potential for replacement in the very near future.

Based on the estimated size of the market for replacement, the industries with the largest value of drone powered solutions include infrastructure, agriculture, transport, security, media and entertainment, insurance and mining. Below we detail some of the industry-specific developments in three key areas.

Current and future drone solutions for infrastructure

Infrastructure, spanning across a range of industries from energy to transport (road and railways) to oil and gas, is an industry where drone technology will benefit more quickly than others. Such industries often require the management of extensive networks of assets covering vast distances. Key drone applications in infrastructure are investment monitoring, maintenance and asset inventory. The precision of work from the estimation/design phase to the construction phase can be improved through the use of drone technology, by providing investors and professionals (particularly managers) with real-time high-resolution videos and images, reducing the costly nature of current work practices based on in-person inspection, a slow and costly process that is often delayed, yields incomplete results and impacts on asset performance. This is also true for the maintenance of assets, where for example, cost savings on standard wind turbine inspection, inspections of bridges and tunnels, were identified as potentially 50%.²¹ Furthermore, drones are already being used for stock-taking and inventory management.

Drones offer greater precision, timeliness and labour cost savings associated with more efficient decisions on the management of natural and physical resources, with drone solutions increasingly providing the intelligence to allow meaningful interpretation of data, as well as applications for the delivery of services.

Using drones, enhanced by other new technologies such as optical barcodes and radio frequency tags, makes the process safer and much more efficient, with database integration creating a more detailed and reliable cataloguing process.

While these processes are already occurring, in the near future, in the 'Clarity from above' report, we could also expect:

- drones not only diagnosing problems with crumbling infrastructure, such as cracks in tarmac, bridges and building facades, and repairing them. For instance, it is expected that in future 3D printing technology will be combined with drone technologies to maintain and repair infrastructure, while also producing parts for damaged elements of infrastructure at the site.
- the use of drone technology to perform hazardous tasks at height, such as painting and window cleaning
- the development of small autonomous drones for building internal infrastructure (e.g. ventilation systems).²²

Current and future drone solutions for agriculture

Other than water, major constraints to agricultural productivity include the low efficiency and precision of crop monitoring, as well as the large areas of farmed land particularly with modern agricultural systems. The most advanced form of monitoring used is satellite imagery, where limitations include the requirement to order in advance, the infrequency (daily), cost, precision and limited effectiveness on a cloudy day.²³ In agriculture, drone technology offers a large variety of crop monitoring opportunities at lower cost, and 'drones can be integrated at every stage of the crop lifecycle, from soil analysis and seed planting to choosing the right moment for harvesting'.²⁴

²² 'Clarity from above: Global report on the commercial applications of drone technology'.

²³ Adão, T. et al (2017). 'Hyperspectral Imaging: A Review on UAV-Based Sensors, Data Processing and Applications for Agriculture and Forestry'. *Remote Sensing*. 2017(9);1110.

The first stage of any agricultural cycle is to analyse the soil, where drones are able to produce precise three dimensional (3D) maps allowing early soil analysis, which can be used to plan seed planting patterns. Drone planting systems have been able to achieve an uptake rate of 75%, and also decrease planting costs by 85%, suggesting the use of drones could revolutionise agricultural practices.²⁵ In addition, agricultural drone surveys can reveal problems with irrigation, pest infestation, or soil variation.

At a cost of around \$15,000²⁶, hyperspectral, multispectral or thermal sensors are able to show precisely which fields lack water or need improvements. Industry commentators state that some agricultural drone models come with software that can provide location-based prescription after the survey data has been processed, allowing farmers to step in with informed corrective actions. Adão et al (2017) state that 'the hyperspectral sensors' ability for measuring hundreds of bands raises complexity when considering the sheer quantity of acquired data, whose usefulness depends on both calibration and corrective tasks occurring in pre-and post-flight stages'.²⁷ For instance, a recent development is the use of sensors to scan a crop using visible light and near-infrared (NIR) light that shows which plants reflect different amounts of green light and NIR light, which produces multi-spectral images that spot changes in plants and indicate their health.²⁸ Artificial intelligence will be required to interpret the large database of 'hyperspectral signature', and (at least at this stage) decisions would be made alongside the use of traditional soil assessment data.

There is an increase in awareness of how drones can benefit the agricultural industry, such that some industry commentators have pointed to an increase in the global agricultural drone market by circa 32% per annum from US\$500 million in 2017 to around \$4.6 billion in 2025.²⁸

²⁴ Mikhailova S., "Using Ex-military Drones to Plant Trees", http://www.huffingtonpost.com/pro-journo/using-ex-military-drones_b_8414532.html

²⁵ World Agriculture, 2017. 'Top 3 List of Agricultural Drone Prices'. <https://www.agrotechmarket.com/2017/03/list-of-agricultural-drone-prices.html>

²⁶ 3D Insider, 2018. '5 Best Agricultural Drones'. <https://3dinsider.com/agricultural-drones/>

²⁷ PWC, 2016.

²⁸ 3D Insider, 2018.

Current and future drone solutions focus on high need, low risk applications. These are in testing and show strong potential, albeit with occasional problems that indicates further revision, testing and demonstration will occur prior to wider use.

The use of drones in agriculture is becoming more common, and with the capacity to be used for application of AgVet chemicals, will increase even more so (such as with the DJI Agras T16 Spraying Drone).²⁹ Drones increase the efficiency of spraying by spraying the correct amount of chemical required, reducing the amount of excess chemicals penetrating into groundwater. According to the 'Clarity from Above' report, experts estimate that aerial spraying can be done as much as five times faster than with traditional machinery such as tractors'.³⁰

Agriculture's key requirement from drones is the type and quality of data as well as good data processing capability. In addition, for those not seeking to use drone contractor services, farmers may seek drones that require a minimal level of training and a high degree of automation.³¹

Current and future drone solutions for transport for deliveries

Drones are expected to become an integral part of the transport industry very soon, due to large technological progress with the drivers being their speed, accessibility and relatively low operating costs compared with other forms of transport that require human labour. Congestion and remoteness will be significant variables in two distinct markets: cities and regional/rural Australia. It perhaps has the largest regulatory barriers to overcome, however, to the operation within heavily populated areas. The deliveries provided for by drones may include parcels, spare parts, medical logistics and food parcels.

Amazon has been running Amazon Prime Air, which seeks to automate last-mile delivery of packages using small drones. Early analysis suggested that sending a 2-kg package within a 10 km radius in the US by ground transport costs Amazon \$2 to \$8, compared with just 10 cents using a drone, with capacity for faster delivery timeframes than same-day packages.³²

Others such as Swiss Post, Matternet and Posti have been testing parcel deliveries by UAV since 2015. For instance, Posti, the Finnish national postal company, also tested delivery by drone for the first time in Europe in an inhabited urban environment, carrying a 3kg parcel around 4km. However, Swiss Post has suspended its trials of a drone service used to relay lab samples, after one of its drones crashed, however as of January 2019 had carried out about 3,000 successful flights.³³

Maersk, which operates a large fleet of tankers often in highly remote areas, has been searching for other options to deliver spare parts to its workers, and has also conducted drone delivery tests. Based on positive results, Maersk expects to be able to save \$3,000 to \$9,000 per ship annually using UAV technology.³⁴

Another application for drones is in medical logistics where the risk is low and need is high. The two foremost studies in the field concern drug transport and using drones as flying defibrillators. By decreasing the time between identifying the first symptoms of a heart attack and the defibrillation drone's rapid response, the survival rate can increase from 8% to 80%.³⁵ Flirtey (a US drone delivery start-up), NASA and Virginia Tech received special Federal Aviation Administration approval to perform the first official drone delivery of medication in the US, over a three minute flight.

Food delivery may occur in remote, difficult-to-access places that depend on external supplies such as oil rigs, research stations and isolated islands. This is less likely in the immediate future compared to the delivery of food in inner city areas. While drones would decrease delivery times and increase transport efficiency, it is unclear when regulations would permit the delivery of parcels of substantive weight over head.

²⁹ Drones for hire, 2020. 'Drones and agriculture in 2020'. <https://dronesforhire.com.au/industry/Agriculture>

³⁰ 'Clarity from above': PwC global report on the commercial applications of drone technology'.

³¹ Ibid

³² Business Insider, 2015. 'Amazon's delivery drones could make 30-minute deliveries a reality (and for a \$1 fee)'. <https://www.businessinsider.com/delivery-fee-for-amazon-prime-air-2015-4?r=AU&IR=T>

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³³ Silicon Staff, 2019. Swiss Post Suspends Drone Delivery Trials Following Crash. <https://www.silicon.co.uk/workspace/drone-delivery-trials-crash-274649>

³⁴ PWC, 2016. 'Clarity from above: PwC global report on the commercial applications of drone technology'.

³⁵ Ibid.

3. Compelling use cases for drones

This chapter outlines the findings of use cases for drones and the associated cost savings, enhanced production, safety and environmental benefits accruing from the use of drones.

Overview

This chapter outlines findings from analysis of compelling drone use cases in the Australian context with consideration for initial timing, rates of penetration and barriers to uptake. This is achieved through a partial economic model that provides estimates of drone uptake (number of drones) over time and the potential benefits to the Australian economy in the form of potential cost savings and / or additional value drones add through enhanced production processes.

This analysis is informed by a combination of in-house data-sets, other economic data and previous studies as well as through consultation with the Civil Aviation Safety Authority (CASA) and Airservices Australia (AA).

To account for uncertainty a scenario-based approach is used presenting three possible 'states of the world' with basis' ranging from low to high scenarios

- **Low uptake scenario** – This scenario is characterised by lower compound annual growth rates (CAGRs) across all use cases and lower maximum penetration rates relative to other scenarios. For emerging use cases, initial widespread adoption is also delayed relative to other scenarios. This scenario represents a combination of several barriers to entry acting strongly as slow down the rate of drone uptake.
- **Medium uptake scenario** – This scenario is the 'central case' or most likely scenario. It is characterised by CAGRs and maximum penetration rates that are considered 'middle ground' between the low and high scenarios. This 'middle ground' nature is also reflected in the widespread adoption of emerging use cases.
- **High uptake scenario** – This scenario is characterised by higher CAGRs and faster penetration rates than other scenarios. For emerging use cases, initial widespread adoption occurs earlier than the low and medium scenarios. This is possible as barriers to entry are removed (e.g. physical infrastructure such as vertiports, communication networks and resistance to uptake including externalities such as noise).

Further detail including the methodology and assumptions used for this analysis are outlined in Appendix.

Drone use cases

Due to the flexibility and adaptability of RPAS technologies, drone use cases are numerous and are likely to impact or are currently impacting most industries in some shape or form. In some cases, these technologies are also supporting new industries such as passenger drone transportation or drone deliveries.

In addition to the widespread applicability of these technologies across industries / sectors, there are also numerous market and non-market benefits that can accrue as a result of these technologies. These benefits range from labour cost savings and enhanced production processes, to safety and environmental benefits. For these reasons, this Report focuses on a *subset* of all use cases considered most 'compelling' (refer Table 4). These compelling use cases were agreed in conjunction with DITRDC and canvassed by CASA and AA when developing this report.

Table 4 : Compelling use cases

Category	Use cases
Passenger drones	Airport transfers, Point-to-point transfers, Regional air mobility
E-commerce and deliveries	Courier deliveries, Food deliveries, Pathology deliveries
Government and community services	Police, Fire, Coast guard, Customs and Border Protection
Agriculture	Agriculture, forestry and fishing
Mining and resources	Mineral ore, oil and gas
Defence	Surveillance, warfare etc.
Other	Recreational

Source: Deloitte Access Economics

* Non-market benefits such as environmental or safety benefits are not reflected in market prices. *Vice versa*. Importantly, market and non-market benefits are not additive and are consequently analysed separately.

Estimates for each use case are reflective of the underlying assumptions for each scenario which are based on desktop research and differ based on the level of uncertainty and degree of existing research.

Table 5: Assumptions per use case

Use cases		Total addressable market	Rate of substitution assumptions			
			Maximum penetration rates in 2050 (low-high)	Financial year of introduction	Adoption curve	Year of market saturation
Urban / Regional Air Mobility	• Airport taxi trips	• Airport taxi passengers	1.4% - 23.2%	FY2022-23	Automobile adoption curve (adjusted for initial limitations)	FY2039-40
	• Point-to-point trips	• Taxi passengers (ex. Airport)	0.1% - 2.9%	FY2022-23	Automobile adoption curve (adjusted for initial limitations)	FY2039-40
	• Regional air mobility	• Short-route domestic aviation passengers	0.1% - 2.9%	FY2022-23	Automobile adoption curve (adjusted for initial limitations)	FY2039-40
E-commerce and deliveries	• Express parcel deliveries	• Express parcels with 'droneable' weights	13.3% - 22.1%	FY2019-20	Tablet adoption curve	FY2039-40
	• Food deliveries	• Number of food deliveries in Australia	53.1% - 75.2%	FY2019-20	Tablet adoption curve	FY2039-40
	• Regional and remote pathology deliveries	• Number of pathology tests in Australia outside of major cities	4.4% - 8.8%	FY2019-20	Tablet adoption curve	FY2039-40
Agriculture	• Agriculture, Forestry and Fisheries	• Number of Agriculture, Forestry and Fisheries businesses in Australia	26.7% - 67.1% 35.4% - 63.0%	FY2019-20	Automobile adoption curve (adjusted for more conservative growth)	FY2029-30
Construction	• Construction (incl. surveying)	• Number of construction businesses in Australia	49.5% - 87.5%	FY2019-20	Automobile adoption curve (adjusted for more conservative growth)	FY2029-30
Mining	• Mining and resources	• Number of mining businesses in Australia	42.2% - 59.6%	FY2019-20	Automobile adoption curve (adjusted for more conservative growth)	FY2029-30
Government services	• Police, firefighting, customs, border control	• Derived from global estimate	17.0% - 67.0%	FY2019-20	Automobile adoption curve (adjusted for more conservative growth)	FY2037-38
Defence	• Surveillance and warfare	• Derived from global estimate and forecast Australian defence spend	75.0% - 95.0%	FY2019-20	Derived in order to reach assumed maximum penetration rate in 20 years	FY2039-40
Recreational	• Recreational uses of drones	• Derived from global estimate	2.5% - 40.0%	FY2019-20	Derived in order to reach assumed maximum penetration rate in 20 years	FY2039-40

Source: Deloitte Access Economics based on several sources

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Historical adoption curves for similar technologies provide a basis for estimating the future level of drone uptake under each use case. 'Automobile' and 'tablet' adoption curves formed the basis for all use cases modelled and were adjusted where considered appropriate.

Adoption rate curves

Adoption curves depict the rate of uptake of a new technology over time (refer Chart 2).

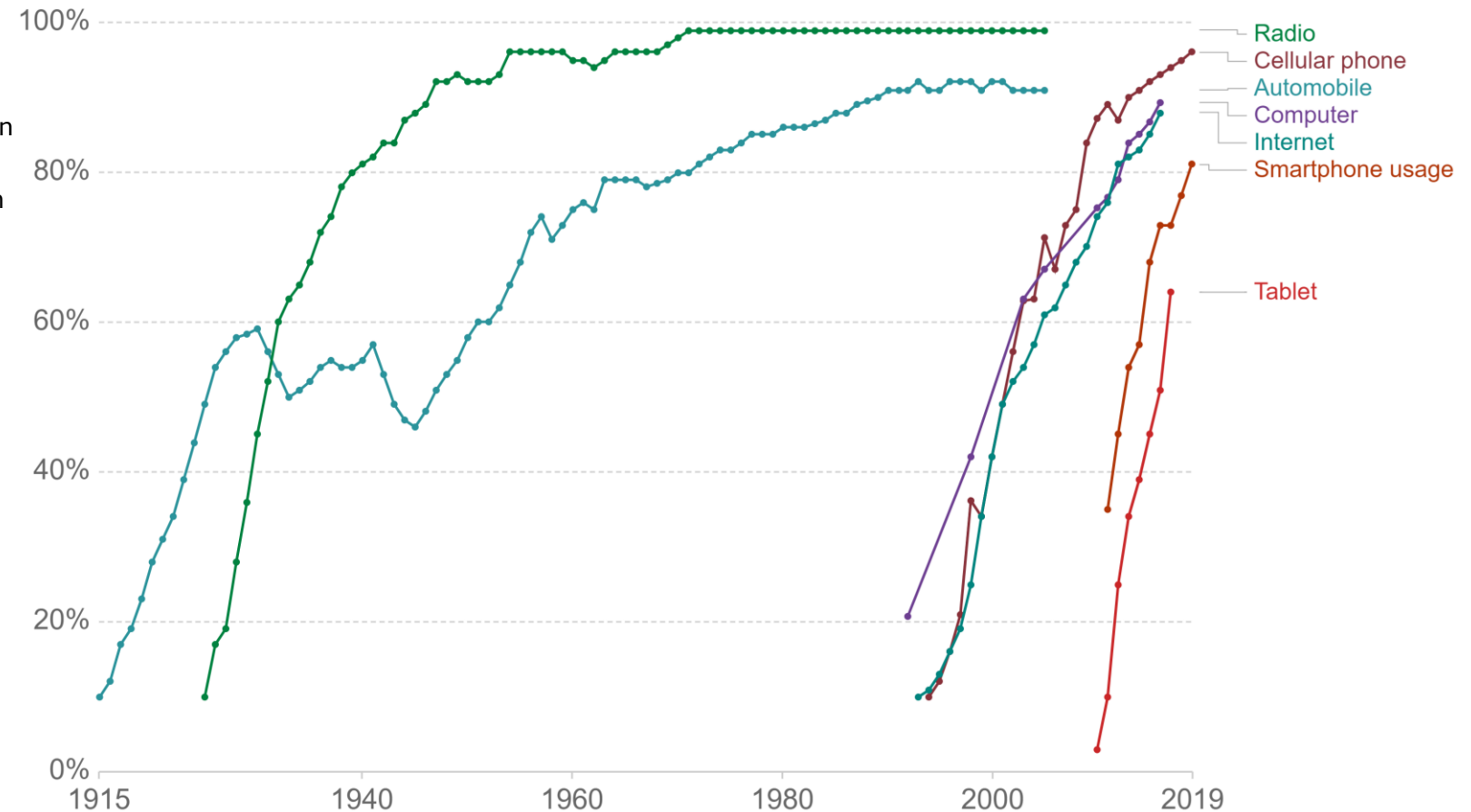
While estimating the future uptake of a new technology such as drones, adoption curves for similar technologies can be useful in providing a basis for future uptake rates.

In estimating the use case profiles for this Report, adoption curves for automobiles and tablet technologies were utilised. For urban air mobility (UAM)/regional air mobility (RAM) passenger drones, the automobile adoption curve is used as a basis for future adoption as it is likely to be reflective of several shared characteristics with drones as an alternate mode of passenger transport (i.e. consumer perceptions of new transport modes, infrastructure limitations etc.).

For delivery drones the tablet adoption curve is used as a basis for the estimated adoption rate. This is a relatively fast adoption rate and is considered reflective of the convenience and time savings offered to users of delivery drones as well as the cost savings available to transport operators.

For existing use cases such as Agriculture, Forestry and Fisheries, Construction and Mining as well as Government services, the automobile and tablet rate of adoption is considered too steep given there is already adoption occurring within these industries. As such, the early automobile adoption curve is used but with a varying adjustment made to scale the rate of adoption to a more conservative level.

Chart 2: Adoption rates for different technologies³⁶



Source: Comin and Hobijn (2004) and others

³⁶Visual Capitalist (2018), 'The rising speed of technology adoption' - <https://www.visualcapitalist.com/rising-speed-technological-adoption/>

UAM encompasses both airport and point-to-point transfers and involves the transportation of passengers between pick-up and drop-off locations requiring the need for supporting infrastructure.

Overview

UAM is an alternative mode of passenger transport in the form of aerial, vertical take-off and landing (VTOL) and eVTOL passenger drones. It refers to a set of vehicles proposed to provide on-demand or scheduled air transportation within a metropolitan area to overcome increasing surface congestion. These drones are likely to be piloted vehicles when first introduced (initial small scale trials anticipated circa 2023) but are expected to transition to fully autonomous vehicles as technologies are further developed, tested and limitations overcome.

In practice, these drones will function as a transport mode between 'infrastructure nodes' sometimes referred to as 'vertiports'. These infrastructure nodes will function as drop-off/pick-up locations for passengers and will require passengers to complete 'first and last-leg' journeys between origin/destination points to/from a 'vertiport'.

For the purposes of this Report, two distinct UAM 'types' are considered:

- **Airport transfers** – Passengers utilise drone technology to journey to and from major airports and central business districts / inner-city suburban infrastructure nodes. This service will compete with conventional taxi services offering travel time savings.
- **Point-to-point transfers** – Passengers utilise drone technology to journey between infrastructure nodes. These infrastructure nodes are likely to be located in high population density regions such as inner city / urban hubs.

Currently, UAM vehicles are in the early stages of the technology lifecycle and are currently viewed by those consulted to be in the *certification phase*³⁷ with several organisations designing and prototyping with demonstrations and trials having been conducted and continuing to run across the globe.

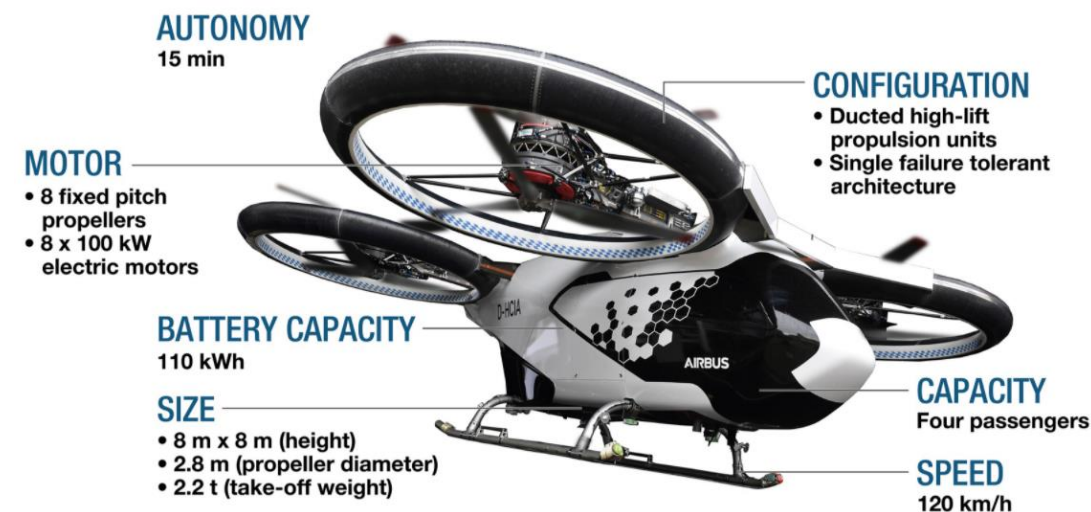
There are varying viewpoints on the potential year of introduction and adoption paths for this technology. In line with the opinion of those entities consulted (including CASA and AA), this Report assumes early introduction in controlled areas between 2023-2025 with more widespread adoption not occurring till later in the decade (circa 2030).

Physical infrastructure and networks represent key barriers to adoption for this use case. Previous studies have indicated that existing ground infrastructure such as heliports that are prevalent in urban areas are poorly suited for UAM operations due to low capacity and sub-optimal locations (low accessibility). Other requirements such as the need for high speed / low latency networks, effective crash avoidance systems, capacity in electricity grids etc. are also key barriers to adoption and are reflected by constraining the rate of adoption in the use case and creating a lag in uptake.

³⁷Seeking regulatory certifications for prototype vehicles

³⁸Airbus (2020), CityAirbus - <https://www.airbus.com/innovation/zero-emission/urban-air-mobility/cityairbus.html>

Figure 3: Example concept vehicle - Airbus eVTOL



Source: Airbus, 2020³⁸

UAM that comprises of airport transfers and point to point trips is expected to result in 10.1 million trips in 2040 in the medium uptake scenario. Uptake is slow until 2030 and increases at a faster rate until saturation in 2040.

Time to market

There is significant investment taking place (including from venture capital firms) to operationalise UAM globally by the mid-2020's. A recent article highlighted that Uber aims to offer aerial ride sharing through its Uber air application by 2023 in Melbourne, Australia. Manufacturers building eVTOL aircraft that will be operated by Uber Air's ridesharing service include Boeing, Bell and Embraer³⁹. The expertise of these high-tech firms is needed to design technologies and infrastructure like landing pads to support this ecosystem.

The time to more widespread adoption is not expected to be till 2030 due to the constraints such as infrastructure (i.e. need for vertiports for take off and landing in urban areas) getting the technology right along with the price of UAM compared to conventional land transport. This was also highlighted by CASA and AA during consultation.

Use cases – airport and point-to-point trips

The potential market size UAM is represented by the proportion of airport passenger trips currently utilising taxis. The market potential for point to point is estimated as total taxi trips after netting out airport trips. Taxi trips are assumed to be more substitutable with UAM's than other forms of land transport based on the higher price and convenience.

The total assessable market (TAM) for UAM represents the potential customer base. This is based on inbound and outbound passenger trips at Australia's top 20 Airports over the period 2009 to 2019. This estimate is assumed to grow at 2.9% on average per annum. A taxi mode share assumption of 20% is applied to derive the UAM customer base. The adoption rate of the technology is proxied by automobile uptake rate in the high and medium cases with a much lower adoption rate assumed in the low scenario. A 'resistance factor' is applied to slow uptake in all cases due to initial infrastructure and network limitations as well as passenger perceptions of flying in these vehicles. The high and medium scenarios assume greater market potential and faster adoption of the technology (refer to Chart 3). The total number of trips ranges from **circa 800,000 trips** in the **low uptake scenario** to **15.5 million trips** in the **high uptake scenario** by 2040. While market saturation is assumed by 2040 the customer base continues to grow increasing the number of trips after 2040 (refer to Chart 4).

Chart 3: Adoption rate UAM (%)

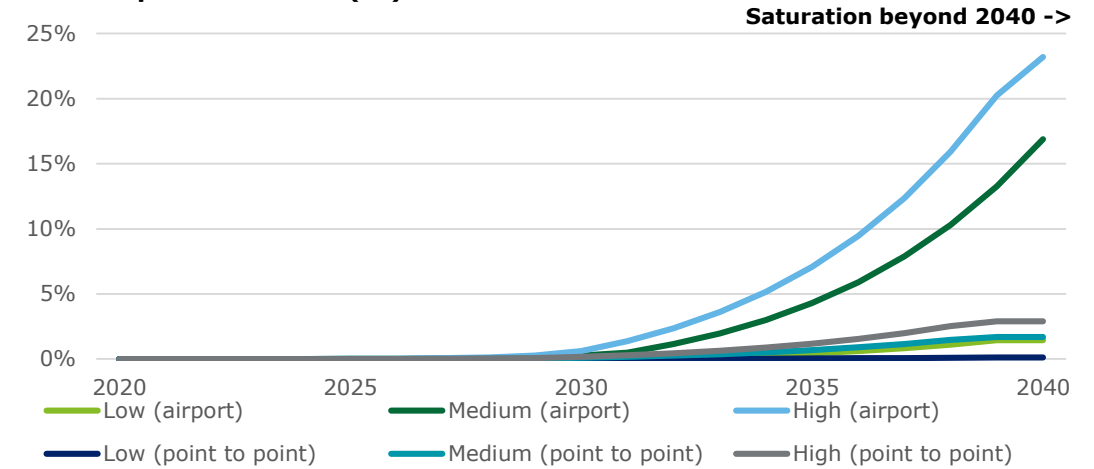
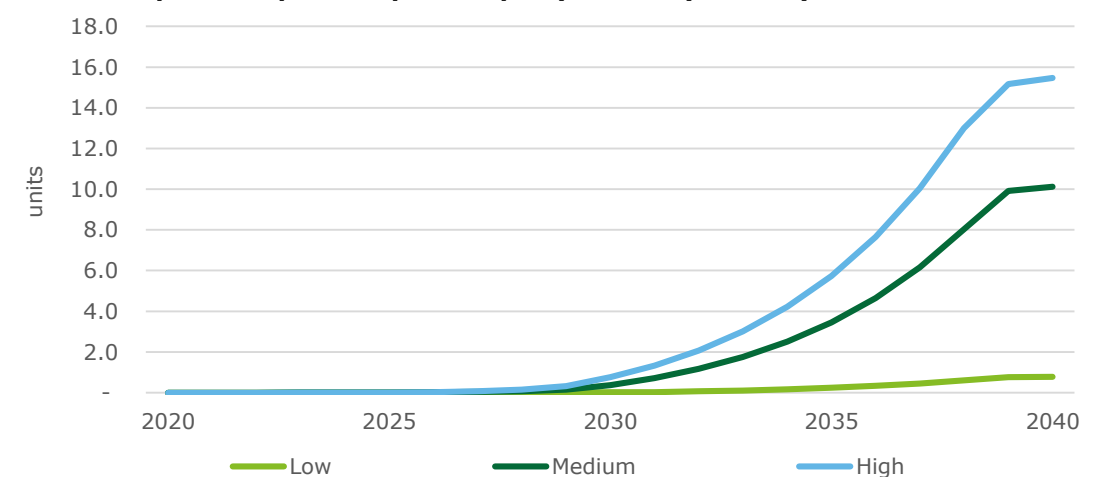


Chart 4: Airport and point to point trips by drones (millions)



RAM is expected to result in a total of circa 70,000 regional air trips Australia-wide by 2040 in the medium uptake scenario with more widespread adoption only occurring after 2030.

Overview

Similar to UAM, RAM represents an alternative mode of passenger transport in the form of aerial VTOL passenger drones. These drones are likely to be piloted vehicles when first introduced, but are expected to transition to fully autonomous vehicles as technologies are further developed and tested and limitations overcome.

RAM differs from UAM in that it focuses on connecting regions rather than relatively small urban journeys (intercity trips). Consequently, RAM is distinguished by longer distances and journey times. Rather than competing with conventional taxi services it competes more with the short-route domestic aviation market. Further, RAM could also potentially fill gaps in the domestic aviation network for short-route trips not currently undertaken by domestic aviation networks.

Time to market

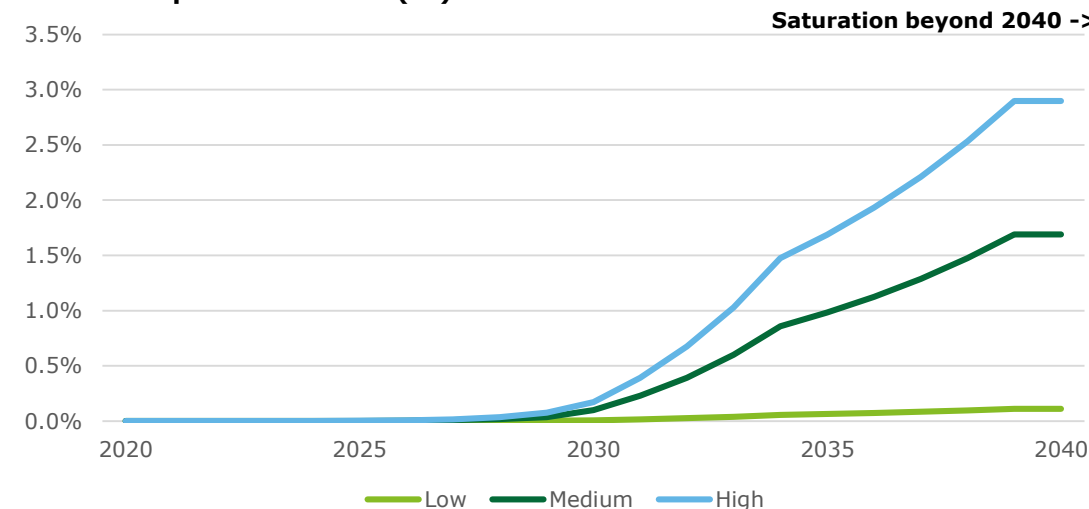
As with UAM, RAM has attracted investment from the private sector to operationalise RAM globally by the mid-2020's. This includes companies developing and prototyping vehicles specifically designed to cater to the potential RAM market. For example, Lilium's regional air mobility prototype is designed to cater for four passengers and initially a pilot to offer high levels of efficiency whilst minimising noise within urban areas.⁴⁰ Despite early introduction by the mid-2020's, RAM is not expected to be more widely adopted till circa 2030.

Use cases – RAM

The potential market size for RAM is estimated by the proportion of domestic aviation passengers on short-routes averaging 393km. This is at the upper end of passenger drone vehicle travel capabilities. The market is assumed to grow at an annual average rate of 2.09%. This is based on historical growth of short-distance domestic passenger volumes from 2009-2019. The growth in the market leads to saturation around 2040. The market penetration rate and adoption rates are lower for RAM than for UAM. As with UAM a 'resistance factor' is used with automobile uptake rate assumptions for the high and medium scenarios. A much more conservative adoption rate is employed in the low uptake scenario. By 2040, the number of regional air trips ranges from circa **4,000 trips** (low uptake scenario) to **115,000 trips** in the high uptake scenario.

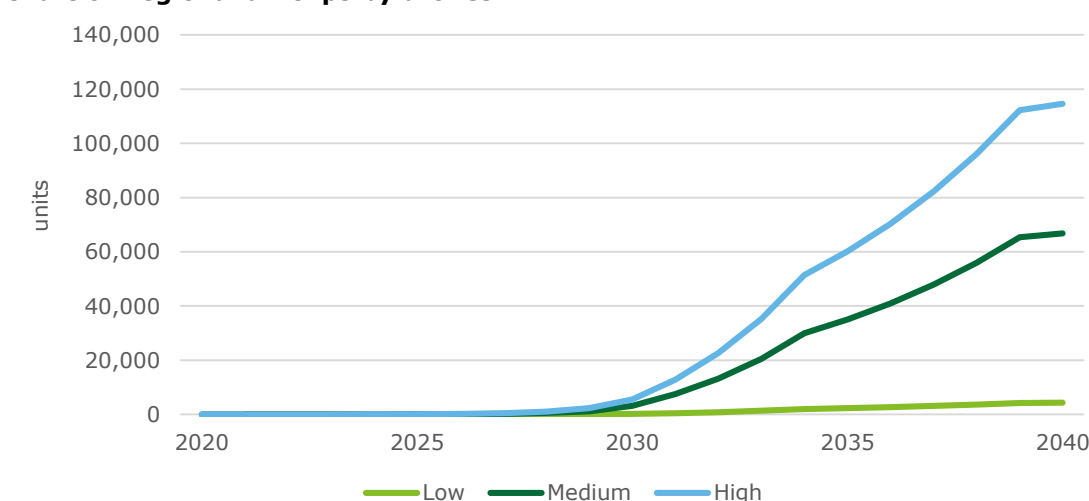
⁴⁰Lilium (2020), 'All electric regional air mobility' - <https://lilium.com/>
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Chart 5: Adoption rates RAM (%)



Source: Deloitte Access Economics

Chart 6: Regional air trips by drones



Source: Deloitte Access Economics

E-commerce and deliveries encompasses express parcels, food and pathology deliveries. This represents an alternative form of delivery by automated drones and the items that could potentially be delivered in the future are numerous.

Overview

E-commerce and drone deliveries represent an alternative delivery mode in the form of automated drones. Under this use case, these drones carry packages to / from a central distribution hub to / from a drop-off / pick-up location. This central distribution hub could range from a courier distribution centre, to a retail shop or food outlet or even a medical centre (such as a pathology clinic). Provided the payload meets the weight requirements to be carried by a drone and meets aviation guidelines, the potential items available for delivery are numerous.

In practice, these drones are already operating in several countries at a small scale with larger scale operations also running in Australia. As an example, Wing has conducted over 100,000 flights across three continents that are approved by CASA for ongoing drone delivery operations in North Canberra (ACT) and Logan (QLD).^{41,42} CASA and AA indicated during consultation that Wing has already completed 'multiple thousands' of flights, with growth in demand particularly strong during the COVID-19 pandemic.

For the purposes of this Report, three 'types' of E-commerce and drone deliveries are examined:

- **Express parcel deliveries** – Deliveries utilising automated drone technology to complete the 'last leg' of a delivery from a distribution centre or retail shop direct to a pre-specified location. For existing operating models, this can utilise smart phone and global positioning satellite (GPS) technologies to direct the drone to the drop-off location. This service competes primarily with traditional van deliveries.
- **Food deliveries** – This is set to use automated drone technology to complete the delivery from a food outlet / restaurant direct to the consumer. This service is likely to utilise similar technology to express parcel deliveries and will compete primarily with traditional food delivery companies (such as UberEATS, Menulog, Deliveroo and others).
- **Pathology deliveries** – Utilises automated drone technology to facilitate direct delivery of pathology samples from local medical / pathology centres to hospitals and testing laboratories. This service will compete primarily with existing van delivery methods.

Australia's relatively fast adoption of new technologies and the geographical spread of Australian cities could be a catalyst for a relatively fast uptake of this technology. In line with advice from CASA and AA, this Report assumes that early adoption is already occurring with more widespread use occurring over the next 2-3 years (circa 2023).

Figure 4: Delivery drone – Alphabet's Wing delivery drone



Source: Engadget, 2019⁴³

⁴¹Wing (2020), 'About Delivery' - https://wing.com/en_au/about-delivery/

⁴²CASA (2020), 'Drone delivery systems' - <https://www.casa.gov.au/drones/industry-initiatives/drone-delivery-systems>

⁴³Engadget (2019), 'Alphabet's Wing launches drone delivery service in Australia' - <https://www.engadget.com/2019-04-09-alphabet-wing-drone-delivery-service-australia.html>

E-commerce and deliveries will be a significant market for drones over the medium to long term. Localised trials are already occurring in Australia and elsewhere with future demand for parcels and food deliveries likely to be considerable.

Time to market

The time to market is expected to be over the short to medium term with e-commerce and delivery drones. A recent report suggested the number of delivery drones in the global E-commerce market could be as high as the 2.2 million units by 2025. The nearness to market is evidenced by drone delivery trials in 15 countries including Australia the United States, United Kingdom and Japan. These trials are benefiting from the expertise and knowledge of specialized companies such as Flirtey, Flytrex, and Zipline collaborating with companies such as Amazon, Alphabet, Alibaba, JD.com, Airbus, and UPS⁴⁴.

Three use cases are discussed in terms of e-commerce and deliveries.

Use cases

Express parcel deliveries

This is based on the number of parcel delivered in Australia and this moves in line with growth in Australian gross domestic product (GDP). The market size is narrowed down to express parcel deliveries, which represented about 17% of the market in 2019. This segment is considered to be most suited to drone deliveries that has the added requirement of timely delivery. A drone for instance, could facilitate more timely delivery by avoiding road congestion. The adoption rate of the technology follows the growth profile of a tablet computer. This is based on the number of companies trialling this technology. It is expected to expand rapidly once available given the potential benefits. The expected demand or number of express parcel deliveries by drones in Australia is estimated to range from **37 million trips** (low uptake scenario) to **61 million trips** (high uptake scenario) in 2040.

Food deliveries

Australian online food ordering and delivery services generated circa \$690 million of revenue in 2019. With the popularity of the market this is expected to increase to \$1.4 billion by 2025. There is a significant opportunity for drones to deliver food directly to consumers. This has the scope to replace conventional forms of food delivery on scooters, bicycles and motor vehicles.

The market penetration rate is assumed to be 60% in the low uptake scenario, increasing to 80% in the high uptake scenario. This is based on the potential benefits drone deliveries can bring to the market. These will be characterised by short distances on average with higher volumes.

The adoption rate of this technology is also assumed to follow the growth profile of a tablet computer. It is expected that food deliveries by drones will grow rapidly after commencement.

The demand for food deliveries by drones in Australia is estimated to range from **46 million trips** (low uptake scenario) to **65 million trips** (high uptake scenario) in 2040.

Regional and remote pathology delivery

The total market for pathology in Australia consists of around 24,000 people who collect, process and report on approximately 500 million pathology tests each year⁴⁵. Based on the proportion of the population outside of capital cities the number of regional and remote pathology tests is estimated to be circa 138 million. Market penetration ranges from 10% to 20% in the low to high uptake scenarios. This is set more conservatively as there could be more complexities associated with these deliveries based on the geographical size of Australia and carrying of pathology samples. The adoption rate is based on the tablet computer but scaled by 50% to flatten out the growth profile.

The demand for pathology deliveries by drones in Australia is estimated to be lower ranging from **8 million trips** (low uptake scenario) to **17 million trips** (high uptake scenario) in 2040.

Adoption rates and market demand for each of the delivery types are shown overleaf.

⁴⁵ RCPA factsheet <https://www.rcpa.edu.au/Library/Fact-Sheets/Pathology-The-Facts/Docs/Path-Fcts-Booklet#:~:text=Australia's%20pathology%20workforce%20consists%20of,decisions%20related%20to%20patient%20care> .

⁴⁴ Based on work by Frost and Sullivan, <https://www.eft.com/technology/report-expects-22-million-delivery-drones-e-commerce-sector-2025>

Adoptions rates and total number of deliveries for each E-commerce and delivery drone use case is shown in the charts below. The number of estimated express parcel and food deliveries is much higher compared to pathology deliveries.

Chart 7: Adoption rate, express parcel deliveries (%)

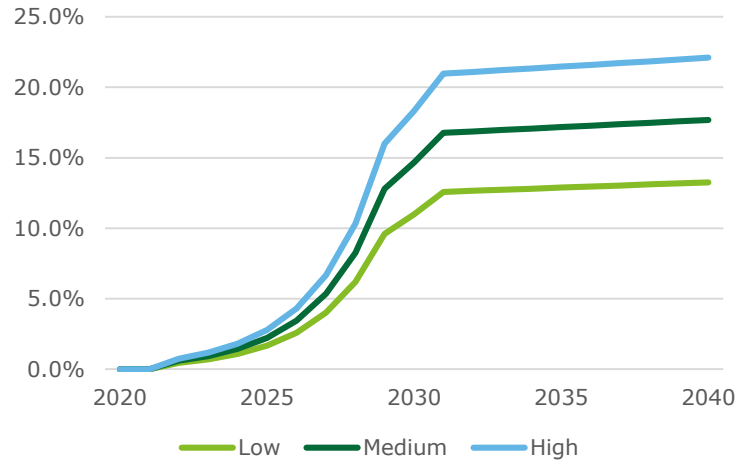


Chart 8: Adoption rate, food parcels (%)

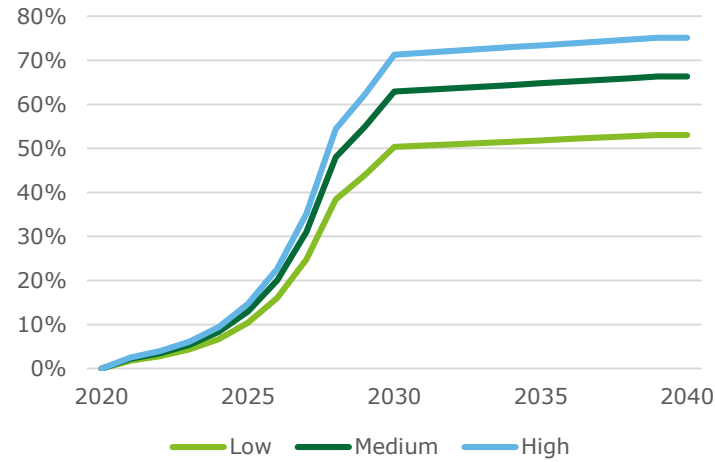


Chart 9: Adoption rate, remote and rural pathology (%)

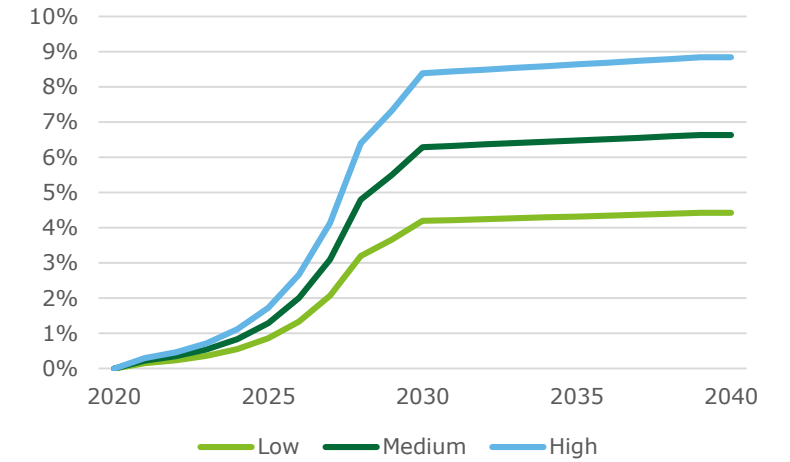


Chart 10: Express parcel deliveries

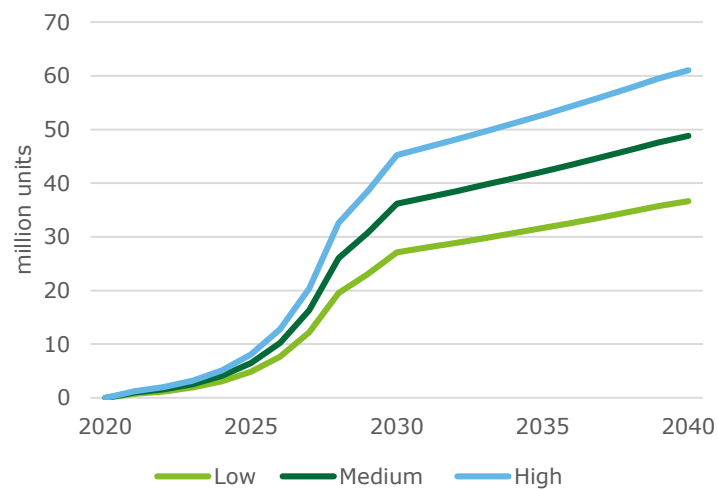


Chart 11: Food parcels deliveries

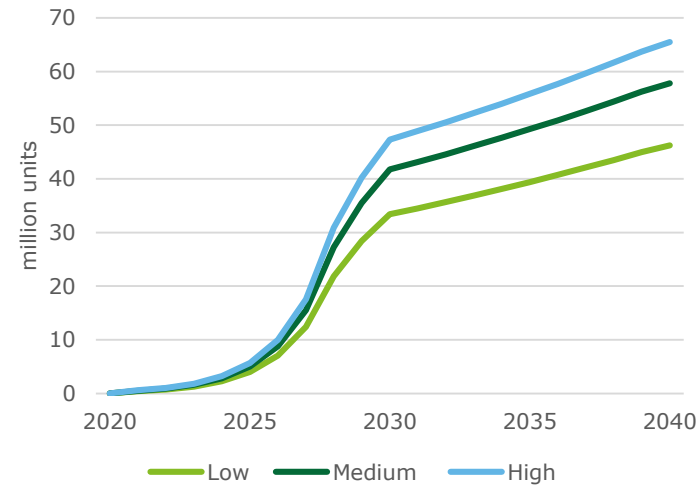
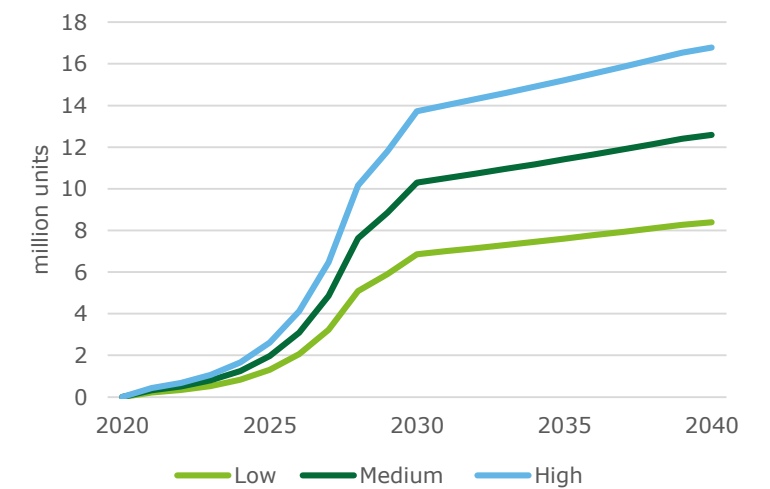


Chart 12: Remote and rural pathology deliveries



Source: Deloitte Access Economics

Source: Deloitte Access Economics

Source: Deloitte Access Economics

The use of drones is already well underway in agriculture with this trend expected to continue in the future as technology improves. Current applications include crop spraying, mapping and livestock management to name a few.

Agriculture

There are several uses for drones in the primary produce industries that lead to efficiencies. High-tech drones are already in use in agriculture, allowing operators to remotely pilot, and in some cases automate processes such as planting, livestock management, crop spraying and mapping. These potential drone uses are leading and supporting a new branch of agricultural processes, sometimes referred to as precision agriculture. This use case encompasses drone use in Australian agriculture.

In practice, the use of drones in this industry is subject to a number of limiting factors including the capital cost outlay of drones (particularly those required to carry payloads that are typically larger in size) that is estimated on average to be \$45,000.⁴⁶ However, this has not stopped the use of drones in agriculture in a number of applications.

Availability of complementary software was also identified by those entities consulted as a key factor in generating benefits from drone use, particularly in terms of imagery and mapping uses. Specifically, software that can take large amounts of observation data and convert this into tangible and actionable information for drone users.

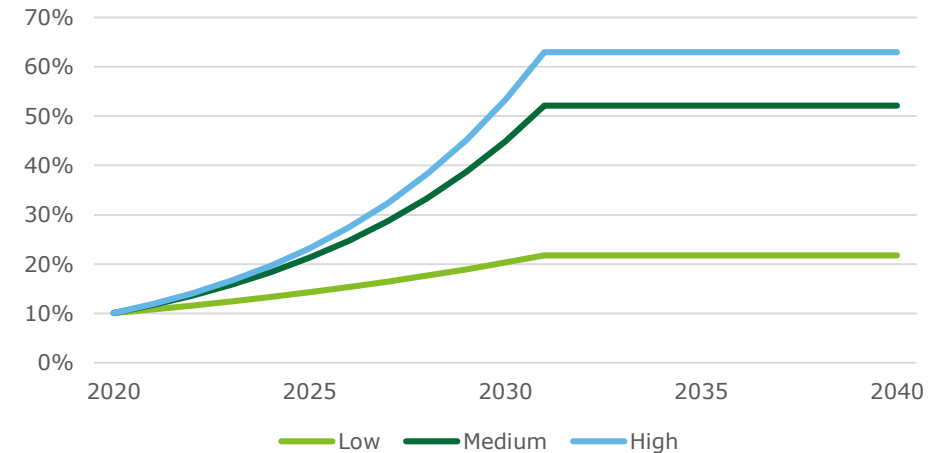
Satellite technology is also considered as a barrier to growth as a direct competitor with drone technology for visual observation and mapping uses. This has been considered in the setting of the market penetration rate for each uptake scenario.

Use case

There were an estimated 89,400 agricultural businesses in Australia in 2018-19 comprising a total area of 384 million hectares⁴⁷. The current market penetration of drones is assumed to be 1 in 10 agricultural businesses. This is supported by ABS innovation data that highlighted that 10% of businesses in agriculture, forestry and fishing introduced a new or significantly improved operational process. Using this as a proxy for current drone usage there could be 8,940 agriculture businesses using drones. Market saturation is assumed by 2030 with a maximum potential of 38,000 units. The adoption curves for agricultural drones are representative of early automobile adoption curves and are adjusted slightly to induce slower adoption under the medium and low uptake scenarios. The number of drones used in agriculture ranges from circa **8,300 units** under the low uptake scenario to **23,900 units** under the high uptake scenario in 2040.

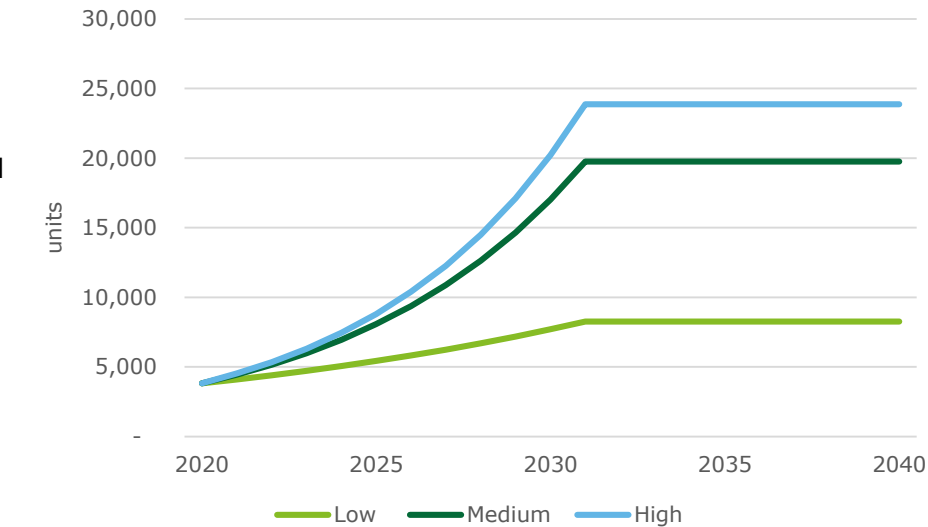
⁴⁶Goldman Sachs (2016), 'Technology driving innovation' - <https://www.goldmansachs.com/insights/technology-driving-innovation/drones/>
⁴⁷ABS 7121.0 - Agriculture commodities Australia 2018-19
.ABS 8158.0.0 - Innovation in Australia Businesses
An steady uptake growth rate has been applied rather than an option curve that is applied to new technologies that have not reached the market as of yet.
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Chart 13: Adoption rate, drones in agriculture (%)



Source: Deloitte Access Economics

Chart 14: Expected number of drones



Source: Deloitte Access Economics

The construction industry is already using drones in a range of different applications and uptake is set to increase as technology improves. The key to value-added will be the capability for drones to better analyse the data they collect.

Construction

There are several uses for drones in the construction industry that lead to efficiencies and has historically been the fastest growing commercial adopter of drones ahead of mining and agriculture.⁴⁸

Drones are already in use in construction, allowing operators to survey, map, deliver accurate measurements, etc. This ultimately saves labour costs and improves safety on-site. The ability for drones to quickly render 3D maps of terrain could be essential in the future to get the most out of drones. High resolution cameras and data processors will need to be able to survey the landscape at 1mm per pixel. Drones will need improved 'surveyor grade' global positioning satellite systems that are better georeferenced so the internal coordinate system of a digital map or aerial photo can be related to a ground system of geographic coordinates.

Project managers and virtual design coordinators can save valuable time and eliminate risk through the use of drone maps and 3D models on job sites. Whether keeping construction projects on track with sharable maps, comparing building inventory management models, inspecting job sites for safety, or measuring stockpiles, drones and software improve communications and make construction a more efficient and safer industry to work in.

Currently drones offer the ability to gather data and visual images easily. This next step to generate further value is to turn these inputs into useful outputs for operators. Outputs such as detailed measurements for visualisation software and more generally, data analytics integration etc, reflect where drones could generate further value for the construction sector. Consultation with CASA and AA highlighted that the use of drones in construction could be contingent on the establishment of these complementary services. This notion is reflected in the uptake rate for drones which assumes a greater proliferation of complementary technology until 2040.

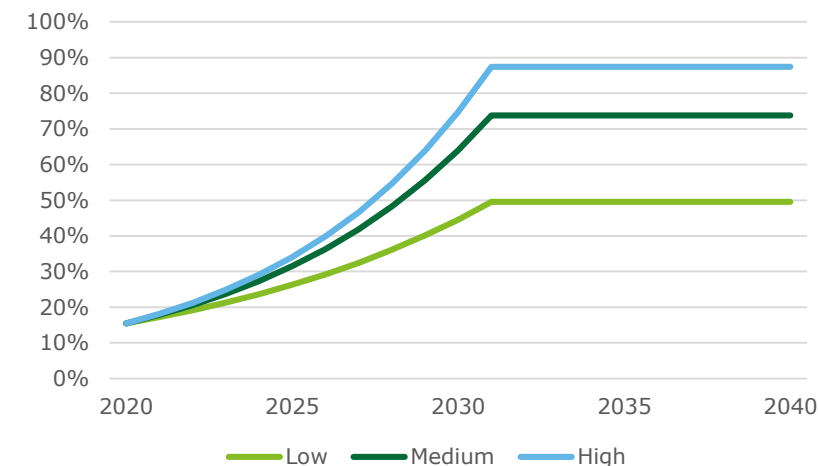
It is estimated there were approximately 3,715 survey and mapping businesses in Australia in 2019⁴⁹. ABS innovation data⁵⁰ highlighted that 15.5% of businesses in construction introduced a new or significantly improved operational process. Based on this relationship, the number of businesses using drones in a construction related activity could be 580 businesses across Australia. Total market potential is estimated to be in the order of 38,500 drones units. The adoption curve for construction businesses is broadly reflective of the early automobile adoption curve with an adjustment to reduce growth under all scenarios. The number of drones used in construction could range from circa **19,000 units** under the low uptake scenario to **33,600 units** under the high uptakescenario by 2040.

⁴⁸DroneDeploy (2018), 'The rise of drones in construction' - <https://www.dronedeploy.com/blog/rise-drones-construction/>

⁴⁹IBISWorld 'Surveying and mapping services'

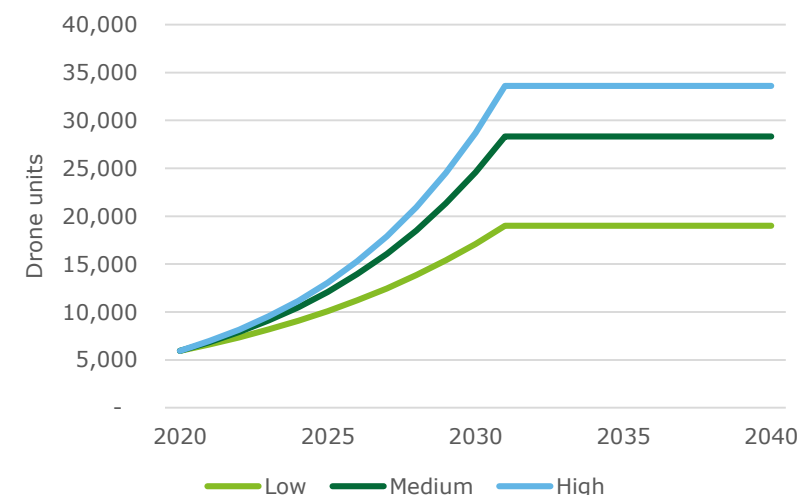
⁵⁰ABS 8158.0.0 - Innovation in Australia Businesses

Chart 15: Adoption rate, drones in construction (%)



Source: Deloitte Access Economics

Chart 16: Expected number of drones units



Source: Deloitte Access Economics

Mining and resources is a use case with untapped potential for drones in the future. Drone usage is being tested in open cut mining operations for inspection as well as mapping and is already being used to support underground mining operations.

Mining and resources

There are several uses for drones in the mining and resource industry that could lead to production efficiencies and increased safety. Drones are already in use in mining, and allow mining operators to monitor and conduct inspections of sites with greater efficiency, automate surveying and mapping, stockpile management and road and dam management.

CASA and AA have indicated that following changes to regulations in 2016, that allowed visual line of sight (VLOS) drones to be operated without certification, there has been extensive growth in the use of drones in mining and resources sectors. The key constraint for further growth is the need for certified drone operators to use beyond visual line of sight (BVLOS) drones. There are already examples of BVLOS drone use for underground mining along with autonomous ground vehicles to map areas and facilitate emergency operations; however, wider spread adoption can still occur. This enhanced use for drones offers significant potential benefits in the future.

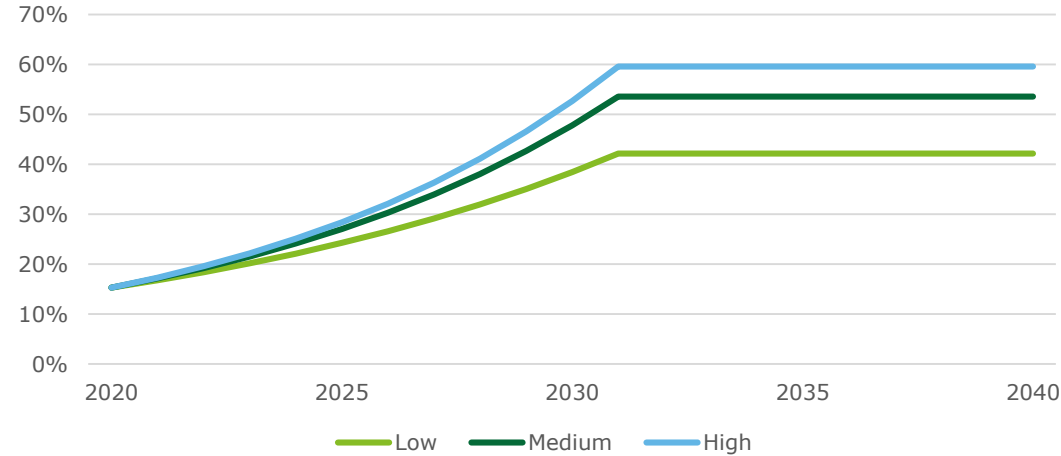
The mining industry is one of the sectors where drone usage has potential to deliver significant value to business. There is potential for drones to replace humans in dangerous and repetitive jobs. They have advantages over helicopters and could be more cost effective than them, along with being faster, easier to navigate and emitting less pollution than mining vehicles. Drones are currently being tested and used in open cut mining operations where they have potential to replace more labour intensive methods of inspection, mapping and surveying and also adding to safety⁵¹. Drones are also being used to support underground mining along with autonomous ground vehicles. They are being used to map areas and to facilitate emergency operations as well as numerous other applications underground.

The total number enterprises in the mining industry in Australia was estimated to be 7,565 in 2019⁵². The estimated total market potential by saturation in 2030 is estimated to be 5,700 drones. The uptake profile under all scenarios is representative of early automobile adoption curves with an adjustment to make growth more conservative under all scenarios. This follows the same profile as that assumed for the construction industry. The number of drones used in mining could range from circa **2,400 units** under the low uptake scenario to **3,400 units** under the high uptake scenario by 2040.

⁵¹Clarity from above, 2016

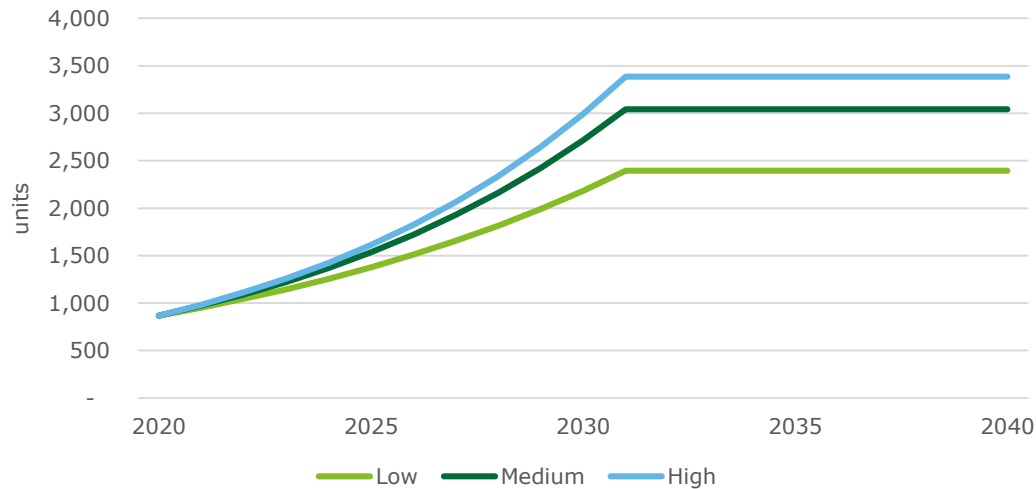
⁵²IBISWorld Industry Report, Mining in Australia

Chart 17: Adoption rate, drone in mining and resources (%)



Source: Deloitte Access Economics

Chart 18: Mining and resources drones



Source: Deloitte Access Economics

The use of drones has many applications across the public sector including, policing, disaster recovery, rescue efforts, firefighting, monitoring/inspection of infrastructure. These multiple uses should see growth in the use of drones in the future.

Government services

Drones offer several efficiency and safety improvements for civil use cases. In fighting fires, drones can be used to scout fire locations, using thermal imaging cameras to see through smoke and assist first responders to deploy assets efficiently and to assist in rescue efforts. Additionally, drones can be used post-fire in disaster management to survey or map scenes to assess damages or to search and locate missing people. The data available through drone technology can result in better informed decision making, accruing additional safety benefits.⁵³

Further, drones have several uses in other civil areas such as police, customs or border control. For instance, drones can be used to map cities for disaster management efforts, monitor ports and patrol coastline, pursue suspects in a far more cost effective manner than conventional helicopters, crime scene investigation and 3D reconstruction of vehicle accidents.⁵⁴

Drones are already in use throughout Australia for government services. In Western Australia, drones were used by the State police force to deliver public announcements at public spaces such as beaches, parks and café strips to assist in enforcing COVID-19 social distancing and mass gathering rules.⁵⁵ As such, lower scale drone uptake is assumed within government services with widespread acquisitions occurring over the decade to 2030. Widespread adoption to 2030 is supported across Australia in terms of civil government applications that are less subject to infrastructure and telecommunication network limitations.

The potential size of the market for drones is developed using a 'top down' approach based on global estimated potential for the civil government market and scaling this figure to reflect the size of the Australian market, which is circa 7.65% of the global market ⁵⁶. The total market potential is estimated to be in the order of circa 35,000 drones units. The uptake rate is broadly reflective of automobile adoption curves with adjustment for more conservative growth. After 2040, saturation is assumed with an underlying steady state rate of growth assumed.

The number of drones used for government purposes could range from **6 200 units** under the low uptake scenario to **26,350 units** under the high scenario by 2040.

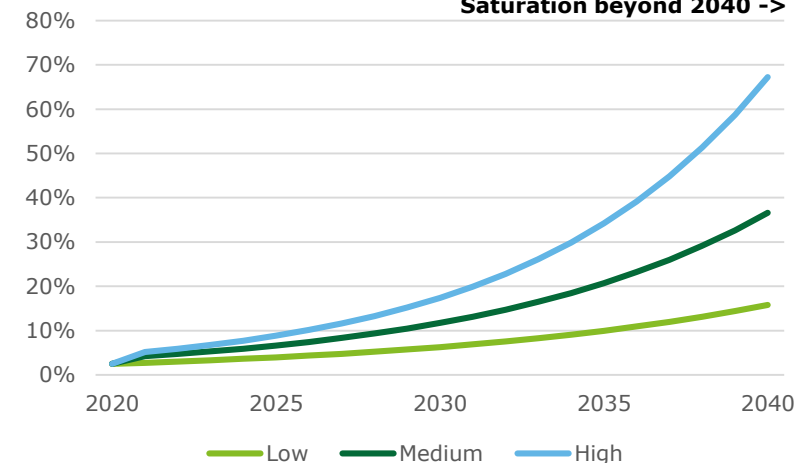
⁵³Goldman Sachs (2016), 'Technology driving innovation' - <https://www.goldmansachs.com/insights/technology-driving-innovation/drones/>

⁵⁴Drone nodes (2015), 'Firefighting drones - how drones are being used for helping fire departments' - <https://dronenodes.com/firefighter-drones/#:~:text=Firefighter%20Drones%20are%20sent%20to,responders%20in%20their%20rescue%20efforts.&text=From%20wildland%20firefighting%20to%20burning,and%20where%20the%20crew%20is.>

⁵⁵Forbes (2019), '10 ways that police use drones to protect and serve' - <https://www.forbes.com/sites/stephenrice1/2019/10/07/10-ways-that-police-use-drones-to-protect-and-serve/#2c37feb06580>

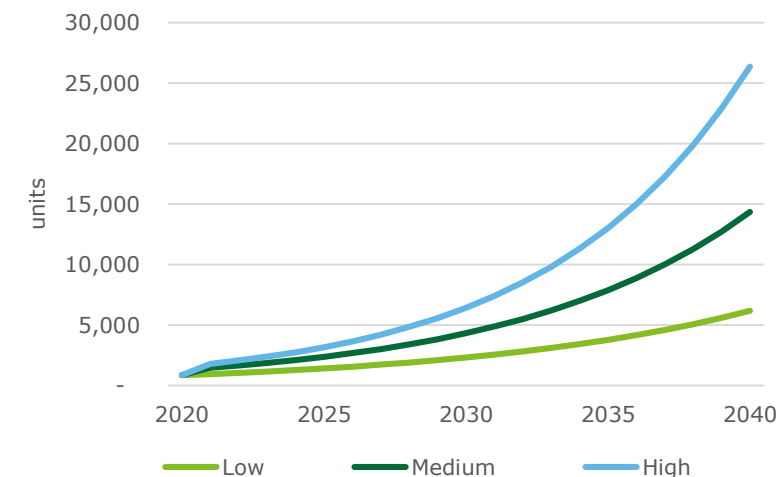
⁵⁶Western Australia Police Force (2020), 'Use of remotely piloted aircraft systems for public announcements' - <https://www.police.wa.gov.au/About-Us/News/Remotely-Piloted-Aircraft-Systems-for-public-service-announcements>

Chart 19: Adoption rate, government services (%)
Saturation beyond 2040 ->



Source: Deloitte Access Economics

Chart 20: Expected number of drones units



Source: Deloitte Access Economics

Drones are expected to be increasingly deployed by the military for surveillance operations and directly in warfare. The number of drones in use is expected to increase as this technology will further enhance Australia’s defence capabilities.

Defence

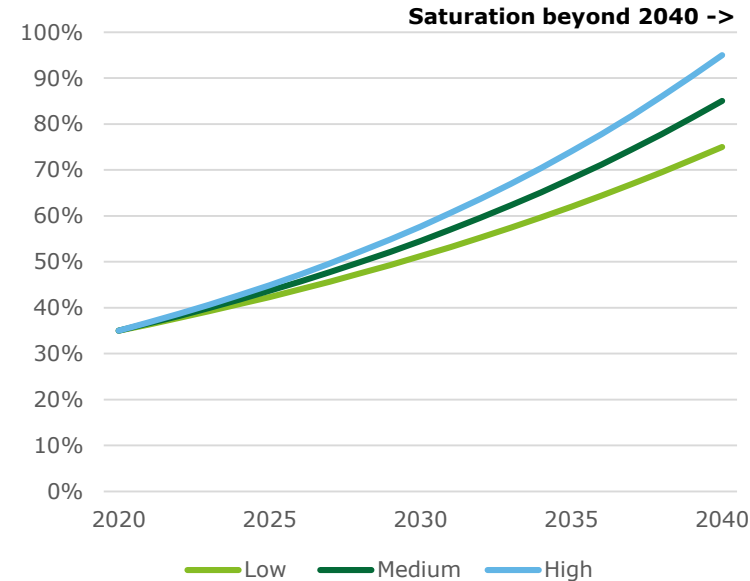
The original use case for drones was for military purposes. Some sources claim the first unmanned aerial vehicle was used as early as the 18th/19th century, but as UAV technology has advanced, drones have become far more capable in modern defence forces.⁵⁷ Today, drones are a key operational capability for defence forces and are used for both reconnaissance and direct warfare. Ranging in size, from as large as a manned aircraft to as small as to fit in the hand, military drones offer a broad range of capabilities. Drone uptake in the military is assumed to be commensurate to historical proportions of drone budget spend and grow in line with forecast military expenditure. Drone capabilities are anticipated to be a fundamental area for investment by the Australian Defence Force (ADF) and as such, is expected to grow to 2040. The market size for defence is estimated using a ‘top down’ approach based on global estimates. The size of the Australian market is circa 1.5% of global spending on drones or \$1.5 billion AUD. This is equivalent to a total potential market size of 3,460 drone units. The market size is assumed to grow in line with defence spending over the initial 10 years, circa 4% on average per annum⁵⁸. It subsequently moderates to 2% after this period. The maximum adoption rate applied is 35% in the low uptake scenario, increasing to 95% in the high uptake scenario. The number of drone units is expected to range from circa **5,000 units to 6,300 units** by 2040 based on the assumed adoption rate.

Figure 5: Australian Army drone examples



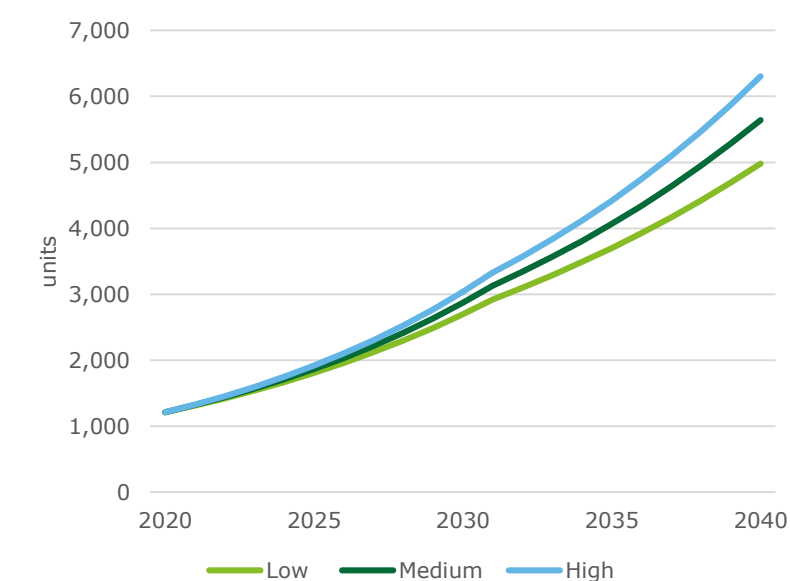
Source: ADF, 2020⁵⁹

Chart 21: Adoption rate, defence (%)



Source: Deloitte Access Economics

Chart 22: Expected number of drones units



Source: Deloitte Access Economics

⁵⁷Consortiq (2020), 'A short history of UAV' - <https://consortiq.com/short-history-unmanned-aerial-vehicles-uavs/#:~:text=The%20earliest%20recorded%20use%20of,that%20were%20loaded%20with%20explosives.&text=The%20United%20States%20began%20developing,created%20the%20first%20pilotless%20aircraft>.

⁵⁸IBISWorld Defence Industry Report

⁵⁹ADF (2020), 'Drone' - <https://www.defence.gov.au/DASP/Docs/Media/Drone-Military.pdf>

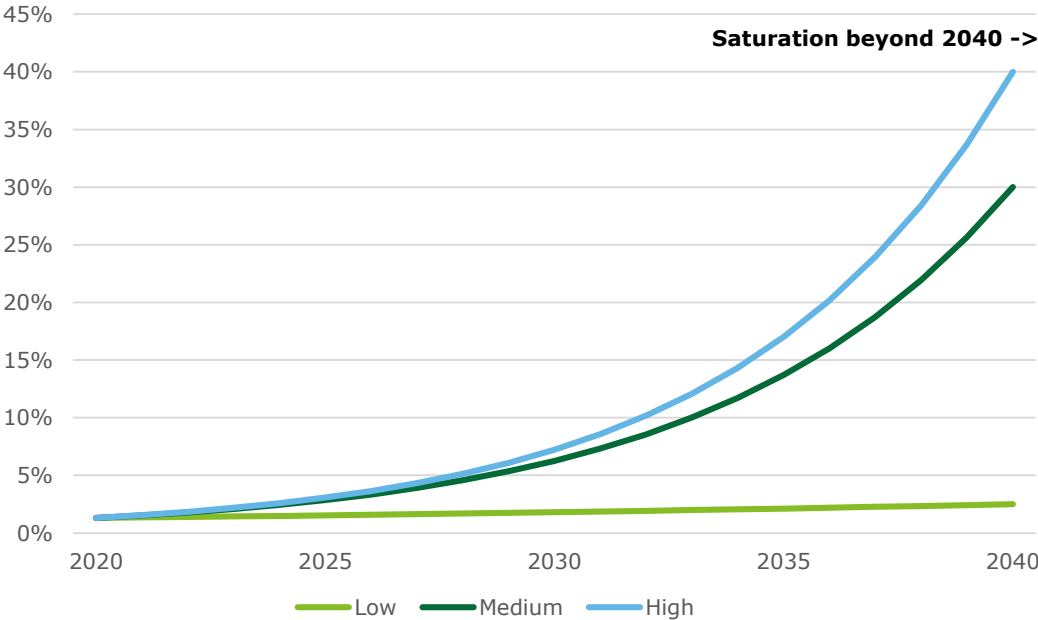
Recreational use of drones is Australia’s largest use case in terms of drone units, which has been aided by the relatively low unit cost of drones making them affordable along with the regulatory environment that has reduced barriers to entry.

Recreation

Recreational use of drones is Australia’s largest use case in terms of units as reported by CASA and AA, and confirmed during consultation. Recreational use of drones is also expected to grow in the future. This growth in recreational drones numbers is aided by low regulatory barriers that do not require operators to be certified drone operators and a low entry price point (circa. \$300 on average for low-end models).

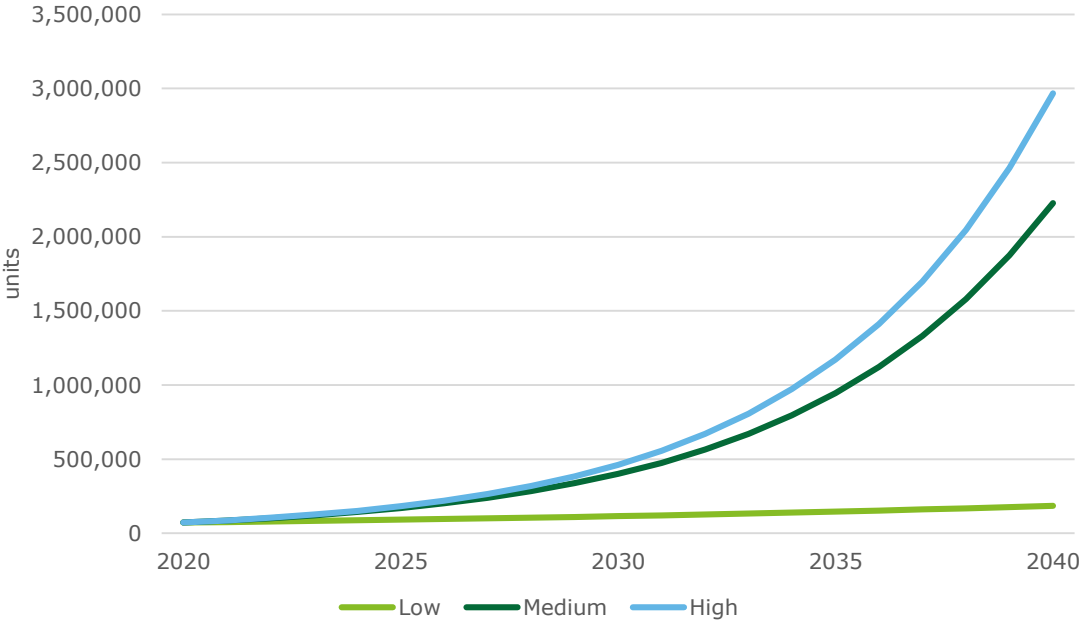
In practice, recreational drone use encompasses recreational flights, competition flying (noting that some competitions can accrue prize pools), recreational photography and videography, and other hobby-based uses. Recreational use of drones is expected to continue to grow rapidly reaching a saturation point around 2040 (refer Chart 23). The number of recreational drone units is expected to increase from **185,000 units** to circa **3 million units** by 2040 in the low to high uptake scenarios.

Chart 23: Adoption rate, recreational use of drones (%)



Source: Deloitte Access Economics

Chart 24: Recreation drone uptake



Source: Deloitte Access Economics

4. Analysis of cost savings from drones

There are potentially significant benefits from the use of drones through cost savings to end users, enhanced production, safety and environmental benefits associated with the use cases outlined in Chapter 3 of this Report.

Overview

This chapter outlines findings of potential benefits to Australia from the uptake of drone technology. The cost savings are considered in reference to a 'economy with minimal drone uptake' or the 'baseline' where there is assumed to be minimal growth in drones beyond those applications that already exist. This is estimated through a bespoke scenario based model that estimates drone uptake (number of drones) over time and the potential cost savings taking into consideration the additional value drones add, which is embedded in the technology capability of drones.

This analysis is informed by a combination of in-house data-sets, other economic data and previous studies as well as through consultation with the CASA and AA.

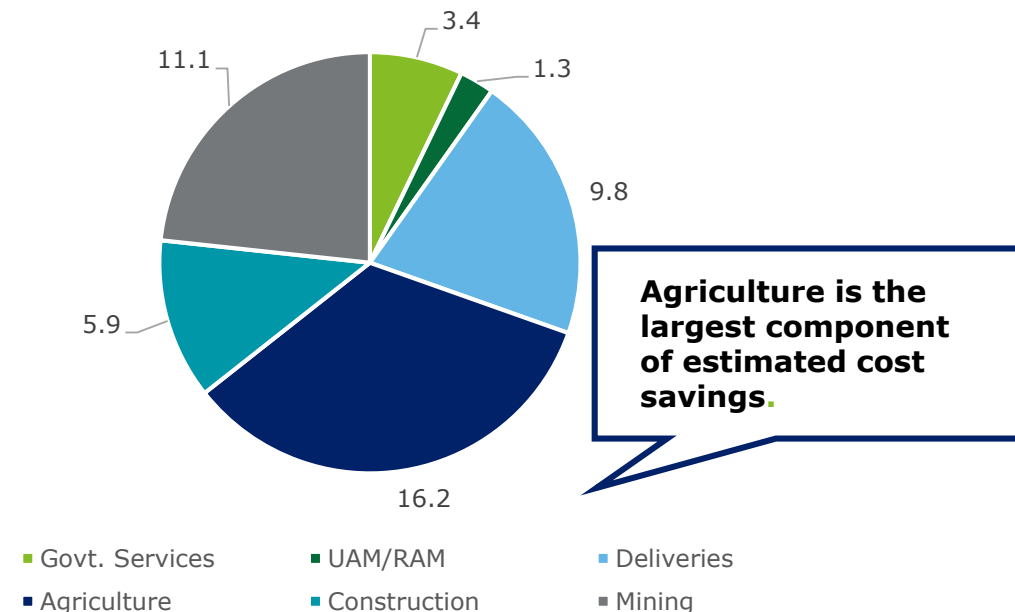
To account for uncertainty a scenario-based approach is used presenting three possible 'states of the world' ranging from pessimistic to optimistic in nature:

- **Low uptake scenario** – This scenario is characterised by lower compound annual growth rates (CAGRs) across all use cases and lower maximum penetration rates relative to other scenarios. For emerging use cases, initial widespread adoption is also delayed relative to other scenarios. This scenario represents a combination of several barriers to entry acting strongly as resistors to drone uptake.
- **Medium uptake scenario** – This scenario is the 'central case' or most likely uptake scenario. It is characterised by CAGRs and maximum penetration rates that are considered 'middle ground' between the low and high uptake scenarios. This 'middle ground' nature is reflected in the widespread adoption of emerging use cases.
- **High uptake scenario** – This scenario is characterised by higher CAGRs and maximum penetration rates than other scenarios. For emerging use cases, initial widespread adoption occurs earlier than the low and medium uptake scenarios. This represents a combination of several barriers to entry having a lessened effect on drone uptake.

Overview of medium uptake scenario, drones cost savings (real 2020\$)

Cumulative estimated cost savings (2020-2050) of circa \$48 billion undiscounted

Chart 25: Breakdown of costs savings, undiscounted \$billion (real 2020\$)



Estimates of the cost savings for UAM/RAM as well as E-commerce and deliveries use cases reflect the underlying assumptions for each scenario and are based on desktop research, in-house Deloitte sources and other studies of drone benefits

Table 6: Assumptions per use case

Use cases		Cost savings assumptions	Travel time savings assumptions
Urban / Regional Air Mobility	Airport taxi trips	80% of trips are business related; 20% private - Average taxi cost of \$3.01 per km - Average initial UAM cost of \$7 per km - Average airport taxi distance of 18.5km - Comparable UAM average trip distance (haversine) of 12.1km - Average ATAP value of time for passengers (2020 real dollars) - \$56.77 per passenger per hour (business); \$17.50 per passenger per hour (private)	- BITRE representative hourly distribution of delay intensity used to calculate average taxi trip travel time - Average travel time for UAM passengers to / from vertiport of 10min - Average loading / unloading time for UAM passengers of 5min - UAM average flight speed of 200km per hour
	Point-to-point trips	80% of trips are business related; 20% private - Average taxi cost is derived from Australian Taxi Industry Association (ATIA) data on average trip cost 2004-2014 - Average initial UAM cost of \$7 per km - Average point-to-point taxi distance of 8.4km - Comparable UAM average trip distance (haversine) of 5.5km - Average ATAP value of time for passengers (2020 real dollars) - \$56.77 per passenger per hour (business); \$17.50 per passenger per hour (private)	- Travel time for average point-to-point taxi trip derived from ATIA data on average trip times from 2004-2014 - Average travel time for UAM passengers to / from vertiport of 10min - Loading / unloading time for UAM passengers of 5min - UAM average flight speed of 200km per hour
	Regional air mobility	50% of trips are business related; 50% private - Average trip distance of 393km - Average ATAP value of time for passengers (2020 real dollars) - \$56.77 per passenger per hour (business); \$17.50 per passenger per hour (private)	- Average RAM travel speed of 300km per hour - Average travel time for RAM passengers to / from vertiport of 10min - Average loading / unloading time for RAM passengers of 5min - Average travel speed for domestic aircraft of 800km per hour - Average travel to airport and travel time excluding flight time (check baggage, security etc.) of 154 minutes (both sides)
E-commerce and deliveries	Express parcel deliveries	- Next best alternative for express parcel deliveries is assumed to be electric vans - Average cost per delivery for express parcel electric van deliveries is \$7.30 - Average cost per delivery for express parcel drone deliveries is \$1.67	-
	Food deliveries	- Next best alternative for food deliveries is assumed to be electric bikes - Average cost per delivery for food electric bike deliveries is \$3.18 - Average cost per delivery for food drone deliveries is \$1.49	-
	Regional and remote pathology deliveries	- Next best alternative for regional and remote pathology deliveries is assumed to be electric vans - Average cost per delivery for electric vans is \$7.67 - Average cost per delivery for drone deliveries is \$3.21	-

Source: Deloitte Access Economics based on several sources

Estimates of the cost savings for the remaining use cases are reflective of the underlying assumptions for each scenario which are based on desktop research, Deloitte in-house sources and other studies.

Table 6: Assumptions per use case (cont.)

Use cases		Cost savings assumptions
Agriculture	Agriculture, Forestry and Fisheries	- Yield increase accruing to crop-based agricultural businesses due to drones of 2% - Yield increase accruing to other agricultural businesses due to drones of 1% - Weighted average yield increase accruing to all agricultural businesses due to drones of 1.49% - Dynamic efficiencies due to further developments in technology are estimated to increase yield increase due to drone use by 0.25% to 1.56% by 2030
Construction	Construction (incl. surveying)	- Average labour cost of surveying and mapping businesses of \$323,365 increasing at 0.31% (estimated CAGR 2019-2025) - Labour cost reduction for surveying and mapping businesses adopting drones of 30% (initial) increasing at a CAGR of 7% to 60% (by saturation in 2030) representing dynamic efficiencies and the development of complementary technology
Mining and resources	Mining and resources	- Total potential drone savings for the Australian mining and resources industry of \$940 million is derived from a BHP estimate of cost savings in QLD mines of \$5 million. Total potential drone savings grows at 2.1% (historical mining and resources 2010-2020 sales and revenue) - BHP market share assumed at 15.4% - Proportion of cost savings accruing to QLD assumed to be reflective of counts of mining businesses in the State – 22.5%
Government services	Police, firefighting, customs, border control	- Under a lack of available data, government services are anticipated to experience similar labour cost savings to the construction industry but without dynamic efficiencies. - On average, government services drones are assumed to operate 10% of all hours in a week - Assumes an average weekly earnings of \$1,752.26
Defence	Surveillance and warfare	Assumes an average weekly earnings of \$1,752.26
Recreational	Recreational uses of drones	Consumer surplus for recreational drone users is assumed to be 5% of average purchase price of a drone

Source: Deloitte Access Economics based on several sources

UAM in the form of airport and point-to-point trips are expected to substitute for existing taxi transport due to travel time savings. UAM pricing may be cost prohibitive for many passengers until technologies develop more leading to lower unit prices.

Cost savings profile

Passengers have several alternative modes of transport for airport, point-to-point and intercity trips including public transport such as buses and rail, taxi or uber, private vehicles, bikes or scooters etc.

UAM is more likely to be utilised by passengers with relatively low price sensitivity with higher values for travel time due to the high initial estimated price per passenger trip relative to alternative transport modes (discussed opposite). As such, UAM is expected to compete with users of taxi services most closely than users of other alternate modes.

To determine an average travel time saving, a profile for a representative taxi journey was developed and compared incrementally to an equivalent UAM journey.

For a representative airport taxi trip, an average distance of circa 19km was used with an estimated travel time (average of on and off-peak) of 27 minutes calculated using Bureau of Infrastructure Transport and Regional Economics (BITRE) distributions of traffic density.⁶⁰ For point-to-point trips an average historical taxi trip distance was sourced at circa 8.5 km with an estimated travel time of nearly 17 minutes.⁶¹

Subsequently, a UAM profile was developed over an equivalent average trip distance (circa 12.1km for airport trips and circa 5.5km for point-to-point trips). For a user to complete an equivalent journey using UAM, there is assumed travel time to/from the vertiport infrastructure of 10 minutes, an assumed loading and unloading vehicle time of 5 minutes and an assumed average flight speed of 200 km/hr.⁶²

The incremental travel time savings of UAM versus a taxi over the same distance is estimated at just over 8 minutes per passenger for an average airport trip and less than a minute per passenger for point-to-point trips.

Using a midpoint estimate for UAM costs per km it is assumed that UAM would initially cost circa \$7/km.⁶³ As such, the estimated average cost for an airport trip is circa \$85/one-way with an average point-to-point trips estimated at circa \$39/one-way.

An equivalent taxi journey is estimated to cost on average circa \$56/one-way for an airport journey and circa \$25/one-way for an average point-to-point journey. These profiles represent an additional price per trip for users of UAM of circa \$29/one-way for an average airport trip and circa \$14/one-way for an average point-to-point trip.⁶⁴

It is possible for the travel time savings offered, that UAM will be cost-prohibitive for many users. As price elasticities are not considered in this study, it is implicitly assumed that prices for UAM trips will decline as technology is further developed and potential economies of scale are leveraged, thus decreases prices and improving the service offering of UAM relative to existing taxi services. This is reflected in the UAM adoption curves outlined in the previous Chapter.

⁶⁰BITRE (2015), 'Traffic and congestion cost trends for Australian capital cities' - https://www.bitre.gov.au/sites/default/files/is_074.pdf

⁶¹ATIA (2014), 'Taxi statistics' - <https://www.atia.com.au/taxi-statistics/>

⁶²NASA (2018), 'Urban air mobility (UAM) market study' - <https://www.nasa.gov/sites/default/files/atoms/files/uam-market-study-executive-summary-v2.pdf>

⁶³UberElevate, 'Fast-forwarding to a future of on-demand urban air transport' - <https://www.uber.com/elevate.pdf>

⁶⁴TTF (2014), 'Accessing our airports' - <https://www.ttf.org.au/wp-content/uploads/2016/06/TTF-Accessing-Australias-Airports-2014.pdf>

UAM could result in a total of \$6-\$91 million per annum in travel time savings for businesses along with \$0.4-\$7 million per annum in travel time savings for private users in 2040.

Market benefits

Market benefits for UAM are represented by the travel time savings accruing to business passengers. Under the low uptake scenario, these travel time savings are estimated at around \$6 million in 2040, increasing to circa \$66 million and circa \$91 million under the medium and high uptake scenarios (refer Chart 26) (real 2020\$, undiscounted). Cumulatively, travel time savings over the period 2020 to 2040 amount to circa \$24-\$453 million under the various scenarios.

Due to the need for ‘first and last-leg’ journey’s to infrastructure nodes, the largest proportion of travel time savings are accrued through airport trips as opposed to point-to-point trips (upwards of 95% of travel time savings relate to airport trips).

Other market benefits that have not been quantified include a reduction in road maintenance costs for government due to a decline in the number of road-based vehicle trips as passengers potentially substitute away from taxi transport.

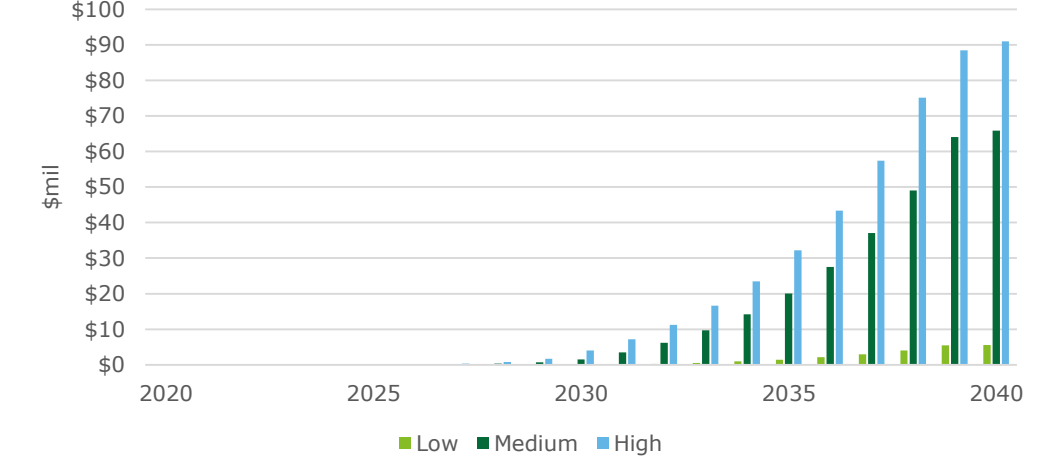
Non-market benefits

Non-market benefits for UAM are represented by the travel time savings accruing to private passengers. Under the low uptake scenario, these travel time savings are estimated at around \$0.4 million in 2040, increasing to circa \$5 million and circa \$7 million under the medium and high uptake scenarios, respectively (refer Chart 27) (real 2020\$, undiscounted). Cumulatively, travel time savings for private users over the period 2020 to 2040 are estimated at circa \$2-35 million under the different scenarios.

The use of eVTOL vehicles for UAM passenger journeys may also lead to a reduction in emissions associated with the transport sector. The magnitude of these environmental benefits will depend on the level of substitution occurring and the proportion of emissions-intensive combustion vehicles used by the conventional taxi industry.

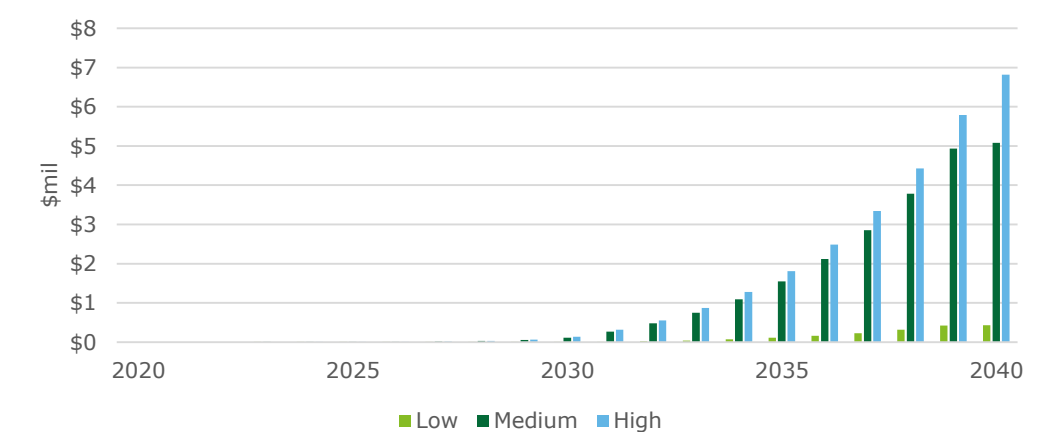
With less congestion on roads, it is also likely that passenger drones will reduce the likelihood of crashes and consequently accrue safety benefits. In addition, as crash-avoidance and automation technologies further develop, UAM may see a reduction in the likelihood of crashes due to the impossibility of human-error under autonomous flight. These factors have not be considered as part of this analysis.

Chart 26: Undiscounted estimated cost benefits for business users* – UAM (real 2020\$)



Source: Deloitte Access Economics
*Cost savings are reflective of the opportunity cost of travel time

Chart 27: Undiscounted estimated cost benefits for private users* – UAM (real 2020\$)



Source: Deloitte Access Economics
*Cost savings are reflective of the opportunity cost of travel time

RAM is expected to compete primarily with short distance domestic aviation. The unit price is currently likely to be too high for most users. Achieving 'economies of scale' and operational efficiencies are required to make RAM more accessible.

Cost savings profile

Passengers have several alternative modes of transport for RAM (intercity trips). These include busses and rail, taxis (in some cases), private vehicles, aircraft, etc.

Similar to UAM, RAM is expected to be utilised by passengers with relatively low price sensitivities and higher values for travel time due to the high initial estimated price per passenger trip. Unlike UAM, due to longer average travel distances it is expected to compete more closely with short-route domestic aviation or private vehicles and rail.

To determine an average travel time savings, a linear function for UAM and domestic aviation travel times as a function of distance were constructed. Each function reflects a profile for a representative trip.

For UAM, passengers are assumed to take 15 minutes to get to/from a vertiport and the eVTOL vehicle is assumed to travel at an average speed of 300 km/hr. For domestic aircraft, passengers are assumed to take approximately 55 minutes to get to/from the airport, spend 40 minutes checking baggage and security with around 20 minutes either side for the plane to be loaded and unloaded and an additional 20 minutes for security and baggage collection. Further, domestic aircraft are assumed to travel at an average speed of 800 km/hr.^{65,66,67}

On a travel time basis and ignoring the capacity of VTOL aircraft for longer journeys, RAM is estimated to be competitive with domestic aviation up to distances of 500km. An average representative journey is calculated at slightly less than 400 km. This distance is towards the upper bound of what VTOL passenger prototype vehicles are capable of flying.

For this representative trip, a 90 minute travel time saving per passenger is estimated.

Using similar estimates for UAM costs per km as for airport and point-to-point trips, this representative trip is estimated to initially cost circa \$2,750/one-way. This cost is significant and is considered cost-prohibitive throughout early adoption. The uptake of RAM will be dependent on the ability for users to leverage 'economies of scale' such as through ridesharing whereby passenger numbers per vehicle may increase and for technology to reduce costs for operators. It is expected that larger VTOL vehicles will be used to facilitate RAM journeys (relative to UAM) whereby price can be distributed over more passengers and ultimately, journeys become more economical.

Longer distances and larger travel time savings are expected to result in a more even split of business and private passenger use.

⁶⁵Airliners (2020), 'Airbus A320' - <https://www.airliners.net/aircraft-data/airbus-a320/23>

⁶⁶NASA (2018), 'Urban Air Mobility (UAM) Market Study' - <https://www.nasa.gov/sites/default/files/atoms/files/uam-market-study-executive-summary-v2.pdf>

⁶⁷Uber Elevate (2016), 'Fast-forwarding to a future of on-demand urban air transportation' - <https://www.uber.com/elevate.pdf>

RAM could result in a total of \$0.3 to \$9 million per annum in travel time savings for businesses long with \$0.1 to \$3 million in travel time savings for private users in 2040.

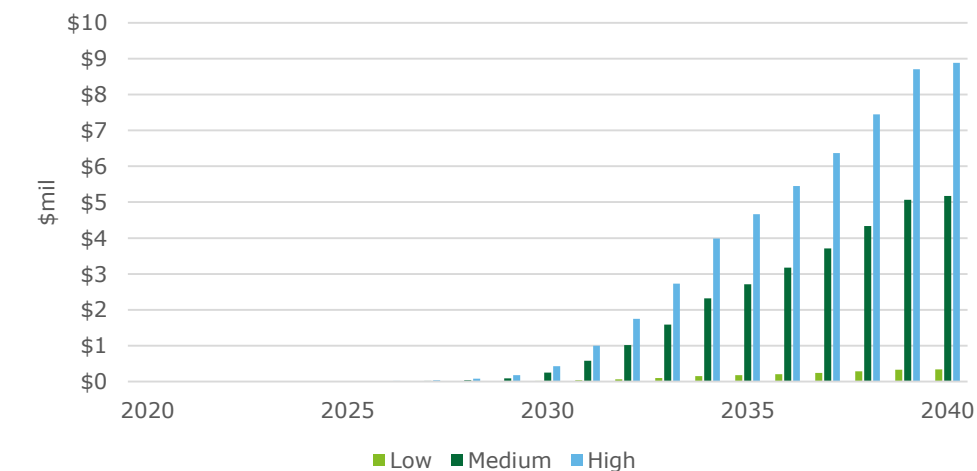
Market benefits

As with UAM, RAM market benefits are represented by the travel time savings accruing to business passengers. Under the low uptake scenario, travel time savings are estimated at around \$0.3 million in 2040, increasing to circa \$5 million and circa \$9 million under the medium and high uptake scenarios (refer Chart 28) (real 2020\$, undiscounted). Cumulatively, travel time savings over the period 2020 to 2040 amount to circa \$2-\$52 million between scenarios. As with UAM and in addition to travel time savings, other market benefits include a reduction in road maintenance costs for government; however, this has not been quantified and is also potentially less than UAM due to RAM’s greater substitutability with short-distance domestic aviation.

Non-market benefits

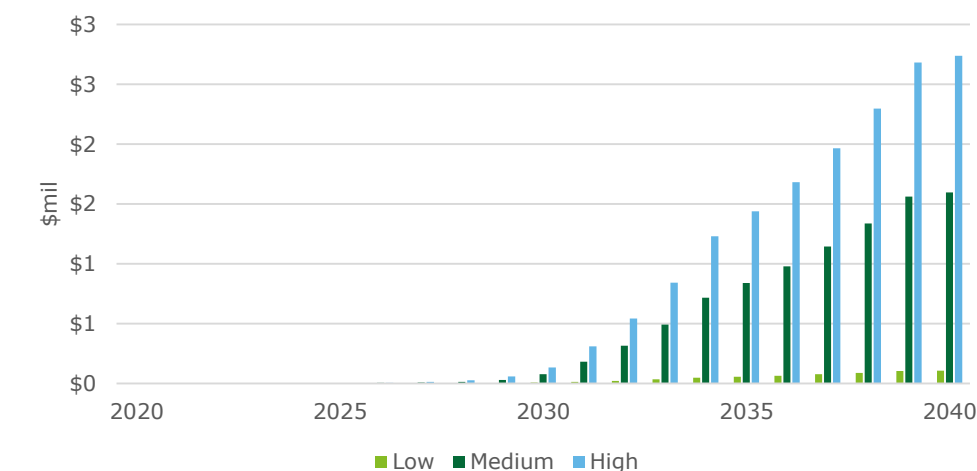
Non-market benefits for RAM are represented by the travel time savings accruing to private passengers. Under the low uptake scenario, these travel time savings are estimated at around \$0.1 million in 2040, increasing to \$2 million and circa \$3 million under the medium and high uptake scenarios, respectively (real 2020\$, undiscounted). As with UAM, the use of eVTOL vehicles for RAM passenger journeys may also lead to a reduction in emissions associated with the transport sector. This is particularly the case, if passengers substitute away from domestic aviation routes. Also, it is possible that passenger drones will reduce the likelihood of road crashes and consequently result safety benefits.

Chart 28: Undiscounted estimated cost benefits for business users* – RAM (real 2020\$)



Source: Deloitte Access Economics
 *Cost savings are reflective of the opportunity cost of travel time
 © 2020 Deloitte Access Economics. Deloitte Touche Tohmatsu.

Chart 29: Undiscounted estimated cost benefits for private users* – RAM (real 2020\$)



Source: Deloitte Access Economics
 *Cost savings are reflective of the opportunity cost of travel time

Express parcel deliveries offer the greatest opportunity for cost savings on a per delivery basis followed by pathology and food. Relatively low upfront capital and operating costs (including labour costs) lend themselves to sizeable cost savings.

Parcel delivery cost savings profile⁶⁸

The most cost-efficient delivery method for 'last leg' parcel journeys from distribution centres to destination locations (and vice versa) is currently electric vans. Electric vans have several disadvantages relative to drones for deliveries, these include the large upfront capital cost relative to drones, comparatively higher operating costs for both labour and maintenance of vehicles (including registration, insurance and repairs).

A cost study conducted by European economics consultancy Valdani Vicari & Associati for a parcel distribution centre in Brussels, Belgium found that drones were cost competitive for express deliveries within 30 minutes from the order. The report found a cost saving per drone delivery of circa \$5.60 with the potential for drone deliveries equipped with GPS and navigational technologies to take as little as 7 minutes until delivery. This is relative to an estimated average of 352 minutes per delivery for conventional e-van delivery.

Food delivery cost savings profile⁶⁸

The most cost-efficient delivery method for food deliveries from restaurants to customers is currently electric bikes, ahead of car deliveries. Although electric bikes do not require as large an initial capital outlay or operating costs such as those required by cars or vans, electric bikes accrue labour costs. On the other hand, drones require far less labour input to deliver the same number of food deliveries (1 drone operator can potentially replace 13 couriers on electric bikes for the same quantity assuming 1.9 drones on average per restaurant).

The same cost study by Valdani Vicari & Associati analysed a case study for Domino's pizza in London, United Kingdom that found drones equipped with GPS and navigational technologies are cost competitive over all distances serviceable by e-bikes. The report found a cost saving per drone delivery of circa \$1.70 with the potential for drones to take as little as 6 minutes per delivery. This is relative to an electric bike that is estimated to take circa 13 minutes per delivery.

Pathology delivery cost savings profile⁶⁸

For pathology deliveries the most cost-efficient mode of delivery for pathology tests from pathology clinics to hospitals and testing centres is electric vans. As with parcel deliveries, electric van deliveries are subject to large upfront capital costs relative to drones and comparatively higher operating costs. The Valdani Vicari & Associati study estimates that for every 2 couriers, 1 drone operator is needed to substitute, providing potential for significant labour cost savings.

For pathology deliveries, Valdani Vicari & Associati analysed a case study for Rouen, France that found delivery drones have the potential to provide cost savings in the order of \$4.50 per delivery assuming an average of 2.5 drones per hospital. In addition, drones may result in delivery times as low as 15 minutes per delivery with the counterfactual 42 minutes per delivery for an electric van.

⁶⁸valdani Vicari & Associati (2020), 'Comparing the cost effectiveness of drones' - <https://www.unmannedairspace.info/commentary/comparing-the-cost-effectiveness-of-drones-v-ground-vehicles-for-medical-food-and-parcel-deliveries/>

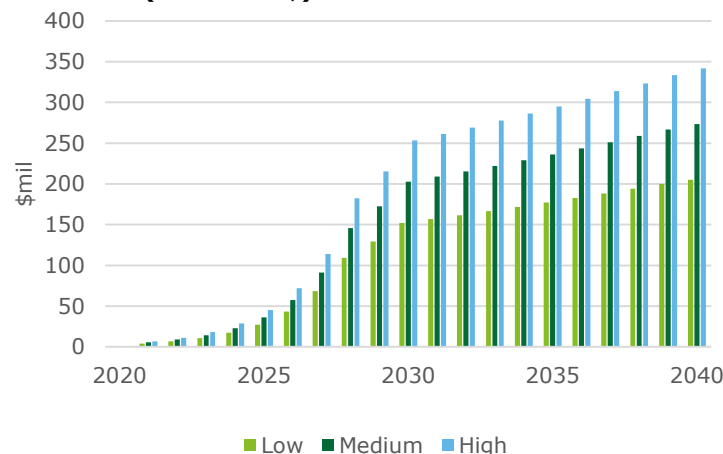
Parcel delivery drones could result in \$205 to \$340 million in cost savings in 2040 with food deliveries the second largest (circa \$80 to \$110 million) followed by pathology (circa \$35 to \$75 million).

Parcel deliveries (market and non-market)

Under the low uptake scenario, market benefits include cost savings for transport operators estimated at around \$205 million in 2040, increasing to circa \$275 million and circa \$340 million under the medium and high uptake scenarios (refer Chart 30) (real 2020\$, undiscounted). Cumulatively, cost savings over the period 2020 to 2040 amount to circa \$2.4-\$4.0 billion over the low to high uptake scenarios.

Other market benefits include reductions in road maintenance costs for government's due to a reduction in delivery vans. Non-market benefits are primarily safety benefits accruing due to the substitution of road vehicles and a reduction in congestion and accident risk.

Chart 30: Undiscounted estimated cost benefits – Parcel deliveries (real 2020\$)



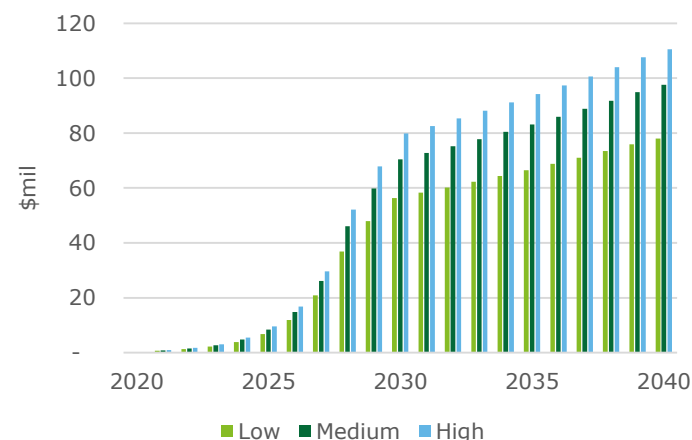
Source: Deloitte Access Economics
© 2020 Deloitte Access Economics. Deloitte Touche Tohmatsu.

Food deliveries (market and non-market)

Under the low uptake scenario, cost savings are estimated at circa \$80 million in 2040, increasing to circa \$100 million and circa \$110 million under the medium and high scenarios (refer Chart 31) (real 2020\$, undiscounted). Cumulatively, cost savings over the period 2020 to 2040 amount to circa \$0.9-\$1.2 billion over the low to high uptake scenarios.

Similar market and non-market benefits to parcel drones are relevant for food deliveries albeit to a lesser extent due to the use of e-bikes.

Chart 31: Undiscounted estimated cost benefits –Food deliveries (real 2020\$)



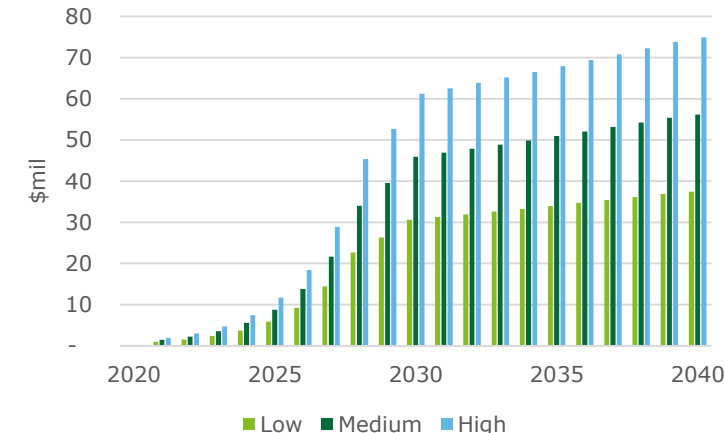
Source: Deloitte Access Economics

Pathology deliveries (market and non-market)

Under the low uptake scenario, cost savings are estimated at circa \$35 million in 2040, increasing to circa \$56 million and circa \$75 million under the medium and high scenarios (refer Chart 32) (real 2020\$, undiscounted). Cumulatively, cost savings over the period 2020 to 2040 range from circa \$0.5-\$0.9 billion over the different scenarios.

Other market and non-market benefits are similar to other delivery drone uses.

Chart 32: Undiscounted estimated cost benefits – Pathology deliveries (real 2020\$)



Source: Deloitte Access Economics

Agriculture, forestry and fishing offers the largest potential for cost savings and improvements in productive processes to improve agriculture yields with savings ranging from \$310 to \$940 million in 2040 in the low to high uptake scenarios.

Cost savings profile

Drones can be used to augment existing agriculture, forestry and fishing processes including soil and field analysis, crop monitoring, crop dusting, seed planting or for general surveillance / mapping. Conventionally, these processes are either labour-intensive or require expensive machinery or hire charges for example, for light aircraft surveillance.

Proponents of drones argue that for many of these applications, drone use will deliver faster, more precise results than traditional processes. For crop monitoring, drones have the potential to operate more accurately, frequently and affordably, delivering higher quality data.

In addition to existing processes, drones are also an enabling technology for advanced agricultural practices. Relatively low cost, 3D mapping and aerial imagery of farms are enabling farmers to tailor the level and distribution of soil and chemical additives over the crop, ensuring each area of the farm receives the optimal amount of additive. Consequently, drones have the potential to be a catalyst for increases in agricultural yields.

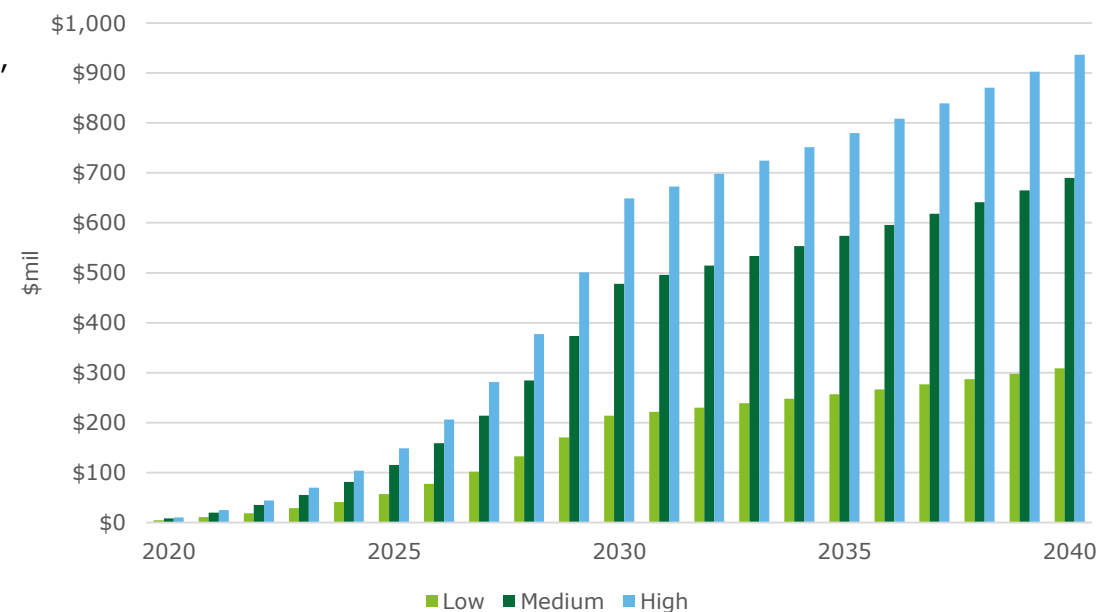
According to specialised drone manufacturer SenseFly, the utilisation of drones by the Ocealia group resulted in a 10% average increase in crop yields. A more conservative yield increase for agricultural crops of 2% and 1% for other agriculture were employed with a weighted average yield increase determined using ABS production data of 1.49%. This yield increase is assumed to grow by 0.25% over ten years to reflect dynamic efficiencies from improvements in technology and improved uses of data and complementary software.⁶⁹

Market and non-market benefits

Under the low uptake scenario, market benefits include cost savings for the agriculture, forestry and fishing industry of circa \$310 million in 2040, increasing to circa \$690 million and circa \$940 million under the medium and high scenarios (refer Chart 33) (real 2020\$, undiscounted). Cumulatively, cost savings over the period 2020 to 2040 amount to around \$3.5-\$10.4 billion over the various scenarios.

In addition to market benefits there are also potential for environmental non-market benefits as drones have the potential to reduce the total quantity of additives for crops including pesticides as well as crop water use.

Chart 33: Undiscounted estimated cost savings – Agriculture, forestry and fishing (real 2020\$)*



Source: Deloitte Access Economics

*Cost savings are outweighed initially by upfront capital costs to 2030 under all scenarios.

⁶⁹European Commission (2018), 'Drones in agriculture' - https://ec.europa.eu/growth/toolsdatabases/dem/monitor/sites/default/files/Drones_vf.pdf

The use of drones in the construction industry could result in labour cost savings in the order \$130 to \$310 million in 2040 in the low to high uptake scenarios as well as support increased safety in the construction industry.

Cost savings profile⁷⁰

Drones can be used to substitute existing labour intensive processes in construction such as surveying and inspections. In practice, builders can use drones to collect real-time data about projects and understand on-site conditions to track progress as well as helping to catch problems before project timelines are delayed.

Complementary software enables builders to use site mapping data to plan, communicate and keep projects on schedule. Further to these potential operating efficiencies, drones also offer occupational health and safety benefits in the form of safer work environments.

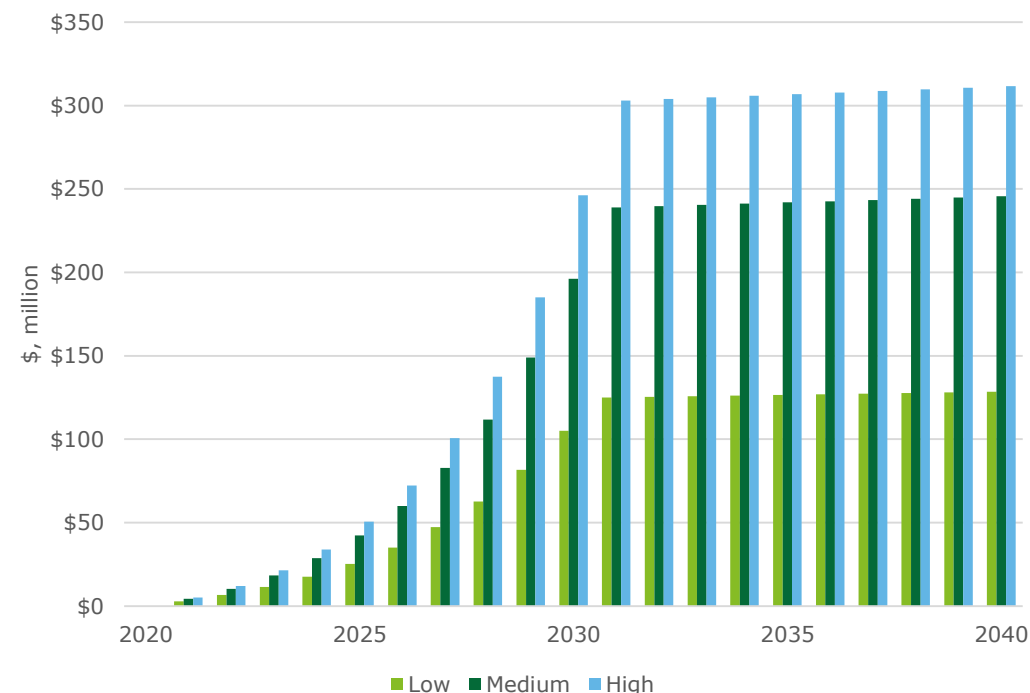
Respondents to a survey conducted by drone software company *DroneDeploy*, anecdotally indicated that drones were responsible for a 75% or greater cost and time improvement. A more conservative labour cost saving for surveying hours of 30% is assumed with a large dynamic component of 30% assumed to accrue over ten years. This dynamic component reflects the opinions of CASA and AA that indicated in consultation that software and greater data uses, once unlocked, could provide significant benefits to the construction industry.

Market and non-market benefits

Under the low uptake scenario, market benefits including labour cost savings for the construction industry are estimated at circa \$130 million in 2040, increasing to circa \$2465million and circa \$310 million under the medium and high scenarios (refer Chart 34) (real 2020\$, undiscounted). Cumulatively, cost savings under this use case over the period 2020 to 2040 is estimated at circa \$1.8-\$4.3 billion over the low to high uptake scenarios.

Non-market benefits include occupational, health and safety benefits through improved site safety.

Chart 34: Undiscounted estimated net cost savings – Construction (real 2020\$)*



Source: Deloitte Access Economics

*Cost savings are exceeded by capital costs to 2026.

⁷⁰Drone Deploy (2018), 'The rise of drones in construction' - <https://www.dronedeploy.com/blog/rise-drones-construction/#:~:text=Drones%20do%20more%20than%20improve,drones%20on%20the%20job%20site.>

The use of drones in mining and resources offers several potential cost savings through operational efficiencies. These cost savings could range from \$295 to \$550 million in 2040.

Cost savings profile

Mining and resource operations use surveying for volumetric measurements based on global navigation satellite systems (GNSS), mining exploration and site monitoring. This process is a time demanding and labour intensive process, and in the case of mining exploration may include additional costs such as plane and pilot hire. Drones offer an alternative and potentially more cost effective method for these processes.

For stockpile management, drone aerial imagery can be used to generate digital surface models, digital terrain models and 3D reconstructions of mining sites, including stockpiles. This enables calculation of stockpile values that are more precise than traditional GNSS methods, enabling better planning. The lower operational cost for drones also enables more frequent surveys for more up-to-date data.

For mine or quarry monitoring and operational planning, drones can be used for accurate site models to support mine managers in efficient design and management of site operations across teams. This includes visual imagery of mine roads as well as water and sediment flows.

Potential efficiencies for mining drones are quoted by drone manufacturer *Wingtra* at up to 30 times faster than traditional land-based methods without the need for surveyors on site. The BHP head of production for mining BMA Frans Knox stated that drones at BHP's QLD sites were responsible for \$5 million in drone cost savings. The cost savings for the national mining and resources industry are derived from this case study using an assumed BHP market share of 15.4% and a QLD share of total mining businesses of 22.6%.^{71,72,73}

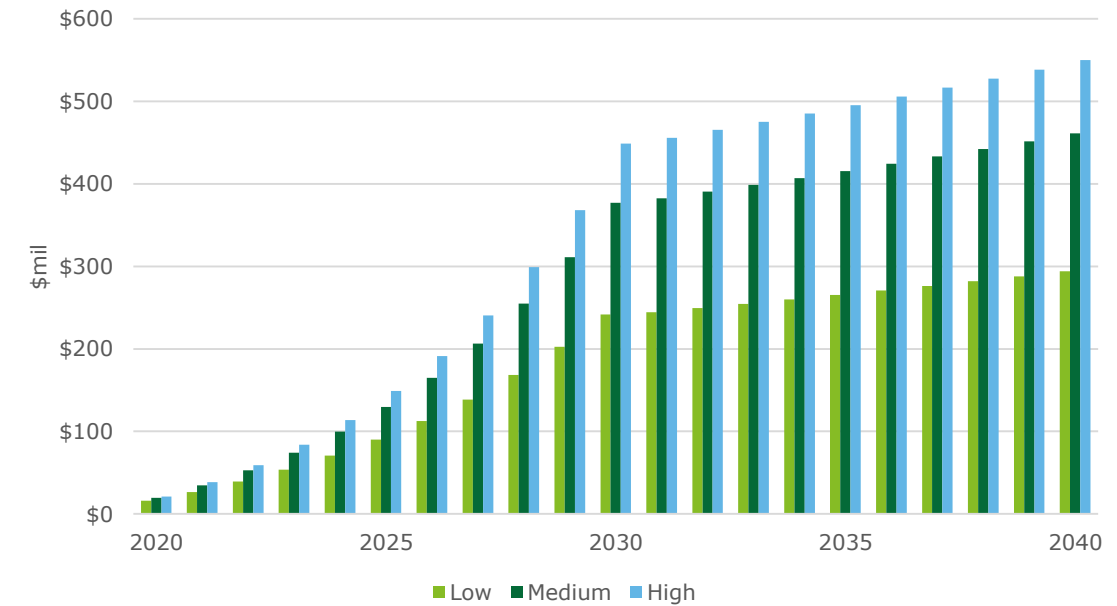
⁷¹IBISWorld (2020), 'Australia Industry Reports – Mining' - <https://clients1.ibisworld.com.au/reports/au/industry/majorcompanies.aspx?entid=55>
⁷²Wingtra (2020), 'Mining and aggregates' - <https://wingtra.com/drone-mapping-applications/mining-and-aggregates/>
⁷³Mining Technology (2018), 'How drones are changing the art of mineral surveying' - <https://www.mining-technology.com/features/drones-changing-art-mineral-surveying/>

Market and non-market benefits

Under the low uptake scenario, market benefits include labour cost savings for the mining and resources industry estimated at circa \$295 million in 2040 under the low uptake scenario and increasing to circa \$460 million to \$550 million under the medium and high uptake scenarios (refer Chart 35) (real 2020\$, undiscounted). Cumulatively, cost savings over the period 2020 to 2040 is estimated at around \$3.8-\$7.0 billion.

In addition to cost savings, there are sizeable safety benefits for mining operators. These have not been quantified.

Chart 35: Undiscounted estimated cost savings – Mining and resources (real 2020\$)



Source: Deloitte Access Economics

Drones use by government has the potential to achieve labour cost savings in the order of \$85-\$325 million in 2040. There are also many potential benefits to the community including improved search and rescue efforts and disaster management.

Cost savings profile⁷⁴

Government services such as fire, police, customs, border security and emergency disaster responses are typically labour-intensive in nature and may involve other operating costs such as those for helicopters or planes etc.

Drones offer the potential for efficiencies and safety improvements for civil use cases. In fighting fires, drones can be used to scout fire locations, using thermal imaging cameras to see through smoke and assist first responders to deploy assets efficiently and to assist in rescue efforts. Additionally, drones can be used post-fire in disaster management to survey or map scenes to assess damages or to search and locate missing people. The data available through drone technology can result in better informed decision making, accruing additional safety benefits.⁷⁵

Further, drones have several uses in other civil areas such as police, customs or border control. For instance, drones can be used to map cities for disaster management efforts, monitor ports and patrol coastline, pursue suspects in a far more cost effective manner than conventional helicopters, crime scene investigation and 3D reconstruction of vehicle accidents.⁷⁶

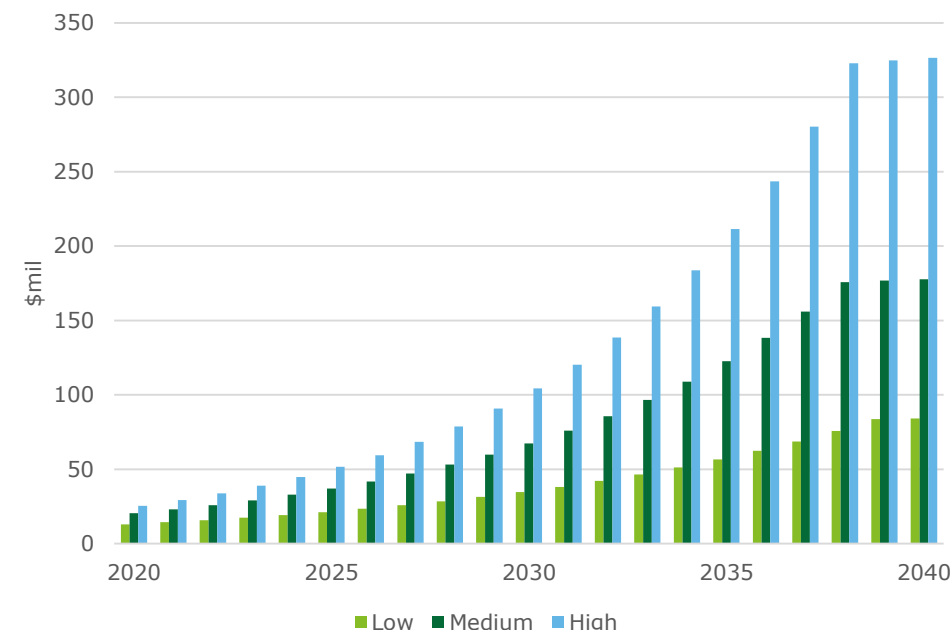
As many of the drone use cases for government services involve surveillance and mapping, labour cost savings are assumed to be comparable with those in the construction and mining industries at circa 30% over the case without drones.

Market and non-market benefits

Under the low scenario, market benefits include labour cost savings for various government services and are estimated at circa \$85 million in 2040 the low uptake scenario, increasing to circa \$178 to \$326 million under the medium and high uptake scenarios (refer Chart 36) (real 2020\$, undiscounted). Cumulatively, cost savings over the period 2020 to 2040 is estimated at circa \$0.8-\$2.6 billion.

In addition, as drones have the potential to improve search and rescue efforts and offender apprehension there are likely to be sizeable safety benefits accruing to drones. These non-market benefits are not quantified.

Chart 36: Undiscounted estimated net cost savings – Government services (real 2020\$)



Source: Deloitte Access Economics

Note: Cost savings are exceeded by capital costs until 2024

⁷⁴Drone Deploy (2018), 'The rise of drones in construction' - <https://www.dronedeploy.com/blog/rise-drones-construction/#:~:text=Drones%20do%20more%20than%20improve,drones%20on%20the%20job%20site.>

⁷⁵IBISWorld (2020), 'Australia Industry Reports - Mining' -

<https://clients1.ibisworld.com.au/reports/au/industry/majorcompanies.aspx?entid=55>

⁷⁶Wingtra (2020), 'Mining and aggregates' - <https://wingtra.com/drone-mapping-applications/mining-and-aggregates/>
Mining Technology (2018), 'How drones are changing the art of mineral surveying' - <https://www.mining-technology.com/features/drones-changing-art-mineral-surveying/>

Recreational use of drones represent the largest industry use case in terms of drone units. There is the potential for \$45 million in benefits in 2040 under the high uptake scenario.

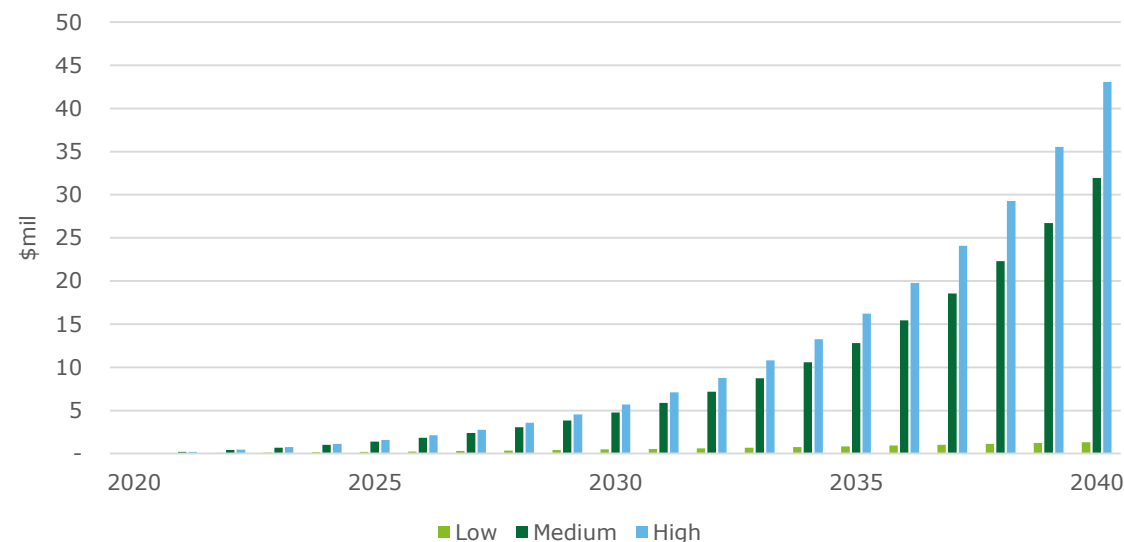
Market and non-market benefits

Reported in consultation with CASA and AA as Australia's largest drone use case in terms of unit, recreational drones continue to grow strongly. The strong growth in recreational drone numbers are aided by low regulatory barriers that do not require operators to be certified drone operators and a low entry price point (circa. \$300 on average for low-end models). Growth in recreational drones has been further aided through regulatory changes made by CASA in late 2016 that removed licensing requirements for low-risk operations and added an exclusion category for drones on private property.

Users of recreational drones are by virtue, private users. Additionally, the derived consumer surplus (a measure of the value derived by private users between the willingness to pay and market prices) is considered a non-market benefit. This consumer surplus is assumed to be 5% of the unit price on average all else equal.

The benefits derived by recreational users is estimated at circa \$1.5 million under the low uptake scenario in 2040, increasing to \$30 to \$45 million in the medium and high uptake scenarios (refer Chart 37) (real 2020\$, undiscounted). Cumulatively, derived consumer surplus over the period 2020 to 2040 is estimated to be \$11-\$231 million.

Chart 37: Undiscounted estimated benefits to consumers from recreational drone use (real 2020\$)



Source: Deloitte Access Economics

5. Economy-wide impacts of drones – medium uptake scenario

This chapter estimates the broader economy-wide impacts associated with the uptake of drones to the Australian economy using the Deloitte Access Economics Regional General Equilibrium Model (DAE-RGEM). The focus of this chapter is the economic impacts of the medium uptake scenario or 'most likely' case.

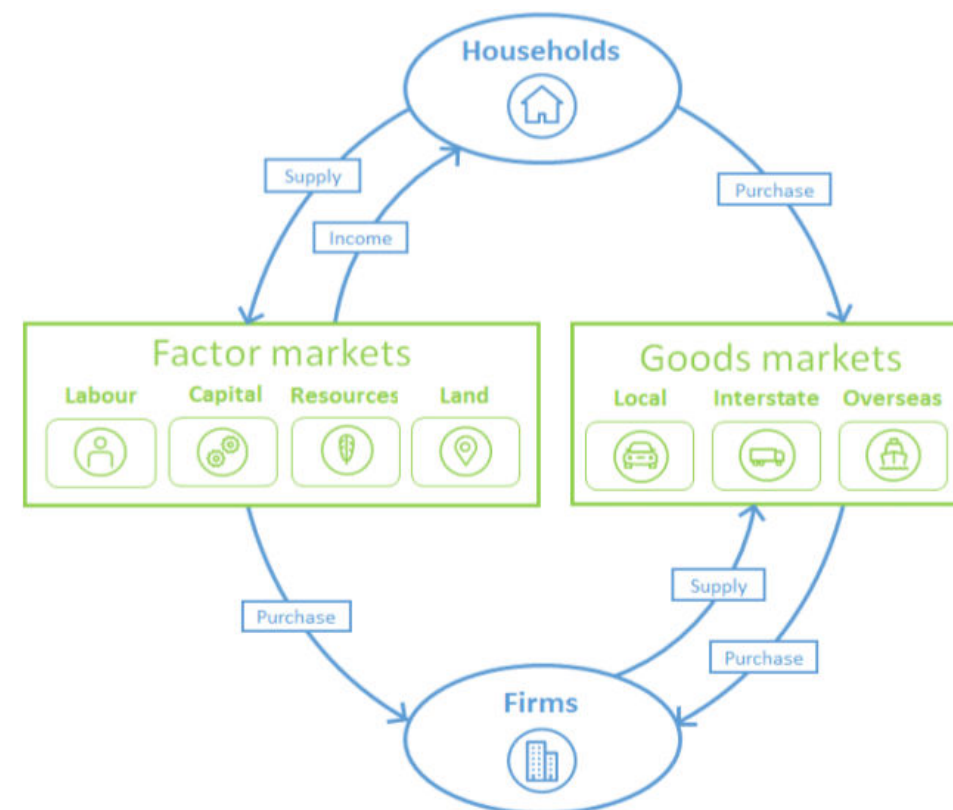
Computable general equilibrium (CGE) modelling is a framework that is well suited to modelling the economic impacts of large projects or policies on the economy, including the uptake of drones. In this framework, it is possible to account for resourcing constraints and opportunity costs, and to model changes in prices and the behaviour of economic agents in response to changes in the economy.

The Deloitte Access Economics regional general equilibrium model (DAE-RGEM) is a model of the Australian and world economy and represents the interaction of households and firms with factor markets and goods markets over time. DAE-RGEM represents all economic activity in the economy, including production, consumption, employment, taxation and trade. It can be customized to represent regions and industries of interest. The stylised diagram (refer Figure 6) shows the circular flow of income and spending that occurs in DAE-RGEM. To meet demand for products, firms purchase inputs from other producers and hire factors of production (labour and capital). Producers pay wages and rent (factor income) which accrue to households. Households spend their income on goods and services, pay taxes and put some away for savings. More detail on the modelling framework used is provided in Appendix B.

As part of this project, the DAE-RGEM was modified to explicitly represent all Australian states and territories. Additional work was then undertaken to split out East Coast Capital Cities.

The full list of regions and industries identified in the model are highlighted on the following page.

Figure 6: Stylised representation of DAE-RGEM



Source: Deloitte Access Economics

DAE-RGEM has been customised for the purposes of this report to represent the drones industry across a number of Australian states and territories. This included the disaggregation of greater capital cities and rest of state for New South Wales, Victoria and Queensland in the model database to provide the regional detail needed by the DITRDC.

The full list of regions in the DAE-RGEM are highlighted below:

- Greater Sydney
- Rest of New South Wales
- Greater Melbourne
- Rest of Victoria
- Greater Brisbane
- Rest of Queensland
- South Australia
- Western Australia
- Tasmania
- Northern Territory
- Australia Capital Territory.

The DAE-RGEM was also customised to explicitly identify the drones industry, as well as relevant supply chain and end use industries.

A summary of the industries identified in the model is shown below:

- Agriculture, forestry and fishing
- Mining
- Drones
- Other manufacturing
- Trade
- Transport
- Utilities
- Construction
- Communications
- Finance and business services
- Government services
- Other services.

As noted, it was necessary to develop a customised industry aggregation that included a drones sector. This was achieved by applying superior data to split out drone activity from the heavy manufacturing industry using Deloitte’s in house CGE modelling database software.

This process leveraged off the splitcom program developed by the Centre of Policy Studies, Victoria University that was modified to suit DAE-RGEM. This program allows the user to input data on sales/cost weights to split out an existing industry (i.e. parent industry) into two components. One part represents the new industry of interest (i.e. drones), while the other part represents the remainder of the parent industry (i.e. the rest of manufacturing).

The weights used for splitcom were developed with reference to economic datasets from the ABS (including the Australian Industry Publication and ABS National Input Output tables) and IBIS World industry reports where relevant.

The baseline scenario provides the reference case against which the economic impacts are measured. This allows the deviation to key economic variables of interest such as gross regional / state / domestic product, aggregate employment and industry output to be measured over time. This includes the profile of economic impacts of over the short term (5 years to 2025), medium term (10 years to 2030) and long term (20 years to 2040).

The modelling projects the baseline forecast over the long term to 2040. The modelling assumes steady state underlying growth forecasts in each region of around 2% per annum. This approach is adopted given the uncertainty associated with short to medium term growth forecasts as a result of the COVID-19 pandemic.

The development of the drones industry in Australia and subsequent uptake by a number of end use industries allows them to achieve cost savings and expand their output relative to the baseline scenario.

The development of the drones industry and uptake of such technologies by various end use industries allows for a range of cost savings. The rationale for, and scale of, these cost savings are informed by the analysis undertaken and presented in Chapter 4. For the purposes of the modelling, the cost savings for the business component of the UAM and deliveries were allocated to transport as the most representative industry.

In particular, the modelling is based on the medium uptake scenario, as this is considered the 'most likely' growth path, and is incremental to a 'baseline scenario' (refer Table 7). As mentioned previously, the headline modelled impacts of costs savings for the low and high scenarios are presented in Appendix A for completeness. The cost savings are modelled as increase in the output of each industry, achieved through an increase in total factor productivity.

Table 7: Incremental growth in the drones industry and cost savings for end use industries by region over the period 2020 to 2040 (real 2020\$ millions), medium uptake scenario

Industries	Regions											Australia
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	
Drones	8,411	3,062	9,927	1,558	4,702	3,552	3,765	5,075	1,066	730	613	42,461
<i>Cost savings to end use industries (undiscounted)</i>												
Agriculture, forestry and fishing	274	1,834	374	1,384	283	1,471	859	823	322	66	15	7,706
Mining	176	864	135	124	347	1,277	292	2,526	64	128	0	5,930
Transport	1,042	637	958	415	489	570	363	545	111	51	88	5,269
Construction	712	332	644	182	347	353	202	442	61	51	47	3,373
Government services	285	154	242	78	175	135	118	162	38	43	163	1,591

Source: Deloitte Access Economics

The increased uptake of drone technology is estimated to stimulate economic growth across Australia and its regions. The present value of the increase in Australia’s Gross Domestic Product (or economic dividend) could be \$14.5 billion over the period 2020 to 2040 at a 7% real discount rate.

The development of the drones industry has the potential to drive economic growth across Australia and its regions. Under the medium uptake scenario, the modelling indicates that this would increase Gross Domestic Product (GDP) in Australia by \$14.5 billion in present value (PV) terms (using a 7% real discount rate) over the period 2020 to 2040.

This growth is driven by the development of the drones industry in Australia, including the drones industry itself, as well as a number of end use industries. The increased uptake of drones across these key downstream industries enables them to achieve cost savings and expand their output (the sectoral impacts are subsequently discussed in more detail).

The profile of the gross regional / state / domestic product by region highlights that the largest impacts are experienced across the East Coast Capital Cities, including Greater Sydney, Greater Melbourne and Greater Brisbane where the density lends itself to the activity. However, there is also activity across of the rest of New South Wales, Victoria and Queensland, where end use industries such as agriculture, forestry and fishing and mining are concentrated (refer Chart 38 and Table 8).

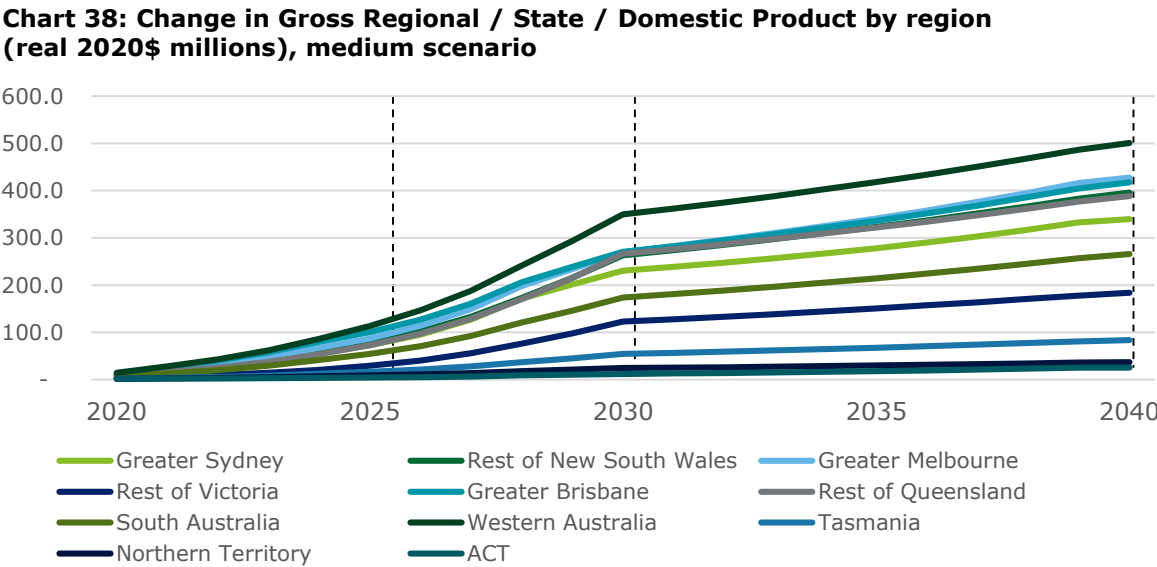


Table 8: Change in Gross Regional / State / Domestic Product by region (real 2020\$ millions), medium uptake scenario relative to the baseline

	Regions											
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia
2025 (short term)	73	77	87	29	101	72	54	113	16	9	4	636
2030 (medium term)	230	263	269	122	270	266	174	350	54	25	12	2,036
2040 (long term)	340	396	428	184	417	388	265	501	84	37	26	3,066

Source: Deloitte Access Economics

This additional activity in the drone industry and end use industries that benefit from use of drones is expected to create employment across Australia's states and territories. Australia could have an annual average of over 5,500 new FTE jobs over the period 2020 to 2040 under the medium uptake scenario.

The activity associated with the uptake of drones is similarly modelled to create additional employment in Australia. The modelling estimates that aggregate employment in Australia would increase by circa 5,500 Full Time Equivalent (FTE) jobs, in average annual terms over the period 2020 to 2040.

As with economic output, the employment impacts across Australia are supported by both drones output and the uptake of drones across various downstream industries.

The profile follows a broadly similar profile as the increase in economic output. Again, the impacts are concentrated across the East Coast Capital Cities, but there are also some positive employment impacts across the rest of the Australia’s states and territories (refer Chart 39 and Table 9).

Chart 39: Change in aggregate Full Time Equivalent employment by region

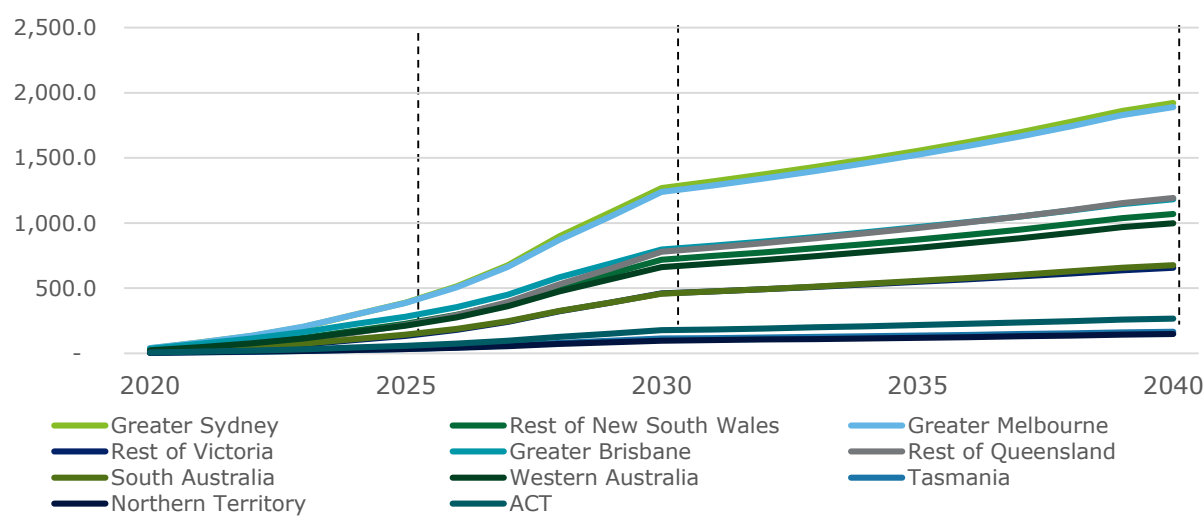


Table 9: Change in aggregate Full Time Equivalent employment by region, medium scenario

	Regions											
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia
2025 (short term)	390	227	387	135	281	217	144	213	34	34	58	2,121
2030 (medium term)	1,270	719	1,238	459	796	779	458	662	114	98	177	6,770
2040 (long term)	1,922	1,069	1,889	656	1,181	1,192	677	998	165	148	267	10,165

Source: Deloitte Access Economics

The sectoral impacts highlight that the uptake of drones generates activity in the drone sector directly, as well as having positive flow-on effects across a range of end use industries across Australia’s regions.

The uptake of drones stimulates activity across Australia's regions, including the drones sector directly, as well as the key end use industries including agriculture, forestry and fishing, mining, transport, construction and government services (refer Table 10). A summary of the impacts by region is discussed overleaf.

Table 10: Change in industry output by region, present value^ over the period 2020 to 2040 (real 2020\$ millions), medium scenario

Regions															
Industries	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia			
Agriculture, forestry and fishing	68	858	153	567	124	866	352	337	132	27	6	3,488			
Mining	46	382	58	53	87	555	126	1,090	27	55	0	2,480			
Drones	2,330	1,245	4,003	628	5,167	525	1,518	2,047	430	294	247	18,435			
Other manufacturing	414	178	716	196	371	352	328	354	120	19	70	3,118			
Trade	475	163	450	96	280	208	164	197	33	18	42	2,126			
Transport	459	148	382	168	340	144	145	218	44	20	35	2,104			
Utilities	60	35	132	49	44	24	35	36	19	3	16	453			
Construction	170	185	274	77	113	185	86	188	26	22	20	1,345			
Communications	79	11	67	5	6	18	17	25	10	0	6	246			
Finance and business services	360	107	333	48	110	142	91	146	19	15	32	1,403			
Government services	83	65	101	33	72	56	49	68	16	18	68	628			
Other services*	50	28	50	-	12	32	20	11	23	1	-	0	-	1	201

Source: Deloitte Access Economics

Note: ^ present value is calculated using a 7% real discount rate over the period 2020 to 2040.

* The other services industry includes recreational and dwellings services.

The impacts to the drone and key end use industries are distributed across Australia’s regions, including East Coast Capital Cities and the rest of Australia

The activity is initially driven by the development of the drones industry, and subsequently there are some positive flow-on impacts to end use industries that benefit from the uptake of drones.

In present value terms over the period 2020 to 2040 (using a 7% real discount rate), the increase in the output of the drones industry is over \$18 billion for Australia. However, there are also positive impacts to end use industries that are able to benefit from the uptake of drone technology (in total, around \$10,045m). This is evident in agriculture, forestry and fishing (\$3,488m), mining (\$2,480m), transport (\$2,104m), construction (\$1,345m). government services (\$628m). There are also some broader positive impacts in aggregate across all other industries in the Australian economy (\$7.6 billion) (refer Table 10).

This incremental activity is distributed across Australia’s regions:

- *The East Coast Capital Cities* (including Greater Sydney, Greater Melbourne and Greater Brisbane) – the majority of the activity in the drones industry itself is concentrated across these densely populated regions. Similarly, a large proportion of the increased transport activity (which includes the business component of UAM and deliveries) is realised across these Capital Cities.
- *The rest of Australia* (including the rest of New South Wales, rest of Victoria and rest of Queensland, Western Australia, South Australia, Tasmania, Northern Territory and ACT) – a number of industries are stimulated across the rest of Australia. In particular, this region (which includes non-urban/regional geographies) accounts for the vast majority of the agricultural and mining activity.

Table 10: Change in industry output by region, present value^ over the period 2020 to 2040 (real 2020\$ millions), medium scenario

Industries	Regions		
	East Coast Capital Cities#	Rest of Australia#	Australia
Drones	11,501	6,934	18,435
Agriculture, forestry and fishing	344	3,144	3,488
Mining	191	2,288	2,480
Transport	1,180	924	2,104
Construction	556	789	1,345
Government services	256	372	628
All other industries*	4,030	3,517	7,547

Source: Deloitte Access Economics

Note: ^ Net present value is calculated using a 7% real discount rate over the period 2020 to 2040.

* All other industries include other manufacturing, trade, utilities, communications, finance and business services and other services (which itself includes recreational and dwellings services).

East Coast Capital cities include Greater Sydney, Greater Melbourne and Greater Brisbane. Rest of Australia includes the rest of New South Wales, rest of Victoria and rest of Queensland, Western Australia, South Australia, Tasmania, Northern Territory and ACT.

6. Regulatory considerations

Australia has historically been a leader in developing regulations for the operation of drones. However, in order to achieve the full economic potential of drones it is important that regulations remain agile to keep pace as drone technology evolves. The objectives should be to support industry growth while maintaining a safe operating environment.

In Australia, the *Civil Aviation Act 1988* (the Act) establishes the regulatory framework for maintaining, enhancing and promoting the safety of civil aviation. The Act establishes the role of the CASA as the regulator. Reflecting the particular emphasis of the regulation on the prevention of aviation accidents and incidents, the current regulatory approach is risk-based, allowing for 'low risk' activities without special planning or permission whilst also requiring certification processes for higher risk use cases.⁷⁷

Convention on International Civil Aviation

The basis of international legislation governing aviation is to do-no-harm. As remote piloted aircraft systems are indeed aircraft, they too are subject to national and international regulatory controls, including the Convention on International Civil Aviation. Article 8 of the Chicago Convention, which has had a 'profound impact' on the international regulatory regime concerning drones, states:

*"No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by that State and in accordance with the terms of such authorization. Each contracting State undertakes to ensure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft."*⁷⁸

Civil Aviation Safety Amendment (RPAS or model aircraft – Registration and Accreditation) Regulations 2019⁷⁹

In response to the increase in use of RPAS in Australia, which directly correlates with a significant increase in reported RPAS safety incidents, posing potential life safety risk, a series of changes were made to Part 11, Part 47 and Part 101 of the Civil Aviation Safety Regulations 1998 (CASR).

These changes introduce the requirement for persons intending to operate RPAS or model aircraft over 250 g, to register for different types of operations and to complete a short online course and pass a corresponding examination to gain accreditation. It also introduces a minimum age (of 16 years for accreditation with supervision by accredited person for remote pilot under the age of 16 years).

Airservices Australia

AA is responsible for the delivery of air traffic control services under the Airservices Act of 1995. Its inaugural operational concept for the management of drones, *Management of Remotely Piloted Aircraft Systems (RPAS) in ATM operations*, was released on 10 May 2016. This report identified its approach to the management of RPAS operations at the domestic level and how the national air traffic management system will evolve in response to RPAS technological and regulatory changes.

Key to this document is the AA proposed approach of 'RPAS advise and fly' or 'RPAS Green' zones, where direct air traffic control service provision arrangements are not required provided the RPAS operator gives prior notification. AA states that visual line of sight operations below 400 feet are managed on a risk assessment basis and using approved segregation methods, where segregation methods will evolve in line with emerging technologies.

Regulatory and air traffic implications for achieving economic benefits

Effective regulatory frameworks influence behaviour without stifling innovation. As a regulator, striking this balance is difficult, particularly in a fast-paced changing environment such as that for drones. Whilst drones have the potential to offer numerous safety, environmental and economic benefits, it is important that the right regulatory setting is in place to ensure drones can achieve the level of economic benefits as detailed in Chapter's 4 and 5, whilst preserving amenity, safety and appropriate certifications / training where needed.

⁷⁷Commonwealth of Australia, (2018). *Current and future regulatory requirements that impact on the safe commercial and recreational use of Remotely Piloted Aircraft Systems (RPAS), Unmanned Aerial Systems (UAS) and associated systems*.

⁷⁸Australian Certified UAV Operators (2016). *A New Safety Focus for the Australian Remotely Piloted Aircraft Systems (RPAS) Sector*.

⁷⁹Civil Aviation Safety Amendment (Remotely Piloted Aircraft and Model Aircraft—Registration and Accreditation) Regulations 2019. July 2019. Available at: <https://www.legislation.gov.au/Details/F2019L01027/Explanatory%20Statement/Text>

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Appendices

Appendix A: Summary of economy-wide modelling results - low and high uptake scenarios

CGE modelling results showing the impacts on regional, state and national economies under the low and high uptake scenarios.

The core economy-wide modelling presented in Chapter 5 focussed on the medium uptake scenario as the 'most likely' growth path. This Appendix presents the range of results for the low and high uptake scenarios, in order to present a range of potential futures given the uncertainty about the development of the drones market in the future, as well as future uptake rates by end use industries.

The modelling indicates the potential range of futures for gross regional /state / domestic Product (Tables A.1 and A.2). This highlights that GDP in Australia could be \$1.9 billion to \$4.5 billion higher compared to the baseline in 2040.

Table A.1: Change in Gross Regional / State / Domestic Product by region (real 2020\$ millions), low uptake scenario

	Regions											
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia
2025 (short term)	70	47	61	16	76	43	37	77	10	6	2	446
2030 (medium term)	210	144	182	59	196	141	107	221	32	16	6	1,312
2040 (long term)	293	205	266	85	291	192	156	306	47	23	11	1,876

Source: Deloitte Access Economics

Table A.2: Change in Gross Regional / State / Domestic Product by region (real 2020\$ millions), high uptake scenario

	Regions											
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia
2025 (short term)	147	96	122	42	132	95	72	142	22	11	6	889
2030 (medium term)	466	343	381	179	362	361	235	455	74	31	20	2,907
2040 (long term)	728	523	618	276	570	536	367	664	117	49	47	4,495

Source: Deloitte Access Economics

CGE modelling results showing the impact on aggregate employment for Australian regions under the low and high uptake scenarios.

The modelling highlights that aggregate employment under the low and high uptake scenarios could range from 6,640 to 14,655 FTEs. Consistent with the medium uptake scenario, a large part of the employment impacts are concentrated across East Coast Capital Cities.

Table A3: Change in aggregate FTE employment by region, low uptake scenario

	Regions											
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia
2025 (short term)	325	153	266	89	207	137	99	148	23	25	40	1,512
2030 (medium term)	979	460	799	288	539	468	296	438	73	69	118	4,526
2040 (long term)	1,448	669	1,188	408	783	700	427	640	103	102	172	6,640

Source: Deloitte Access Economics

Table A4: Change in aggregate FTE employment by region, high uptake scenario

	Regions											
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	Australia
2025 (short term)	644	302	513	194	368	300	194	286	48	45	80	2,975
2030 (medium term)	2,079	979	1,672	660	1,080	1,078	625	906	162	133	248	9,622
2040 (long term)	3,186	1,482	2,583	959	1,625	1,667	938	1,387	238	206	383	14,655

Source: Deloitte Access Economics

The modelled impacts under the low uptake scenario use a more conservative set of assumptions with respect to the size of the drones industry and direct cost savings to end use industries.

The modelled economy-wide impacts under the low uptake scenario are based on a more conservative set of assumptions compared to the medium uptake scenario, including the size of the drone industry output and the magnitude of direct costs savings to end user industries.

Table A5: Incremental growth in the drones industry and cost savings for end use industries by region over the period 2020 to 2040 (real 2020\$ millions), low uptake scenario

Industries	Regions											Australia
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	
Drones	6,240	2,272	7,365	1,156	3,489	2,636	2,793	3,765	791	541	455	31,502
<i>Cost savings to end use industries (undiscounted)</i>												
Agriculture, forestry and fishing	124	831	169	627	128	666	389	373	146	30	7	3,490
Mining	114	560	88	80	225	827	189	1,637	41	83	0	3,844
Transport	554	357	509	236	260	315	197	296	60	27	48	2,859
Construction	378	176	342	97	185	187	108	235	32	27	25	1,791
Government services	140	75	119	38	86	66	58	79	19	21	80	781

Source: Deloitte Access Economics

The modelled impacts under the high uptake scenario use a more optimistic set of assumptions with respect to the size of the drone industry and direct cost savings to end use industries. It assumes more rapid development of technology.

The modelled economy-wide impacts for the high uptake scenario assumes a more optimistic state of the world. There is assumed to be more rapid growth in technology that facilitates higher drone uptake and as a consequence there is a potential for larger direct costs savings than represented in the medium or low uptake scenarios.

Table A6: Incremental growth in the drones industry and cost savings for end use industries by region over the period 2020 to 2040 (real 2020\$ millions), high uptake scenario

Industries	Regions											Australia
	Greater Sydney	Rest of New South Wales	Greater Melbourne	Rest of Victoria	Greater Brisbane	Rest of Queensland	South Australia	Western Australia	Tasmania	Northern Territory	ACT	
Drones	10,121	3,685	11,945	1,875	5,658	4,275	4,530	6,107	1,282	878	737	51,093
<i>Cost savings to end use industries (undiscounted)</i>												
Agriculture, forestry and fishing	370	2,475	505	1,868	382	1,986	1,160	1,110	435	90	20	10,400
Mining	208	1,023	160	147	412	1,513	345	2,993	75	151	0	7,027
Transport	2,144	1,332	1,970	872	1,005	1,187	752	1,128	229	105	183	10,905
Construction	897	418	812	229	438	444	255	557	76	65	59	4,251
Government services	472	254	400	129	290	223	195	267	63	71	269	2,632

Source: Deloitte Access Economics

Appendix B: Methodology underpinning DAE-RGEM

CGE modelling methodology

Economic Modelling Framework Overview

The Deloitte Access Economics – Regional Computable General Equilibrium Model (DAE-RGEM) is a large scale, dynamic, multi-region, multi-commodity computable general equilibrium model of the world economy with bottom-up modelling of Australian regions. The model allows policy analysis in a single, robust, integrated economic framework. This model projects changes in macroeconomic aggregates such as GDP, employment, export volumes, investment and private consumption. At the sectoral level, detailed results such as output, exports, imports and employment are also produced.

The model is based upon a set of key underlying relationships between the various components of the model, each which represent a different group of agents in the economy (Figure D.1). These relationships are solved simultaneously, and so there is no logical start or end point for describing how the model actually works. However, they can be viewed as a system of interconnected markets with appropriate specifications of demand, supply and the market clearing conditions that determine the equilibrium prices and quantity produced, consumed and traded.

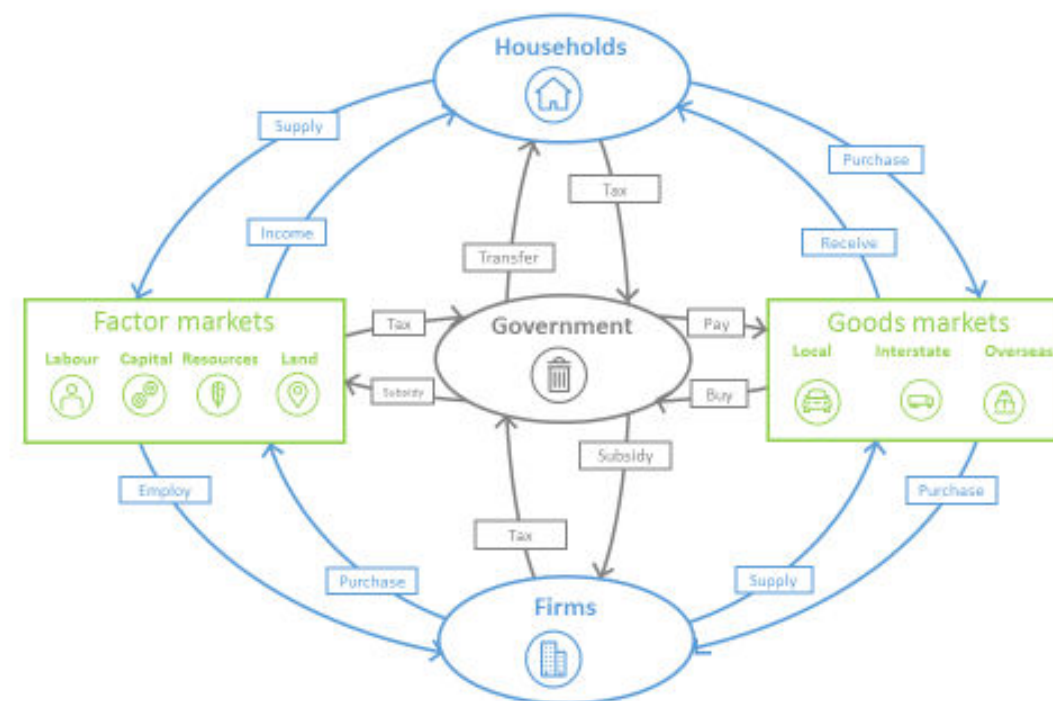
A customised version of DAE RGEM is used to model the impacts of investing in overnight tourism infrastructure and associated growth of the Brisbane River tourism industry. This separately identifies the Brisbane region and includes industries that are representative of tourism activity and the associated supply chain. The baseline used captures the underlying growth of the Brisbane regional economy and incorporates, real gross regional product, labour supply and population growth.

Model Assumptions

DAE-RGEM is based on a substantial body of accepted microeconomic theory. Key assumptions underpinning the model are:

- The model contains a 'regional consumer' that receives all income from factor payments (labour, capital, land and natural resources), taxes and net foreign income from borrowing (lending).
- Income is allocated across household consumption, government consumption and savings so as to maximise a Cobb-Douglas (C-D) utility function.
- Household consumption for composite goods is determined by minimising expenditure via a CDE (Constant Differences of Elasticities) expenditure function. For most regions, households can source consumption goods only from domestic and imported sources. In the Australian regions, households can also source goods from interstate. In all cases, the choice of commodities by source is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.

Figure A.1 Stylised diagram of DAE-RGEM



Source: Deloitte Access Economics

Model Assumptions (cont.)

- Government consumption for composite goods, and goods from different sources (domestic, imported and interstate), is determined by maximising utility via a C-D utility function.
- All savings generated in each region are used to purchase bonds whose price movements reflect movements in the price of creating capital.
- Producers supply goods by combining aggregate intermediate inputs and primary factors in fixed proportions (the Leontief assumption). Composite intermediate inputs are also combined in fixed proportions, whereas individual primary factors are combined using a CES production function.
- Producers are cost minimisers, and in doing so, choose between domestic, imported and interstate intermediate inputs via a CRESH production function.
- The supply of labour is positively influenced by movements in the real wage rate governed by an elasticity of supply.
- Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. A global investor ranks countries as investment destinations based on two factors: global investment and rates of return in a given region compared with global rates of return. Once the aggregate investment has been determined for Australia, aggregate investment in each Australian sub-region is determined by an Australian investor based on: Australian investment and rates of return in a given sub-region compared with the national rate of return.
- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions, and minimises costs by choosing between domestic, imported and interstate sources for these goods via a CRESH production function.
- Prices are determined via market-clearing conditions that require sectoral output (supply) to equal the amount sold (demand) to final users (households and government), intermediate users (firms and investors), foreigners (international exports), and other Australian regions (interstate exports).

- For internationally-traded goods (imports and exports), the Armington assumption is applied whereby the same goods produced in different countries are treated as imperfect substitutes. But, in relative terms, imported goods from different regions are treated as closer substitutes than domestically-produced goods and imported composites. Goods traded interstate within the Australian regions are assumed to be closer substitutes again.
- The model accounts for greenhouse gas emissions from fossil fuel combustion. Taxes can be applied to emissions, which are converted to good-specific sales taxes that impact on demand. Emission quotas can be set by region and these can be traded, at a value equal to the carbon tax avoided, where a region's emissions fall below or exceed their quota.

Below is a description of each component of the model and key linkages between components.

Model Components and Interrelations Between Components

A.1 Households

Each region in the model has a so-called representative household that receives and spends all income. The representative household allocates income across three different expenditure areas: private household consumption; government consumption; and savings.

The representative household interacts with producers in two ways. First, in allocating expenditure across household and government consumption, this sustains demand for production. Second, the representative household owns and receives all income from factor payments (labour, capital, land and natural resources) as well as net taxes. Factors of production are used by producers as inputs into production along with intermediate inputs. The level of production, as well as supply of factors, determines the amount of income generated in each region.

The representative household's relationship with investors is through the supply of investable funds – savings. The relationship between the representative household and the international sector is twofold. First, importers compete with domestic producers in consumption markets. Second, other regions in the model can lend (borrow) money from each other.

A.1 Households

- The representative household allocates income across three different expenditure areas – private household consumption; government consumption; and savings – to maximise a Cobb-Douglas utility function.
- Private household consumption on composite goods is determined by minimising a CDE (Constant Differences of Elasticities) expenditure function. Private household consumption on composite goods from different sources is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.
- Government consumption on composite goods, and composite goods from different sources, is determined by maximising a Cobb-Douglas utility function.
- All savings generated in each region is used to purchase bonds whose price movements reflect movements in the price of generating capital.

A.2 Producers

Apart from selling goods and services to households and government, producers sell products to each other (intermediate usage) and to investors. Intermediate usage is where one producer supplies inputs to another's production.

Capital is an input into production. Investors react to the conditions facing producers in a region to determine the amount of investment. Generally, increases in production are accompanied by increased investment. In addition, the production of machinery, construction of buildings and the like that forms the basis of a region's capital stock, is undertaken by producers. In other words, investment demand adds to household and government expenditure from the representative household, to determine the demand for goods and services in a region.

Producers interact with international markets in two main ways. First, they compete with producers in overseas regions for export markets, as well as in their own region. Second, they use inputs from overseas in their production.

- Sectoral output equals the amount demanded by consumers (households and government) and intermediate users (firms and investors) as well as exports.

- Intermediate inputs are assumed to be combined in fixed proportions at the composite level.
- To minimise costs, producers substitute between domestic and imported intermediate inputs is governed by the Armington assumption as well as between primary factors of production (through a CES aggregator). Substitution between skilled and unskilled labour is also allowed (again via a CES function).
- The supply of labour is positively influenced by movements in the wage rate governed by an elasticity of supply is (assumed to be 0.2). This implies that changes influencing the demand for labour, positively or negatively, will impact both the level of employment and the wage rate. This is a typical labour market specification for a dynamic model such as DAE-RGEM. There are other labour market 'settings' that can be used. First, the labour market could take on long-run characteristics with aggregate employment being fixed and any changes to labour demand changes being absorbed through movements in the wage rate. Second, the labour market could take on short-run characteristics with fixed wages and flexible employment levels.

A.3 Investors

Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. The global investor ranks countries as investment destination based on two factors: current economic growth and rates of return in a given region compared with global rates of return.

- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions, and minimises costs by choosing between domestic, imported and interstate sources for these goods via a CRESH production function.

A.4 International

Each of the components outlined above operate, simultaneously, in each region of the model. That is, for any simulation the model forecasts changes to trade and investment flows within, and between, regions subject to optimising behaviour by producers, consumers and investors. Of course, this implies some global conditions that must be met, such as global exports and global imports, are the same and that global debt repayment equals global debt receipts each year.

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