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Department of Infrastructure, Transport,
Regional Development, Communications and the Arts

BUREAU OF COMMUNICATIONS, ARTS AND REGIONAL RESEARCH

Analysis of Low Earth Orbit Satellites

Implications for Australia’s agriculture and mining sectors

September 2024

The Department of Infrastructure, Transport, Regional Development, Communications and the Arts acknowledges the Traditional Custodians of Country throughout Australia and their continuing connection to land, sea and community. We pay respects to them, their cultures and to their Elders, past, present and emerging.

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Glossary

Artificial Intelligence (AI) – Intelligence exhibited by machines, particularly computer systems which makes it possible for machines to learn from experience, adjust to new inputs and perform ‘human-like’ tasks.

AgTech – Agricultural technology; can be any technological application or innovation in the agriculture sector designed to improve efficiency, profitability and or sustainability. It can include devices, sensors, virtual reality, robotics, automation and artificial intelligence.

Backhaul – The connection between an access node and the core network, essentially expanding the reach of connectivity.

Direct-to-Device (D2D) – Mobile services delivered directly via satellite to smartphones which can be used for voice, SMS/text and sometimes data services in areas without terrestrial mobile coverage.

Digital subscriber line (DSL) – Technology providing broadband internet connections over traditional copper telephone wire.

Internet of Things (IoT) – Objects that use sensors or other technologies to connect to each other and the internet.

Latency – The time delay in sending and receiving information between two points in a network.

Megabits per second (Mbps) – Refers to the units of measurement for network bandwidth and throughput. Mbps are used to show how fast a network or internet connection may be. Each Mbps represents the capacity to transfer 1 million bits each second, or roughly one small photo per second.

Satellite – An artificial body placed in orbit round the Earth or moon or another planet in order to collect information or for communication.

Sensor – A device that detects and responds to a feature in the physical world, such as rainfall or temperature.

Tech stack – A combination of frontend and backend technologies working together.

Economic impacts of LEO satellites for the agriculture and mining sectors

This report focuses on the potential impacts for the agriculture and mining sectors from the adoption of IoT-enabled technologies through increased connectivity – including Low Earth Orbit (LEO) satellites. It synthesises findings from other analyses of various applications and describes the types of potential outcomes, including improved productivity and enhanced decision making. Improved connectivity may be supported by LEO satellites, as well as other connectivity types. Limited analysis is available on the *specific* role of LEO satellites to support digital technologies adoption (and associated benefits) for these sectors. More detailed information is needed to define and quantify the specific impact of LEO satellite connectivity in isolation.

LEO satellites are strengthening connectivity in regional Australia

LEO satellites operate between around 500 and 2,000 kilometres above sea level and orbit the Earth several times a day. These satellites are small, fast moving and are used to serve communications markets and other applications (Scheider Electric 2021). Being closer to Earth, LEO satellites have advantages over Medium Earth Orbit (MEO) and Geostationary Equatorial Orbit (GEO) satellites,[1] including lower latency, increased capacity and lower signal requirements (Low Earth Orbit Satellite Working Group 2023). LEO satellites are not new technologies, however, recent reductions in launch costs, improvements in capability and increased demand for connectivity have contributed to a boom in investment in LEO satellite technology (McKinsey & Company 2020c; Citi 2022). This boom is spurring increased connectivity across Australia and the world.

LEO satellites provide opportunities for consumers and businesses to access new technologies and enhanced services. Regional areas currently underserved by connectivity are particularly well placed to benefit from LEO satellites through improved coverage, better reliability and faster speeds. LEO satellites can also complement the existing telecommunications ecosystem, provide backhaul for mobile networks, facilitate direct-to-device mobile communication and encourage businesses to adopt internet-enabled technologies.

Australia is an attractive market for LEO satellite services due to its large landmass, high income population, and past use of satellite technologies. Consumer subscriptions for LEO satellite services are growing and new providers have identified Australia as a target market (Advanced Television 2024; Talk Satellite 2024). Government has also shown interest in potential LEO satellite applications – for example, $20 million has been allocated to a free community Wi-Fi trial in remote First Nations communities, where LEO satellite connectivity will be considered (DITRDCA 2024; FNDIAG 2024).

As demand for broadband grows, the potential for high-bandwidth, low-latency services with better portability could position LEO satellites as the preferred technology for consumers in areas outside of the fixed line and mobile footprint. Australia's agriculture and mining sectors have large footprints across regional areas, where there has previously been limited access to high-speed broadband. These sectors can involve repetitive and dangerous process work that could be favourably supplanted by connectivity-enabled IoT and other digital technology. The potential connectivity benefits made possible by LEO satellites in these sectors is the focus of this report.

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[1] For more information on LEO satellite technologies, refer to Appendix A.

Australia's agriculture sector stands to gain from LEO satellite connectivity

Agriculture is a diverse industry, comprising activities ranging from growing and harvesting crops to breeding and raising fish and livestock. Agriculture, like other sectors of the economy, increasingly relies on digital connectivity to operate and engage with customers and suppliers. Activity in the sector takes place across rural and remote areas of Australia, often in areas with few forms of connectivity available. In 2021, over 10% of agriculture workers lived in remote or very remote areas (ABS 2022). The main features of LEO satellites – low latency and high-speed connectivity across Australia – could support a diversity of new and enhanced applications for the sector which promote productivity growth as well as other benefits.

Australia's agriculture sector:

- Comprises 170,000 businesses operating across 55% of Australia's total land area.
- Contributed $61 billion in Gross Value Added to the Australian economy and comprised 14% of Australia's exports in 2022-23.
- Employs 262,000 workers, equating to 1.8% of Australia's total workforce.

Sources: ABARES (2024); ABS (2023a)

Connectivity in the agriculture sector has improved significantly in recent years but connections tend to be slower than other sectors

Agriculture has traditionally been one of the least connected industries in Australia, however, connectivity in the sector has increased significantly in recent years. In 2011–12, 84.2% of agriculture businesses had internet connectivity (7.7 percentage points lower than the average for all industries) (ABS 2013). By 2021–22, almost all (99.8%) businesses in the sector had broadband internet access (ABS 2023b).

Despite improvements in connectivity in recent years, agriculture businesses still tend to have slower internet and are less likely to have fixed connections than other industries.[2] In 2021–22, the agriculture sector had the highest proportion of businesses on plans under 50 Mbps (65.4%) and the lowest on plans over 250 Mbps (7.1%).

Agriculture businesses were more likely to have 3G/4G connectivity and satellite connectivity and less likely to have DSL, fibre and 5G connections than other businesses (Figure 1) (ABS 2023b). Slower speed plans for the agriculture sector reflect the connection types available in regional and remote locations. Remote businesses were more likely to have (GEO) satellite connectivity than those in more populated areas (9.9% of regional businesses reported a GEO satellite connection, compared to 1.6% of capital city businesses) (ABS 2023b).

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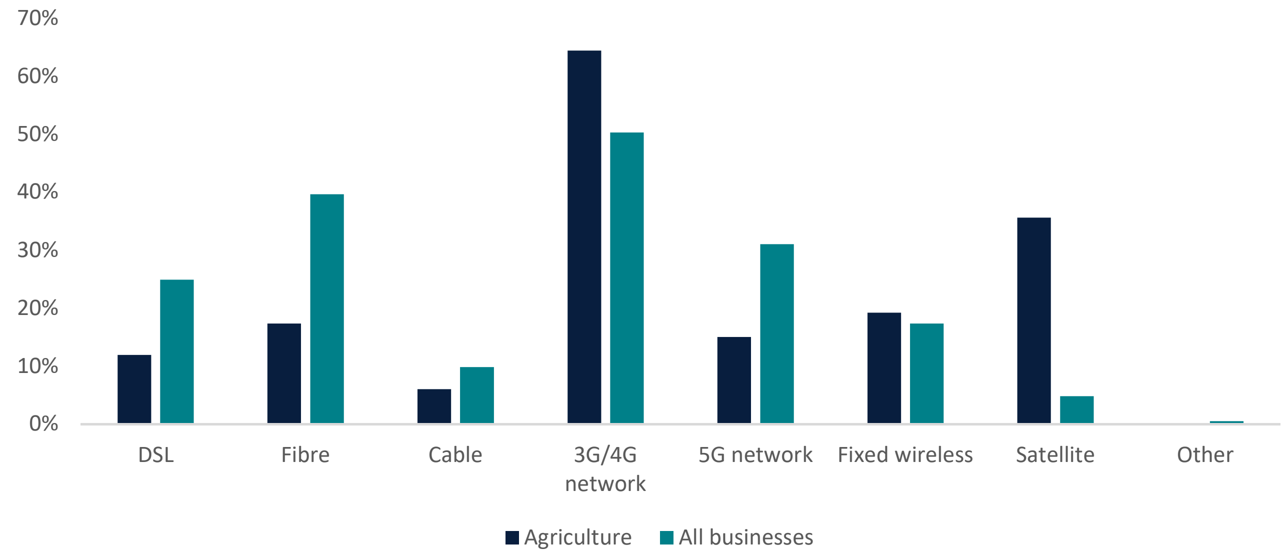
[2] Data for 2021-22 is the latest available from the Australian Bureau of Statistics. This data pre-dates the recent boom in LEO satellite investment and may underestimate connectivity and speed of connectivity for the sector.

Figure 1. Business connectivity types, share of all Australian businesses and agriculture businesses, 2021–22



Source: ABS (2023b). Characteristics of Australian Business, 2021–22.

Notes: Multiple connection types can be recorded. No detail on the types of satellite connections was available from this dataset, but it is likely that satellite connectivity refers to GEO satellite connectivity.

Globally, there is strong and growing demand for digital technology use in agriculture, but take up in Australia has been slow

Digital technology use (including IoT) has continued to grow within the economy, bringing about productivity and cost benefits to businesses. These technologies have many applications in agriculture, including satellite imagery for soil preparation, sensors and GPS-enabled equipment to accurately apply fertilisers, virtual fencing, and GPS-enabled automated tractors for harvesting (Deloitte 2023; McKinsey and Company 2020a).

In 2021, 80% of global large-scale agriculture producers[3] deployed at least one IoT project, up from 22% in 2018 (Inmarsat 2021). In contrast to the strong IoT adoption by large-scale agriculture producers globally, about 12% of domestic agriculture businesses had used IoT in 2021–22 (ABS 2023b). Almost half of Australian agriculture businesses surveyed faced barriers in using information and communications technologies (ICT) in general (compared with only 38% of all Australian businesses – see Figure 2). Factors limiting adoption included 'issues with technology' and 'a lack of understanding of digital technologies', with these types of barriers also mentioned in other studies (Rabobank 2019; CSIRO 2017).

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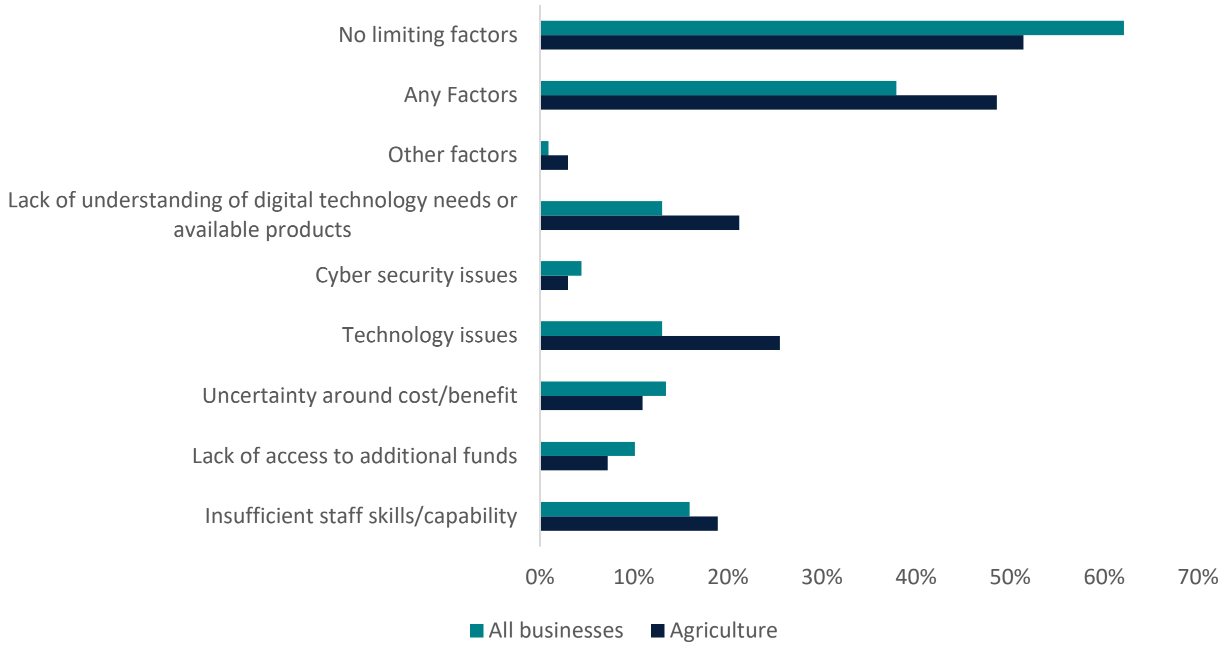
[3] All businesses surveyed had more than 250 employees and turnover of at least US$1 million. For reference, 0.4% of Australian agriculture businesses employed 200 or more employees and 7.8% recorded turnover of AU$2 million or more.

Figure 2. Factors limiting the use of ICT technologies, share of all Australian businesses and agriculture businesses, 2021–22



Source: ABS (2023b). Characteristics of Australian Business, 2021–22

Agriculture businesses were also less likely than others in the Australian economy to experience positive outcomes from using ICT. In 2021–22, 41% of agriculture businesses acknowledged ICT as having supported any outcomes for their business, compared to 51% of all businesses (ABS 2023b). The outcomes reported were also less likely to be productivity-related than was experienced by other sectors.

To some extent, perceived lower productivity gains achieved by ICT use in the agriculture sector may be attributable to poorer connectivity. However, skills, digital and connectivity literacy and costs are all factors impacting on the ability for the sector to benefit from technology developments (RTIRC 2021). Skills are typically a more prominent barrier for farming organisations operated by older farmers and those with fewer employees. Acquiring key skills and knowledge for farmers in these and other cohorts may support positive productivity and other outcomes from ICT use. They could be achieved through the use of farm advisors and networks, for instance, who can demonstrate the potential return on investment from digitalisation and alleviate some of the time burden associated with discovering and using new technologies (Dufty N et al. 2018).

LEO satellites could facilitate increased use of digital technologies in agriculture

While internet connectivity is widespread within the agriculture sector, there is limited real-time data on connectivity quality. Evidence suggests that such connectivity remains patchy (Australian Broadband Advisory Council 2021) and several reports have identified a lack of farm-wide connectivity as having widespread impacts for worker safety, digitalisation, productivity and the functioning of Australia’s farm sector (RTIRC 2021; Australian Broadband Advisory Council 2021).

LEO satellites are well-suited to boost digital technology (and IoT) adoption within the sector by providing always-on, high-speed and low-latency connectivity. Other trends, such as the emerging corporatisation of the agriculture sector, may also increase demand for LEO satellite connectivity and digitally-enabled technologies. Anecdotal evidence suggests LEO satellite connectivity which is supported by an ecosystem of products and services (including education and post-sales support) has the potential to be attractive to producers, particularly when provided at an affordable price point.

While connectivity is a key barrier to digital technology adoption for the sector, not all digitally-enabled technologies require LEO satellite connectivity (Australian Broadband Advisory Council 2021). There is potential for a synergy of technologies to be utilised across farming properties with LEO satellite broadband dispersed using other forms of connectivity such as WiFi or 5G, extending the reach of connectivity and associated technology use further. LEO satellites can also be used within a fit-for-purpose 'tech stack' in conjunction with other technologies to meet the specific needs of each business.

Increased technology use may improve operating and workforce outcomes in agriculture

LEO satellites can have multiple uses. Some LEO satellites will be used only for improved connectivity while others are directly tied to specific forms of technology.[4] To quantify the adoption rate of LEO satellite technology in agriculture, different use cases would need to be considered, including Direct-to-Device (D2D) supporting infrastructure and sensors uptake. At present, there is scant publicly-available data on LEO satellite adoption, and insufficient evidence to identify the specific role of LEO satellites in inducing benefits.

Appendix B examines the potential impacts of improved connectivity for farmers. It highlights how LEO satellites may impact the agriculture sector. As LEO satellite use cases in agriculture are still emerging, the existing literature mostly relates to current IoT applications and related technologies. Impacts include:

- **Operational impacts** through increased productivity (as a result of reduced operating costs and prevention of lost revenue) and alleviation of labour shortages.
- **Health impacts** through reduced social isolation, improved access to emergency services and improved occupational health and safety.
- **Environmental impacts** through reduced consumption of scarce resources and improved reporting.
- **Global food security impacts** through increased production.

Limited information is available to quantify the impact of LEO satellites for the agriculture sector. Most analysis centres on specific technologies in isolation, or the broader impacts of precision agriculture. Key findings from these studies include:

- Strong adoption of IoT technologies which may leverage LEO satellite connectivity, including adoption rates across the sector of between 60% and 100% over a 30-year period (EY 2019a). Other studies suggest an adoption rate of approximately 70% (BCARR 2023).
- Reduction in operating costs as a result of adoption. Globally, in 2021, producers estimated cost savings associated with increased use of IoT technologies (including those using existing forms of connectivity, and not solely LEO satellite technology) of 12% over the next 12 months, 20% over the next three years and 28% in the next five years (Inmarsat 2021).
- Increased production, for example, a 6% increase in US crop production as a result of increased adoption of precision agriculture (Association of Equipment Manufacturers n.d.), and potential for a 7-9% increase in global GDP as a result of increased technology use in agriculture (McKinsey & Company 2020a).

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[4] For example, Starlink has partnered with John Deere to connect internet to tractors and combine harvesters across the US and Brazil.

LEO satellites are likely to support backhaul and network redundancy in the mining sector

The characteristics of the mining sector in Australia (see below), along with its scale and diversity, make it well-placed to benefit from LEO satellite connectivity. Mining is concentrated in regional and remote areas, with a large share of operations located in remote Western Australia and Queensland. Key activities in the sector include exploration, geoscience research and mining. LEO satellites can be used to connect and collect data from any location and support IoT and other technologies in facilitating productivity gains, cost-savings and other benefits for the sector.

Australia's mining sector:

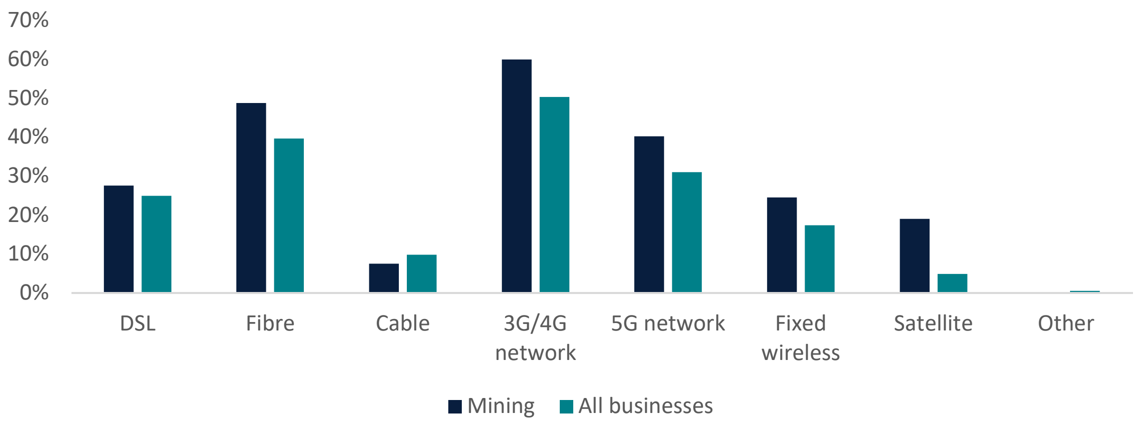
- Is Australia's largest sector by value, producing $344 billion in Gross Value Added in 2022–23.
- Is a low-employing industry relative to its economic value, employing 2% of Australia's workforce (300,000 workers, 70,000 of which are in regional areas) in 2023.
- Contributes about two-thirds of Australia's export revenue, approximately $455 billion in 2022–23.

Source: ABS (2023c)

Mining organisations have fast internet connections, but their connections do not always meet their needs

Australian mining organisations have historically been well connected, with 90% of businesses in the sector having internet connectivity in 2009–10. Over the past decade, the most prominent form of connectivity has shifted from DSL to higher-speed connections (such as 3G/4G networks, fibre, and 5G) – indicating the sector's willingness to invest in faster internet connectivity. Mining organisations are more likely to use satellite connectivity than Australian businesses in general – reflecting the regional and remote location of operations (Figure 3) (ABS 2023b). In 2021–22, businesses in the mining industry were more likely to have higher speed connections than the average Australian business (6% of mining businesses had a plan of 1000 Mbps or higher compared to 3.4% overall) but also more commonly reported that their connection wasn't meeting most business needs (15.5% compared to 12.4% overall) (ABS 2023b).

Figure 3. Connectivity types, share of mining businesses and all Australian businesses, 2021–22



Source: ABS (2023b). Characteristics of Australian Business, 2021–22.

Notes: Multiple connection types can be recorded. No detail on the types of satellite connections was available from this dataset, but it is likely that satellite connectivity refers to GEO satellite connectivity.

Strong investment from large-scale miners may mask demand for connectivity from smaller players

There is evidence of strong demand for digitally-enabled technologies in the mining sector. Some of Australia's largest mining companies are already investing in IoT-enabled and other digital technologies (BHP 2023; Minerals Council of Australia 2022). Types of investments these organisations are making include development of digital twins (detailed digital representations of equipment off-site), use of autonomous vehicles, and use of AI and machine learning to improve exploration activities.

The mining sector, however, comprises a diverse range of organisations. Over half of all mining organisations are non-employing and just over 44% recorded turnover of less than $50,000 in 2023 (ABS 2023a). It is likely that smaller mining businesses, which may not have the financial capacity to invest in fibre connectivity, could use LEO satellite services to improve their connectivity – particularly those involved in exploration and prospecting activities on sites where existing connectivity is not present.

In 2021–22, approximately 11% of Australian mining companies had used IoT technologies, and almost 2% had used a form of AI. In both instances, usage was higher than the national business average (approximately 6% and 1.4%, respectively) (ABS 2023b). However, it is likely the sector has the potential to continue to gain from increased use of IoT and AI given the repetitive nature of some activities and safety concerns on-site. Australian mining organisations also tended to report greater benefits from ICT use in general than firms in other sectors. Benefits included reduced prices from suppliers, better sales or marketing, better coordination of staff and activities, and improved efficiency of workflow management and inventory management. In contrast, businesses in the mining sector were less likely to report that ICT improved the efficiency of production processes than the average Australian business (Figure 4).

Figure 4. Benefits of ICT use, share of mining businesses and all Australian businesses, 2021–22

Source: ABS (2023b). Characteristics of Australian Business, 2021–22.

Although LEO satellites are likely to boost adoption of digital technologies within the sector, connectivity is not the only barrier to adoption faced by the mining sector. Other barriers include insufficient in-house skills, available capital for investment and infrastructure to handle data generated by IoT-based solutions (Inmarsat

2020). In addition, data ownership remains a complex issue for the sector (McKinsey & Company 2020b), particularly regarding security concerns if data is shared.

LEO satellites will play a role within a mix of connectivity types

A lack of consistent connectivity across mine sites is a barrier to digital technology adoption for over one-third of large-scale mining organisations globally (Inmarsat 2020). Only 16% of mining organisations indicated they had reliable internet connectivity across their mine sites. However, these organisations were more likely to have deployed an IoT solution than those struggling with their connectivity. Unreliable connectivity is more likely to be problematic for mobile data producers (a device or machine that gathers data whilst moving, such as automated vehicles), leading static data producers (devices or machines which are stationary) to be more successful and more likely to be fully deployed by mining organisations.

Satellites play a key role in the current connectivity of the mining sector, with LEO satellites playing an emerging (and important) role in this connectivity. Globally, approximately 85% of respondents who had fully deployed an IoT project used satellite connectivity, compared to 70% of those who had not fully deployed an IoT solution. However, even with satellite connectivity, 85% of respondents indicated connectivity challenges impacts their ability to gather data from their data producers (IoT technologies) (Inmarsat 2020).

> Not all IoT and digitally-enabled technologies require always-on connectivity and mining organisations are likely to need a variety of connection types to support their IoT applications. LEO satellites are likely best placed as backhaul to support private network connectivity for the mining sector. Reflecting the role of LEO satellites within a mix of technologies, mining organisations with fully-deployed IoT projects were more likely to have multiple types of connections (e.g., satellite and LPWAN), than those who had not (Inmarsat 2020).

Increased technology use may impact business operations, workers and sustainability

The potential economic benefits of increased use of IoT-enabled technologies are considerable. For some organisations, the benefits will be incremental, including delivering enhancements to existing processes or activity. However, for businesses who are currently struggling with connectivity (often smaller businesses) access to these technologies may lead to transformational changes.

Appendix C examines the potential impacts of improved connectivity for mining organisations. It highlights how LEO satellites may impact the mining sector. As LEO satellite use cases in the sector are still emerging, the existing literature mostly relates to current IoT applications and related technologies. Impacts include:

- **Operational impacts** through increased productivity (including reduced capital and operating costs, and increased centralisation of the workforce).
- **Health impacts** through improved occupational health and safety and improved mental health for on-site workers.
- **Environmental impacts** through improved adoption of sustainability practices.

Consistent with the findings for the agriculture sector, publicly-available analysis centred on the adoption of specific technologies in isolation, or quantified the broader impacts of increased adoption of digital technologies for the mining sector. These documents were analysed, as they provide guidance on the benefits of IoT-enabled technology adoption for the Australian mining sector. It is expected that some of these impacts are attributable to LEO satellites (as part of an overall mix of connectivity and enabled technologies). Key findings from these studies include:

- Potential for strong adoption of IoT technologies which may leverage LEO satellite connectivity, including an uncapped adoption rate across the sector over a 30-year period (EY 2019a).
- Potential for a significant lift in productivity for the sector from increased use of digital technologies of between 9 and 23% (EY 2019b).

- Potential for significant reductions in operating costs as a result of adoption of IoT technologies. Globally, in 2020, producers estimated cost savings associated with increased use of IoT technologies (including those using other forms of connectivity, and not solely LEO satellite technology) of up to 19% across the sector (by 2025) and up to 14% for iron ore producers, specifically (Inmarsat 2020).
- Significant operating cost reductions (totalling up to $1.6 billion in Australia) associated with autonomous vehicle use as a result of improved utilisation of vehicles and equipment, better material management and reduced collisions (EY 2019a).

Next steps

This report focuses on potential impacts for the agriculture and mining sectors based on the adoption of IoT-enabled technologies through increased connectivity (including LEO satellites).

The following section outlines areas for further analysis and the data and information needs to support additional work.

Areas for further analysis

Further research could consider factors that influence the expected adoption of LEO satellites in agriculture and mining and quantify the potential impacts (ideally attributing the specific role of LEO satellites). Such analysis would examine factors that would influence take-up and impacts, including:

- **Regulatory settings**: regulatory arrangements in domestic and international markets and their influence on take up and use of LEO satellites, particularly in agriculture and mining.
- **Supply and demand issues**: costs, benefits and related factors that influence the decisions of agriculture and mining enterprises and take-up of LEO satellite-using technology.
- **Economic conditions**: forecast economic trends for the sectors and their implications for the use of LEO satellites (and supported IoT technologies) in agriculture and mining.
- **Adoption rates**: robust estimation of the industries' adoption of LEO satellite-facilitated connectivity and digital technologies.

These factors could inform a next stage of research – quantifying the potential impacts of LEO satellites for the sectors in focus. This would consider modelling a range of adoption and impact scenarios. Such analysis could quantify the following expected economic impacts for:

- The agriculture and mining sectors: including productivity, revenues, output and employment.
- Other industries: flow-on or indirect impacts.
- The broader economy.

This next stage of research should also include interpretation of the potential impacts for mining and agriculture enterprises, the workforce, First Nations communities and other stakeholders within regional areas of Australia.

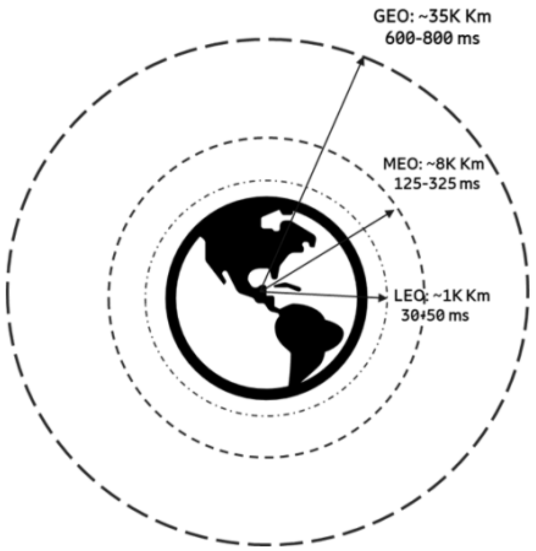
Appendix A – Introduction to LEO satellites

Satellites can be categorised into three groups based on their altitudes and orbit speeds around the Earth (see Figure 5).

- **Geostationary (GEO) satellites** orbit at approximately 35,800 kilometres directly above the equator, at which they travel at the same direction and speed as the rotation of the Earth. This allows ground-based antennas to point directly at the satellite in a fixed position. This feature makes GEO satellites ideal for consistent communication channels, and are widely used for broadcasting television or linking distant continents via telephone and internet.
- **Medium Earth orbit (MEO) satellites** operate between 2,000 and 35,800 kilometres above sea level and have an orbit of less than 24 hours. MEO satellites have a predictable orbit and are used for navigation and telecommunications applications (SES 2020).
- **Low Earth orbit (LEO) satellites** operate between around 500 and 2,000 kilometres[5] above sea level and orbit the Earth several times a day. LEO satellites are small and fast moving and are used to serve communications markets and other applications (Scheider Electric 2021).

The satellite industry is shifting from connectivity based mainly on large long-range GEO satellites to an increasing number of LEO satellite constellations (ReliaSat 2024). LEO satellites are not new – some LEO satellite providers have been operating since the 1990s. However, the deployment of LEO satellites for broadband communications has been realised only since conditions have developed to help them proliferate.

Figure 5. Satellite orbit comparison



Source: 5G Americas (2022) 5G & Non-terrestrial network.

Australia is an appealing market for LEO satellites

Australia has certain characteristics that make it an appealing market for satellite services**:**

- It has a large landmass with areas where satellite is the most viable option for providing connectivity (including remote areas, difficult landscapes, and sparsely populated areas).

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[5] There is no official definition of this region and according to Britannica it is usually considered to be between 160 and 1,600 km (about 100 and 1,000 miles) above Earth. https://www.britannica.com/technology/low-Earth-orbit

- It is located in the southern hemisphere where there is far more ocean than landmass and global satellite companies are often keen to utilise excess capacity.
- It lacks land borders with other countries, has consistent spectrum rules and avoids potential interference issues which can make satellite services easier to roll-out in Australia.
- It has a generally supportive regulatory regime for providing satellite services and accessing spectrum.
- It is a high-income country with customers and established industries which can afford satellite services in remote locations (such as mining).

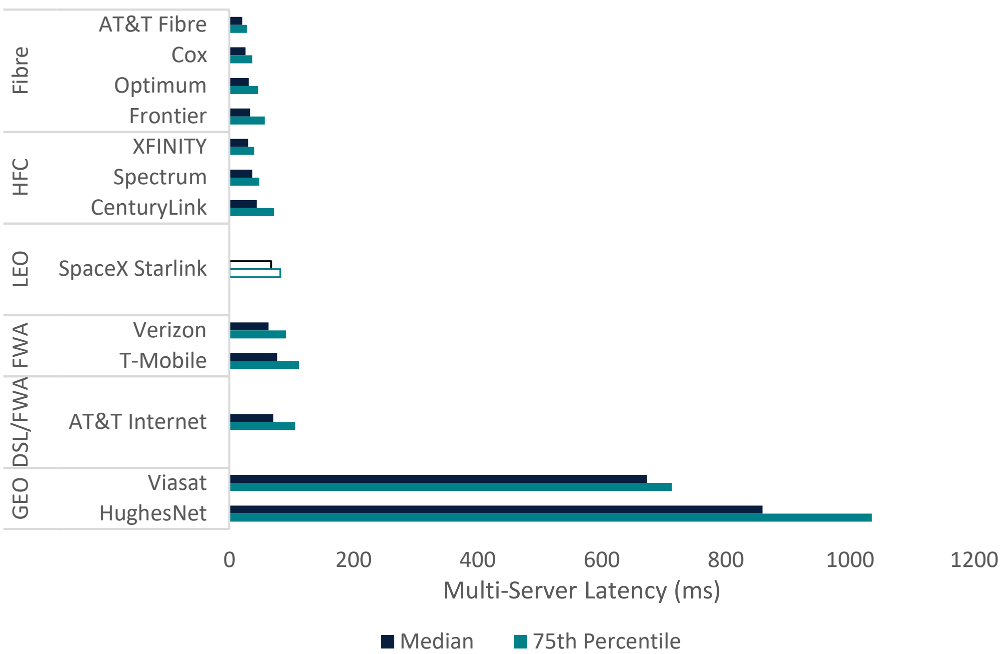
Australia continues to rely on satellite services and products provided by international operators and technology developed for international use.

LEO satellite advantages and enabling benefits

Lower latency

'Low Earth Orbit' reflects these satellites' much shorter distances to the Earth (and users) than GEO satellites. Shorter distances reduce the time delay (latency) in sending and receiving information on the internet. Lower latency is advantageous for applications that require time-sensitive or even real-time communication, such as video conferencing, autonomous vehicle control, remote control of machinery, telehealth, electronic gaming and others. Benchmarking of network performance among US terrestrial and non-terrestrial network operators has highlighted the lower latency of LEO satellite connectivity (such as SpaceX Starlink) compared to GEO satellite connectivity (refer to Figure 6).

Figure 6. LEO satellite performance (latency) comparison against terrestrial wireless and GEO satellites



Source: Ookla (2024) U.S. Starlink Data Points to Larger Addressable Base for LEO Broadband ISPs

Note: GEO satellite broadband services tend to target applications where low latency isn't crucial for remote locations or is used as a back-up service at discounted prices to LEO satellite internet.

Increased capacity

LEO constellations consist of a large number of small satellites. Each LEO satellite covers a much smaller land area and users/devices than GEO satellites. As a result, the capacity of a satellite is shared among a smaller number of users resulting in generally more bandwidth (speed) for each user/device, than GEO satellite users.

Smaller coverage areas (cells) plus radiofrequency re-use (non-adjacent cells re-use the same frequency band) can increase the available communication bandwidth across a region. This higher bandwidth can support high-speed applications like streaming video content or transferring large files.

Improved access

The higher density of LEO constellations means that most locations will see multiple satellites at any one time. A location is less likely to experience signal blockage compared to a GEO satellite which requires a clear access path to a single point in the sky. Increasing the LEO constellation density improves network accessibility and increases the communication capacity available at a location. Furthermore, LEO satellites in general use more ground stations than GEO satellites, meaning that LEO satellites can be connected to a core network access point (ground station) physically closer than the centralised ground station used by GEO satellites. This would lead to lower latency if they actually want to connect to the ‘nearby’ core network, leading to faster communication speeds.

Lower signal power requirements

LEO satellites orbit about 35 times closer to Earth than GEO satellites. Less signal power is therefore required by LEO satellites to communicate between the user terminal and the satellite. This improved energy consumption and cost efficiency make LEO satellite services more accessible to a wide range of users.

Disadvantages and challenges to LEO satellite operators

Though they present significant benefits compared to GEO satellites, LEO satellites do also present challenges for both users and satellite operators. These include:

- **Smaller ground coverage per satellite:** A LEO satellite’s signal covers a much smaller area on the ground than MEO/GEO satellites due to their lower altitude. Many more LEO satellites are, therefore, required to provide continuous global coverage, which requires complex planning and more capital to deploy LEO satellite constellations.
- **Significant infrastructure and launch capital costs:** Deploying and maintaining many LEO satellites requires significant upfront capital costs, including satellite manufacturing, ground stations and launch services. LEO satellites have a shorter lifespan and need to be replaced more often than GEO satellites.
- **Frequent satellite handovers:** LEO satellites require frequent satellite handovers as they move across the sky at very high speed. This continuous handover needs to be managed well for seamless connectivity, in particular, for time-critical applications like voice calls or real-time video streaming.
- **Increased complexity in network management:** Coordinating the LEO satellite constellation orbital positions, maintaining inter-satellite communication and satellite-terminal/device communications, and making seamless handovers between satellites require advanced network management systems.

Components of the satellite ecosystem

Satellite providers

Satellite providers may have multiple roles in the overall ecosystem. For example, providers may also be manufacturers of satellites and devices or they may develop technology (hardware or software) that can be used by developers in new devices. Some may also offer software, data and business solutions.

Business models also differ, for example most offer services on a wholesale basis but some may also offer retail services directly to consumers.

Telecommunications providers

Telecommunications providers are both competitors and partners to LEO satellite providers and services. Satellite and terrestrial mobile/wireless technologies can be used for broadband and IoT services in regional and remote areas; some telecommunications providers have been resellers of satellite connectivity and equipment for many years. New technologies, satellite capabilities, standards and business models, are creating opportunities for more closely connected and complementary satellite and terrestrial services. For example:

- **Direct-to-device (D2D) satellite services** being developed by LEO satellites operators rely on terrestrial mobile network operators for the spectrum needed to operate the service and to on-sell to customers. Both networks need to be closely connected for onboarding customers (roaming) and billing (Analysys Mason 2023).
- **Satellite backhaul** for mobile networks has been available for many years but the entry of LEO satellites into the market has had a positive impact on market pricing and capability which has encouraged increased take-up by telecommunications providers. Satellite backhaul can be quicker to deploy and makes economic sense for telecommunications providers in areas where fibre is difficult or expensive to roll-out and demand is not expected to be high (Analysys Mason 2022).
- **Ground station construction and support** is undertaken by some telecommunications providers for satellite providers.

GEO and MEO satellite providers

An increasing number of satellite operators are developing hybrid (multi-orbit or multipath) satellite systems via mergers or partnerships encouraged by LEO satellite competition, standards and technology developments, and customer demand (Via Satellite 2023a). Hybrid solutions will often be costlier than single orbit solutions in the short to medium term while the technologies to facilitate them (for example, antennas, modems and software that can transmit signals from multiple satellite types) are being fully developed and become more widely available. In addition, some use cases like IoT that require low-cost solutions and can generally be well-serviced by single orbit satellite connectivity will not be the focus for multi-orbit services (World Teleport Association 2023). However, hybrid satellite options (multi-orbit or multi-band) can offer complementary services where a combination of low latency, reliability and stability, and high throughput/capacity is required.

Antennas/ground stations

Most satellite connectivity (including LEO satellites) relies on ground stations and antennas (such as satellite dishes) to receive and deploy signals between space and terrestrial networks. Most of these are proprietary or operate differently for different types of satellites – for example, LEO satellites cannot usually operate using the same base station and antenna technologies rolled out for GEO satellites. Even satellite D2D smartphone and IoT applications rely on developments in antennas (and battery power) to operate.

In addition to 3GPP standards which are facilitating space and terrestrial convergence, satellite industry groups are working on standards to improve interoperability of satellite ground systems which have seen less technological developments than satellites (Via Satellite 2023b). These developments will help improve the capabilities of satellite networks and their ability to work together across multiple satellite types as well as with terrestrial networks. There are also likely to be cost advantages eventually which should make satellite connectivity and services more affordable and attractive to end users.

Equipment/device manufacturers

Utilising satellite connectivity is dependent on devices that are designed to receive/send signals via satellite. The spectrum bands enabled, battery capacity, antenna design/capability and microchips used can all impact the ability of a device to operate via satellite. Satellite services have traditionally been tied to proprietary technologies for use with specialised phones, IoT, or tracking devices; so even satellite-enabled devices may be tied to a single satellite provider.

Increasing interest in IoT and D2D applications, and standards developments will likely expand the number of devices compatible with satellite use:

- Smartphone manufacturers have started to enable satellite connectivity via traditional smartphones. This is still a work-in-progress.
- IoT device manufacturers are increasingly building mixed connectivity options into devices (GoannaAg 2024).

It is expected that more standardised devices and equipment will encourage greater take-up of LEO satellite services as this can improve scalability, interoperability and reduce costs for satellite-enabled devices. Standardisation will also improve trust in the technology if businesses think that devices will have a longer useful life and support, and that they will not get locked into a single vendor with limited options for competition on price and customer service.

Chipmakers and developers

Equipment manufacturers and satellite providers often rely on working closely with chipmakers and developers. Chipmakers have been increasingly adding satellite connectivity capability to the chipsets they develop for potential use in a range of phone and IoT devices.

Resellers and support

A lack of plug-and-play devices and systems, and a lack of interoperability between devices, systems and networks have been identified as barriers to IoT take-up – particularly for agricultural businesses (RTIRC 2021). New entrants to the satellite connectivity market, including LEO satellite providers, have not had time to build the same ecosystem of resellers and support that established satellite firms and telecommunications firms have built up. This will change over time as new businesses develop or existing businesses shift focus.

Cloud/data centres

Both terrestrial and satellite networks are becoming increasingly digital and cloud-based. This provides opportunities for improving the flexibility and capability of networks and network management as well as data analysis and management. Satellite ground stations are increasingly being collocated with data centres to take advantage of computing capacity and connectivity links. A range of players are starting to emerge from these markets, including large technology firms like Amazon and Microsoft.

Data analysis and visualisation

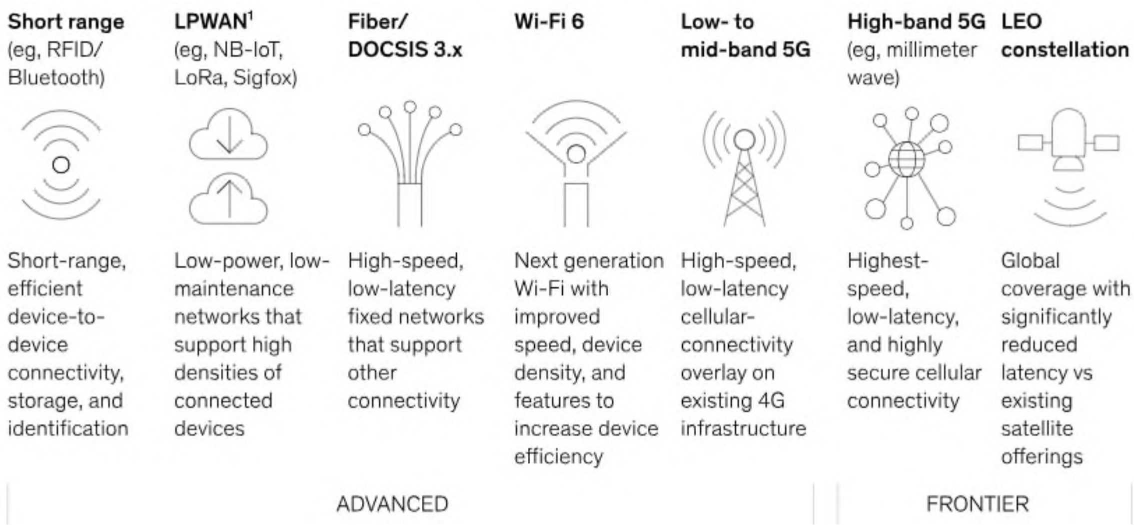
The increasing complexity of applications and devices, including those supported by LEO satellites technology, has created a greater need for more complex data analytics, and a need for greater support for businesses to realise benefits from the massive amounts of disparate data collected. For example, different IoT devices can run over different networks and use bespoke software applications to collect data and information from sensors. Combining this data with other sources of information such as weather forecasts, satellite mapping and business information is difficult and complex. Additional systems are required for pulling this data together to support decision-making and planning by businesses.

In addition, artificial intelligence (AI) is increasingly used to analyse satellite-derived data through terrestrial systems, but also on the satellites themselves. This has a range of potential benefits including analysing data and images on-board the satellite and sending only the most useful to systems on Earth. AI can also be used for applications like enhancing and cleaning up satellite images (Via Satellite n.d.; Defence One n.d.).

Other connection technologies

Even in regional and remote areas, satellite technologies are not the only connectivity option available, especially for IoT applications (see Figure 7). Satellite IoT providers compete with a wide range of existing terrestrial connectivity options. These have different levels of capability, availability and maturity. Some of the factors influencing IoT connectivity choices are decided by technical requirements such as distance/range, data update frequency, power use and/or latency. Other factors are service-related, such as cost, ease of installation, or availability of third-party support.

Figure 7. Connectivity technologies



Source: McKinsey & Company (2020a) Agriculture's connected future: How technology can yield new growth

Appendix B – Potential impacts of LEO satellite adoption for agriculture

Summary of potential impacts of LEO satellite adoption for agriculture.

Operational impacts

Increased productivity

Examples of uses of digital technologies to support productivity include using imagery to enhance yields by identifying and planting in areas more likely to support production, facilitating inter-row planting and/or enhancing yields (EY 2019a; McKinsey & Company 2020a; Association of Equipment Manufacturers n.d.). Soil conditions and plant health may be monitored remotely (using sensors) leading to earlier identification (and treatment) of plant needs. Autonomous vehicles and equipment can more accurately (and more carefully) plant, weed and harvest crops. Virtual fencing to rapidly and cost-effectively contain animals on farm (McKinsey & Company 2020a; GAO 2014; Deloitte 2023; EY 2019a).

Increased productivity may be supported by:

- **Reduced operating costs:** Information gathered from imagery, sensing and other technologies can result in more efficient and accurate deployment of inputs (such as herbicides, pesticides, fertilizer and water) and lower operational costs (EY 2019a). Reduced man-hours may also reduce operational costs, particularly for small organisations which typically require additional workers in peak periods.
- **Prevention of lost revenue:** Technologies which enable earlier identification of disease and more accurate driving across fields reduce damage and loss of crops, reducing lost revenues (McKinsey & Company 2020a; EY 2019a). Animal tracking devices may also reduce livestock loss as a result of reduced predation and illness (EY 2019a).

Alleviation of labour shortages

Automated technologies may replace some repetitive and dangerous tasks, reduce demand for workers and alleviate labour shortages within the sector (GoannaAg n.d.). Beyond the agriculture sector, improved LEO satellite connectivity may attract and retain workers in rural and remote areas (RTIRC 2021).

Health impacts

Improved occupational health and safety

Agriculture records one of the highest rates of worker injury of all sectors of the economy, with 5.4% of workers experiencing a work-related injury in 2021–22 (ABS 2023d). For workers in the agriculture sector, who may be the sole worker in their business, taking long stints of time off work can have significant financial implications. Agriculture also has the highest fatality rate of any industry, with 14.7 fatalities per 100,000 workers in 2022 (Safe Work Australia 2023a). Most worker fatalities were due to being hit by moving objects (41.3%) or vehicle accidents (39.4%) (Safe Work Australia 2023b). Greater use of IoT devices and autonomous vehicles (supported by LEO satellite connectivity) could reduce the amount of driving and limit the number of workplace injuries and fatalities for the sector (Health Direct 2024).

Improved access to emergency services

Rapid response rates from emergency services can improve outcomes in emergency situations (Ambulance Victoria 2017). The time between calling emergency services and the arrival of emergency services can be longer for those in rural and remote locations (including agriculture workers) (Productivity Commission 2024). However, there may also be challenges in making calls to emergency services if mobile coverage is patchy. Reticulated WiFi across the farm could improve connectivity by transforming vehicles into mobile connectivity hubs through satellite connectivity which would provide access to phone services across the farm.

D2D services, supported by LEO satellites, may allow for more rapid contact with emergency services, enabling faster access and improved outcomes. Improved phone coverage could improve communication between those located at the emergency and emergency services and be better prepared to respond to the emergency situation (IP Access International 2023).

Reduced social isolation and mental health concerns for farmers

The geographical and social isolation of farming can impact mental health (Michigan State University 2020). Loneliness has been linked to other mental health concerns for farmers, including depression, anxiety and psychosis. Social isolation among internet users aged 50 years or older (the age of the average Australian farmer) was lower than social isolation for those who did not use the internet (Silva P et al. 2022). Improved connectivity from LEO satellites therefore has the potential to reduce isolation for some Australian farmers. Access to online entertainment options may also improve wellbeing for the agriculture workforce by expanding the diversity of leisure time activities (Walker S 2020).

Environmental impacts

Reduced consumption of scarce resources

Deployment of digital and IoT-enabled technologies within the sector can improve efficiency. Consistent with reduced labour, the sector can reduce its use of environmental inputs, such as water and land and reduce negative environmental impacts (Association of Equipment Manufacturers n.d.).

Improved reporting

Australian farmers are subject to increased reporting on sustainability outcomes. The Australian Agriculture Sustainability Framework is based on 17 principles across Environmental Stewardship, Social responsibility and Good Governance (National Farmers Federation 2023). Increased use of on-farm digitally-enabled technologies, supported by increased connectivity, may facilitate easier and more accurate reporting of on-farm sustainability-related outcomes.

Improved food security

Deployment of digital and IoT-enabled technologies within the sector can improve efficiency. Consistent with reduced labour, the sector can reduce its use of environmental inputs, such as water and land and reduce negative environmental impacts (Association of Equipment Manufacturers n.d.).

Appendix C – Potential impacts of LEO satellite adoption for mining

Summary of potential impacts of LEO satellite adoption for mining.

Operational impacts

Improved productivity

Productivity benefits of using digital technologies supported by LEO satellite connectivity can be significant. Examples include use of automated vehicles and equipment operating non-stop without breaks (continuous mining), as well as improved operational decision making from increased data, and use of AI technologies to provide predictive assessments of potential problems (EY 2019b; Minerals Council of Australia 2022). This includes the ability to accurately identify issues and solutions from 'digital twin' technologies (Minerals Council of Australia 2022).

Increased productivity may be supported by:

- **Reduced capital costs:** Digital and IoT-enabled technologies (supported by LEO satellites) may reduce the significant costs of exploration and mine construction. Earth observation, AI and automated vehicles can improve success rates and reduce exploration costs. Where mining organisations use autonomous vehicles and/or equipment, some capital costs may be avoided (or reduced) (EY 2019b).
- **Reduced operational costs (including maintenance):** Operational cost reductions include more consistent and accurate use of vehicles and equipment (when automated) reduces fuel and other operational costs (including fewer onsite accidents) (Minerals Council of Australia 2022). Less 'downtime' can also reduce the size of the required fleet, further lowering costs (EY 2019b). Digital and IoT technologies can also facilitate earlier identification of equipment issues, facilitating faster and less costly repairs (EY 2019b).

Increased centralisation of the workforce

It is unlikely that improved connectivity would eradicate the need for fly-in, fly-out (FIFO) workers, however some centralisation of the workforce has the potential to improve worker diversity (as has been achieved already at centralised operations centres) and improve worker attraction (Minerals Council of Australia 2022; BHP 2023; Inmarsat 2020).

Health and safety impacts

Improved health and safety of workers

In 2021-22, there were approximately 8,300 mining injuries and 8 fatalities of mining workers (ABS 2023d; Safe Work Australia 2023c). Autonomous vehicles and equipment reduce the need for workers to undertake dangerous activities or enter more dangerous locations on-site, reducing accidents and risk for workers (EY 2019b; Minerals Council of Australia 2022). In addition to benefits associated with increased automation, wearable technologies also have positive impacts. Wearable devices can identify (and predict) worker fatigue as well as environmental factors which may impact on worker's health and safety (such as temperature, humidity and noise) (Minerals Council of Australia 2022).

Improved mental health for on-site workers

During the mining boom, FIFO workforces were found to be twice as likely as the general population to experience mental health illness during their lifetime and one-in-three would have a mental health issue each year (The City of Karratha n.d.). Mental illness amongst FIFO workers includes high depression, anxiety and suicide rates and has been linked to higher rates of alcohol and drug misuse (McPhedran S 2013). Contributing to these outcomes are difficulties in speaking to family and friends whilst on-site, which may be improved from LEO satellite connectivity. In addition, increased access to internet-enabled entertainment whilst on-site, such as gaming and video streaming, may also provide workers with improved quality of life during their leisure time, and benefit broader staff morale and retention (Mining Monthly 2021).

Environmental impacts

Sustainability

Technology affords mining enterprises opportunities to improve sustainability. Approximately 90% of mining firms already using IoT considered that IoT solutions improved environmental outcomes, while 53% agreed that improved automation and digitalisation of the data capture process would improve sustainability impacts (Inmarsat 2022). The research noted an expectation that satellite connectivity will become the most common type of connectivity used by mining firms within the decade (Inmarsat 2022).

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