[IT2165-03]

MARKET RESEARCH TECHNOLOGY
&
TRENDS

REPORT

ASSIGNMENT 1

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FOOD
[SECTION A]

Artificial Intelligence in Singapore (Femina)

Description of Artificial Intelligence

Artificial Intelligence (AI) refers to computer systems that can think and learn in ways similar to humans. It includes systems that can learn from data, recognize patterns, and make predictions or decisions without explicit human input. In Singapore, AI is part of the government's broader Smart Nation effort, with programmes like AI Singapore (AISG) encouraging industries to use AI to improve efficiency and innovation.

In the food sector AI can analyse data from sensors, lab tests and images to check for food quality and safety. It is also being used alongside new methods like **gene editing.** For example, *CRISPR-Cas9,* which scientists use to adjust specific genes in plants to make them stronger, more nutritious, or resistant to disease.

Application of Artificial Intelligence in the food sector

AI is becoming increasingly important in Singapore's food ecosystem, especially in keeping food safe and ensuring a steady supply.

One major application is **AI-based contaminant detection**. Machine-learning systems can study information from spectroscopy and sensor readings to detect traces of pesticides, fertilisers, or other harmful chemicals in "organic" produce. This helps laboratories and importers quickly identify which foods are genuinely organic and which have been exposed to chemicals.

AI is also being used in the **analysis of genetic data** to identify whether crops have been **gene-edited** or cross-bred into hybrid forms. This supports food regulators and consumers who want clear labelling and assurance about what they are eating.

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As global food shortages and climate challenges grow, researchers are turning to **AI-guided gene editing** to develop new crop varieties that can survive heat, drought, or pests. In Singapore's context where most food is imported, AI could be used to monitor both local vertical farms and imported products, checking for chemical residues or genetic modifications. These tools would strengthen food safety systems and help the country reach its food-resilience goal of **30 by 30** (producing 30% of nutritional needs locally by 2030).

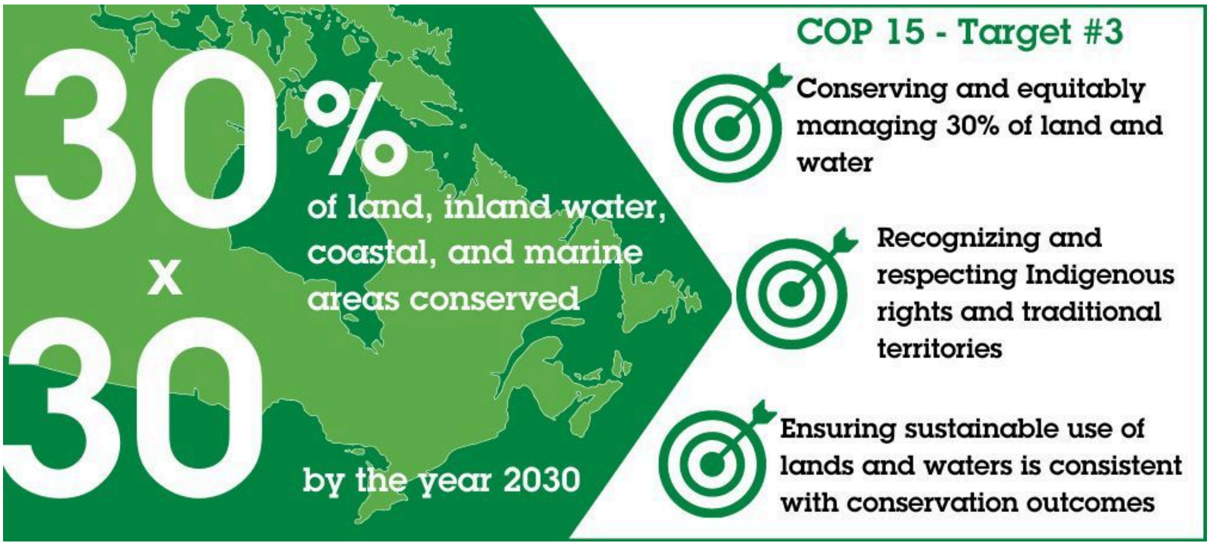

Figure A: 30 by 30 Goal

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Benefits of using Artificial Intelligence in the Food Sector

Integrating AI into food testing and production offers several important benefits.

Firstly, it makes **testing faster and more accurate**, allowing authorities and businesses to detect contamination early and prevent unsafe food from reaching consumers. Automated analysis lowers human error and allows for continuous real-time monitoring along the supply chain.

Secondly, AI encourages **sustainable farming practices**. By enabling early detection of pesticide residues and over-fertilisation, it helps reduce chemical use and supports cleaner, greener agriculture.AI-assisted gene-editing research also supports the development of crops that thrive with less fertiliser or water.

Thirdly, AI improves **transparency and trust**. When data from farms, laboratories, and suppliers are connected, AI-linked data systems can verify whether food truly meets organic or safety standards. This builds consumer trust and aligns with Singapore's strong regulatory focus on food integrity.

Finally, AI can contribute to **food security** helping Singapore adapt to future shortages by identifying safe, locally-grown options and supporting research into crops that produce more food with fewer resources.

Key challenges for adoption of Artificial Intelligence

Even with these benefits, several challenges remain.

Reliable AI systems need **large, high-quality datasets(LLM)**, but collecting and labelling that kind of data is costly and time-consuming. Smaller farms and food businesses may also lack the **Cost and technical expertise** to use advanced sensors and AI software.

There are **ethical and regulatory questions** about gene-edited foods too. Many consumers in Asia are still unsure about how safe or "natural" these foods are, and clear public communication is essential. Finally, connecting all parts of the supply chain , farmers, importers, labs, and regulators requires strong cooperation and compatible technology.

By addressing these issues through education, funding, and collaboration, Singapore can continue to use AI wisely to build a safer, more reliable, and sustainable food future.

Communication & Connectivity (Ryan)

About Connection and Connectivity

Connection and Connectivity refers to the physical and digital infrastructures such as broadband, wireless networks and network infrastructures that enables people, devices and systems to communicate information across the internet.

In Singapore, our digital infrastructure can be illustrated through the Digital Connectivity blueprint, which comprises of three layers:

Figure B: 3 layers of Digital Connectivity Blueprint by IMDA

1. **Hard Infrastructure:** consisting of connectivity networks, submarine cables, data centers and cloud service providers, forms our foundation towards reliable connectivity, large-scale data transmission, and computing capacity, all towards supporting our digital communications both domestically and internationally.

2. **Physical to Digital Infrastructure** - made up of Devices, Middleware and Networks, focused towards ensuring smooth integration between physical devices and digital systems, improving reliability, security and interoperability across our digital ecosystems.

3. **Soft Infrastructure -** by providing shared software foundations that serve as the template on how digital services operate, interact and secure data, this enables accessibility and trust towards our digital systems, ensuring that users are able to easily access digital services and ensures secure and reliable data exchanges across all our digital platforms.

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Applications communication & connectivity in the food sector

In recent years, supported by initiatives and grant programmes by IMDA, F&B companies across food manufacturing and establishments such restaurants and hawkers have been able to integrate various Connection and Connectivity solutions into their business operations.

Integration of Automated and Real-Time Connectivity Solutions

Restaurants and hawkers have integrated digital ordering and payment systems into their operations, shifting core business functions such as order taking and payment handling into automated digital platforms, enabling customers to place orders through the use of their own mobile devices or through self-service kiosks.

Additionally, some restaurants have decided to employ service robotics solutions such as self-serving robots that come equipped with obstacle avoidance and smart scheduling, supporting service staff by taking care of large, bulky orders.

Usage of Sensor Based and Low-Power Connectivity Solutions

Food manufacturing companies utilize sensor-based systems to support inventory tracking and real-time monitoring of freezer and cold-room temperatures, with automated email notifications set to trigger when any abnormal changes require human invention.

Towards agriculture, sensor-based systems are used for automated resource management, ensuring that produce and livestock are properly maintained through monitoring container and water system levels and automatically dispensing resources at the appropriate time when needed.

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Benefits of using communication & connectivity in the food sector

Through the adoption and integration of Communication & Connectivity solutions, the F&B industry has managed to enhance their operational productivity greatly across the service, manufacturing and agricultural operations.

Benefits for Food and Service Establishments

- **The reduction of human errors when carrying out work processes:** thanks to having seamless, cashless payments integrated into their menus and kiosks, service staff would no longer need to spend time processing payments.
- **Contributing to a greener eco-friendly footprint:** with payments being done on a digital platform, it reduces the need for physical receipts, as past payments are now archived digitally, reducing paper consumption for many F&B outlets.
- **Freeing up staff to focus on customer experience:** the use of self-serving robots frees up staff in busy environments, allowing staff to focus on customer interactions and addressing requests quickly, creating a better dining experience for customers.

Benefits for Food Manufacturing and Agriculture

- **Easier maintenance of regulatory compliance:** automated logs of records taken for food safety regulations and auditing eliminates the need for manual keying of data, which is a time consuming process that is prone to human error.
- **Reduced odds of inventory loss:** thanks to consistent and automated temperature control, the shelf life of inventory items are preserved, leading to fewer food spoilage that needs to be discarded, which contributes to both cost and environmental savings.
- **Higher productivity and efficient resource use:** sensors and automated dispensers dispense only what is required, leading to less over-feeding, reduced manual labour and more accurate care for both crops and livestock.

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Key Challenges for Adoption of Communication & Connectivity in the Food Sector

Despite ongoing efforts by IMDA to promote digitalization through initiatives such as the Digital Connectivity Blueprint and “SMEs Go Digital” programme, the adoption of Communication and Connectivity solutions within the F&B solutions continues to see several challenges.

Limited Understanding of Technology Value

One key challenge lies in the communication towards F&B businesses towards the benefits adopting new Connectivity & Communication solutions can offer. While high-speed connectivity and sensor-based solutions are being promoted. Due to the language and delivery of these solutions, many F&B operators, particularly small and medium businesses, struggle to be able to clearly identify its practical benefits that can benefit their operational needs.

Infrastructure and Deployment Constraints

Certain connectivity solutions require supporting infrastructure in order to function. With additional components adding to increased operational overhead costs, and the lack of technical expertise from older generation business owners, these businesses may lack the technical expertise to leverage and maintain these systems on their own.

Cost and Return on Investment Concerns

Finally, the cost of adopting these solutions into their business operations pose as a significant barrier towards small to medium sized businesses. Despite the available grant and subsidies available from IMDA’s initiatives, businesses must still account for long term service costs such as subscription and maintenance costs.

Green Computing and Green Software (Benny)

Description of green computing & green software

Green Computing and Green Software refer to the design, development, and deployment of sustainable digital applications and infrastructure. To achieve sustainability in the food sector, this technology relies on three core principles, as illustrated in the diagram below:

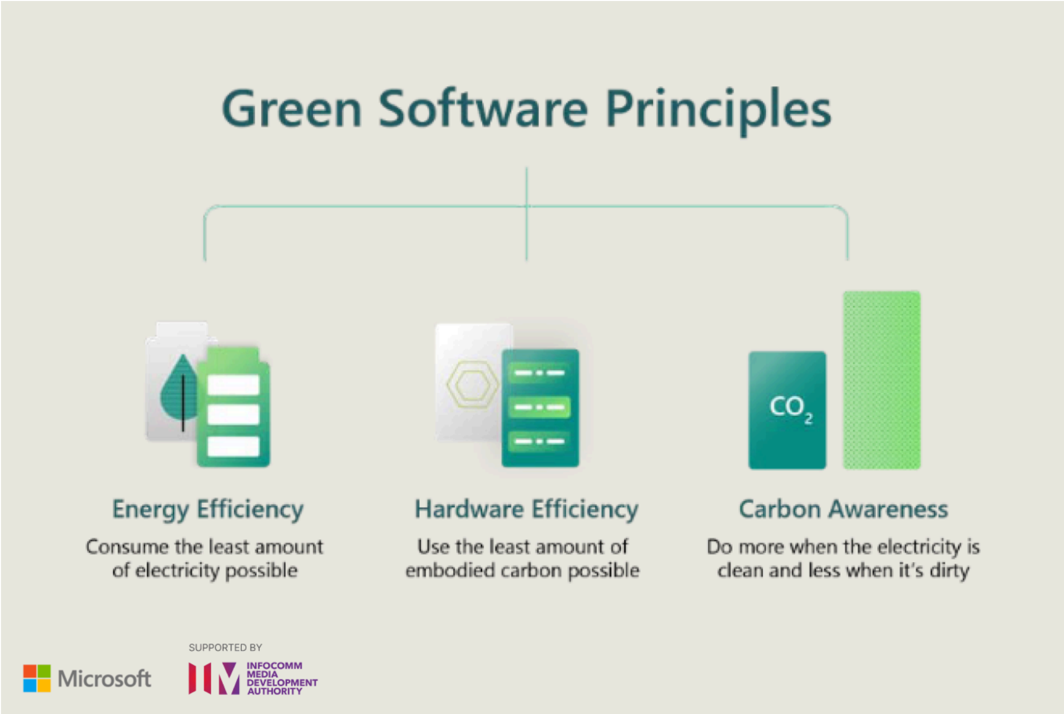

Figure C: The three pillars of Green Software applied to Agri-Tech from Microsoft-IMDA Digital Sustainability Guideline

1. **Energy Efficiency**: This involves creating software that performs its required functions using the minimum amount of power necessary.

2. **Carbon Awareness**: Software is designed to adapt its operations based on the carbon intensity of the power grid, such as shifting intensive tasks to times when renewable energy availability is high.

3. **Hardware Efficiency**: This focuses on optimizing software to reduce strain on physical resources, thereby extending the lifespan of hardware and reducing electronic waste.

The adoption of these principles is actively supported by the IMDA through the **S$30 million Green Computing Funding Initiative (GCFI)**. Furthermore, the IMDA has launched Green Software Trials to test carbon reduction techniques and co-published Sustainable Software Development Guidelines to provide a clear roadmap for developers in the sector.

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Application of green computing & green software in the food sector

1. **Fog & Edge Computing (Data Processing Layer)**: Instead of transmitting all raw sensor data to the cloud which consumes significant bandwidth and energy, data is processed locally at the "Intelligent Gateway." This reduces network traffic and ensures that only essential insights are sent to the cloud, lowering the overall carbon footprint of the network and allowing immediate automated responses to critical environmental changes (like a sudden temperature spike) without internet latency.

2. **Precision Resource Management (Application Layer):** The architecture supports real-time dashboards that precisely control farm systems based on sensor data. By automating irrigation and lighting to operate only when necessary (e.g., dimming lights when natural light is available), farms can minimize energy waste and reduce operational costs.

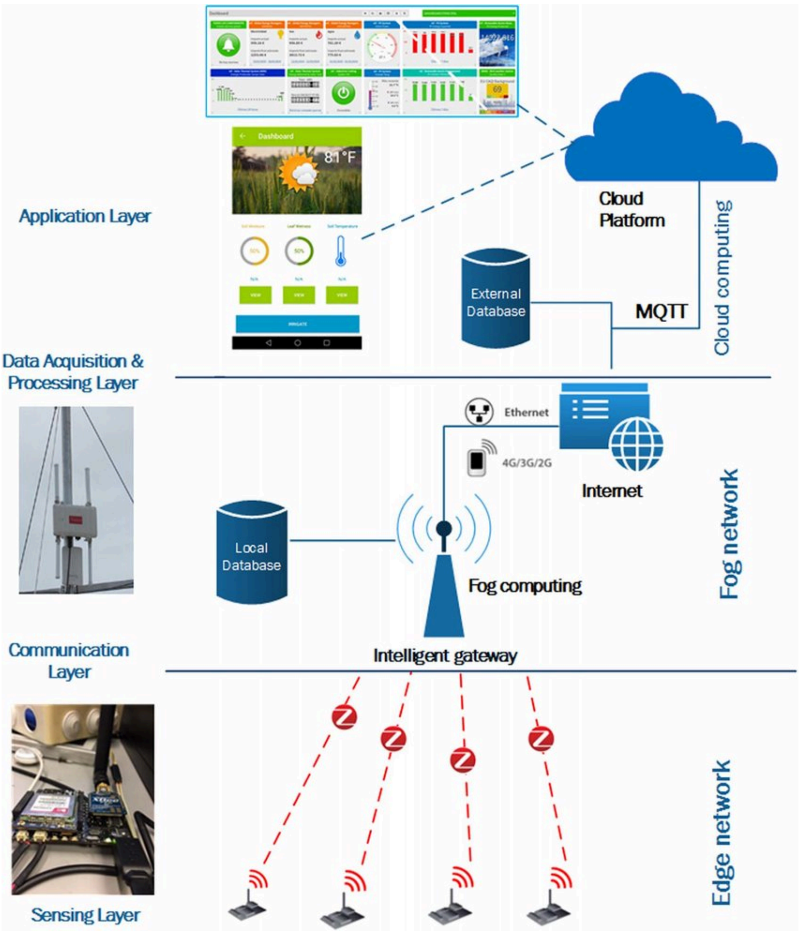

FIgure D: Green IoT Architecture for Smart Farming, illustrating the use of Fog Computing to offload cloud processing from ResearchGate

Green principles also extend to the supply chain. Retailers can apply **Hardware Efficiency** by optimizing inventory software to run on older devices, extending their lifespan and reducing e-waste. Additionally, food delivery apps can adopt **Energy Efficient** code to minimize battery drain on consumer smartphones, lowering the aggregate carbon footprint of the digital food economy.

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Benefits of using green computing & green software in the food sector

The integration of Green Computing into the food sector offers a multitude of benefits:

- **Bolstering food security** is a primary advantage. By significantly lowering energy consumption, which is the largest operational cost for high-tech farms, green software makes local food production more economically viable and resilient.

- **Advancing environmental sustainability** is another key outcome. The technology creates a "Dual Environmental Dividend" by reducing the carbon footprint in two distinct areas:
    - **(Digital):** Reducing the direct energy consumption of the farm's IT infrastructure and data transmission.
    - **(Physical):** Enabling precision agriculture that uses up to 95% less water and significantly less land than traditional farming while minimizing waste.

- **Enhancing economic competitiveness** is also a major benefit. By developing specialized green solutions for urban agriculture, Singapore can position itself as a global leader in the high-value Agri-Tech market, creating jobs and driving innovation.

- Finally, the technology improves **food safety and trust**. Green software can power energy-efficient blockchain systems that provide consumers with transparent and immutable "farm-to-fork" traceability, enhancing trust in local produce.

Key challenges for adoption of green computing & green software

Despite its potential, widespread adoption faces significant hurdles.

- **High operational costs and profitability issues** present the primary challenge. The economic viability of high-tech farms is strained by high costs for energy and skilled labor, making it difficult to compete with cheaper imported produce. This can lead to farm closures and deter investment.

- **Weak consumer demand** is another major factor. Local produce is often priced at a premium, and many price-sensitive consumers are unwilling to pay more. Consumers often also cannot see the carbon savings of sustainable software, making them unwilling to pay higher prices for produce grown using these expensive, energy-efficient systems. This suppresses revenue and prevents farms from achieving the necessary economies of scale.

- **Complexity and a lack of standards** also hinder adoption. A significant technical hurdle is the energy-intensive nature of the AI models used in smart farming. Implementing genuinely green solutions requires deep, specialized skills to optimize these systems, which are often scarce in the Agri-Tech sector. Furthermore, there is a current lack of standardized industry metrics to measure the carbon footprint of software, making it difficult for farms to calculate the return on investment for green technologies.

These factors create a cycle where farms struggle with high costs, which in turn prevents them from investing in the very green technologies that could lower those costs and ensure their long-term survival.

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[SECTION A]

Trust Technologies (Jia He)

Description of trust technologies

Trust Technologies are tools that keep digital information safe and private. They help people and businesses feel confident when sharing information online. IMDA (Infocomm Media Development Authority) in Singapore focuses on four key areas.

The Digital Trust Centre at Nanyang Technological University leads this work in Singapore. It received S$50 million in funding to develop these technologies. Trust Technologies include Privacy Enhancing Technologies (PETs), Blockchain, Cybersecurity, and Data Privacy systems.

Singapore designated the Digital Trust Centre as the AI Safety Institute in 2024. This shows the national priority for trust in technology systems.

Application of trust technologies in the food sector

Singapore imports over 90% of its food. This makes the supply chain vulnerable to contamination and fraud. The new Food Safety & Security Bill passed in January 2025. It requires detailed food traceability records for all items.

Trust Technologies solve this problem in two keyways.

First: Blockchain for Transparent Records

Blockchain creates an unchangeable record. Every step of food production gets recorded. This includes where it came from, how it was stored, and who handled it. Regulators can trace the source of contamination in hours, not days.

Walmart proves this works in real practice. They use blockchain to trace produce origins from days down to seconds. Food companies can identify exactly which batches are contaminated instead of recalling entire product lines.

Second: Privacy Enhancing Technologies for Data Sharing

Small farmers worry about sharing production secrets with competitors. PETs allow data sharing without exposing raw information. Federated learning trains AI models across multiple farms without centralizing sensitive data. Each farm keeps its data private while contributing to a shared AI model.

This builds trust among supply chain partners. Suppliers share information to improve supply chains without losing competitive advantage.

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Benefits of using trust technologies in the food Sector

These technologies bring clear advantages to Singapore's food system.

Cost Reduction: Blockchain can greatly reduce recall costs because contamination sources are found faster. Companies waste less money on large product recalls affecting thousands of items.

Consumer Confidence: Consumers gain trust knowing food origin is verified and transparent. They can see the complete journey from farm to table.

Regulatory Compliance: Compliance with Singapore's new Food Safety & Security Bill becomes easier. Smart contracts verify food safety requirements automatically. Food handlers don't need to fill out manual forms.

Operational Efficiency: Real-time monitoring through IoT sensors linked to blockchain prevents spoilage. Automated alerts warn of temperature changes immediately. Waste decreases. Inventory management improves.

Data Privacy: PETs encourage collaboration without forcing companies to expose secrets. Suppliers share insights while protecting their proprietary methods.

Key challenges for adoption of trust technologies

Implementation costs are high. Building a blockchain system requires significant investment in infrastructure and training. Small food operators struggle to afford these systems.

Food handlers need education on new processes. This takes time and resources. Not all supply chain partners move together. Unless most participate, the system loses value. This is called the "cluster adoption" problem.

Data security remains a concern. Even blockchain systems can suffer cyberattacks and phishing attempts. Different blockchain platforms struggle to work together. A unified standard is needed but doesn't yet exist.

Some suppliers resist sharing any data, even with PETs protecting privacy. Trust in the technology itself must be built. Regulatory clarity is lacking. Singapore's new Food Safety Bill requires traceability but doesn't specify which technologies to use. Companies must decide alone whether blockchain is worth the cost.

Interoperability challenges make implementation complex. Cross-border data flows between Singapore and trading partners need alignment.

Proposed Use Case

We propose shifting Singapore’s urban farming model from "Private Commercial Enterprise" to "National Digital Utility." Currently, high-tech farms struggle with high operational costs and isolation. Our solution, "The Sovereign Food Mesh," transforms underutilized HDB rooftops and void decks into a decentralized network of autonomous micro-farms.

Instead of a single centralized factory, this "Virtual Mega-Farm" connects thousands of rooftops using **5G Connectivity** to coordinate autonomous robotic harvesters. This mesh network operates as a single digital organism.

Our goal is to leverage IMDA’s emerging technologies to solve the specific bottlenecks of local farming scene faces, such as limited space, and a lack of a sustainable business model

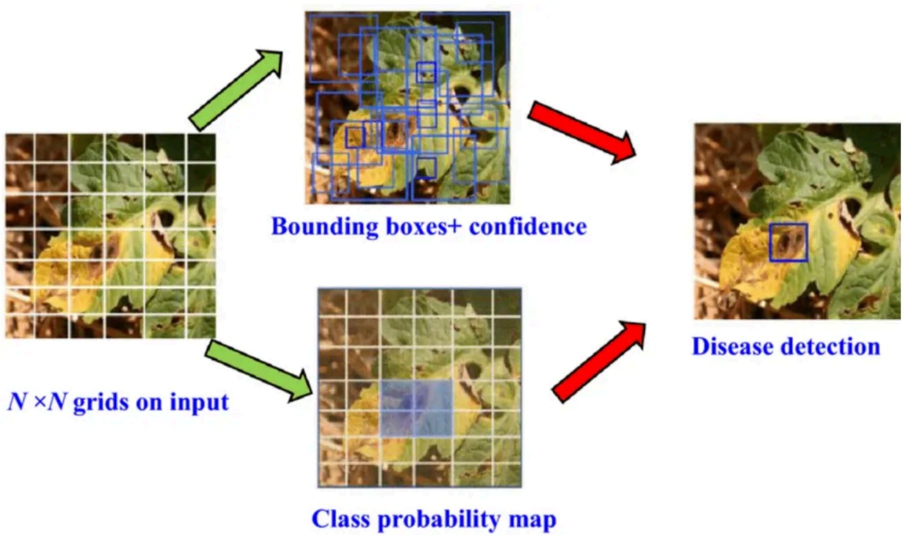
<table>
<tr><th>Technology Pillar</th><th>Application & Strategic Impact</th></tr>
<tr><td>Artificial Intelligence</td><td>AI models analyse visual and environmental data to automate decision-making:
- The system integrates retail APIs with farm operations to dynamically optimize crop selection based on real-time consumer behaviour, seasonal demand patterns and what is lacking in Singapore’s domestic food production (e.g., switching planting from Kale to Spinach when local demand spikes).
- Computer Vision monitors "Vapour Pressure Deficit" to predict disease outbreaks 48 hours before they are visible to the human eye.
By detecting diseases early, we prevent entire crop failures. Knowing what consumers want before planting eliminates overproduction and unsold inventory.


Figure E: Computer Vision models detecting early-stage leaf stress. The system correlates these visual markers with Vapour Pressure Deficit (VPD) sensor data to predict disease outbreaks 48 hours in advance.</td></tr>
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FOOD
[SECTION B]

<table>
<tr>
<td>Communication & Connectivity</td>
<td>A dedicated 5G network slice coordinates a fleet of autonomous robots for harvesting and logistics.

- Allows single technician to manage 50+ HDB blocks remotely by controlling robots in real-time, overcoming manpower shortages.
- Connects thousands of rooftop sensors to a unified control system (central hub) without network congestion.
- Real-time sensor data from each rooftop (temperature, humidity, light levels)

Lesser manpower costs since it can be done by one person to manage multiple rooftops, it also provides fewer manual errors and faster response to problems by connecting farms together.

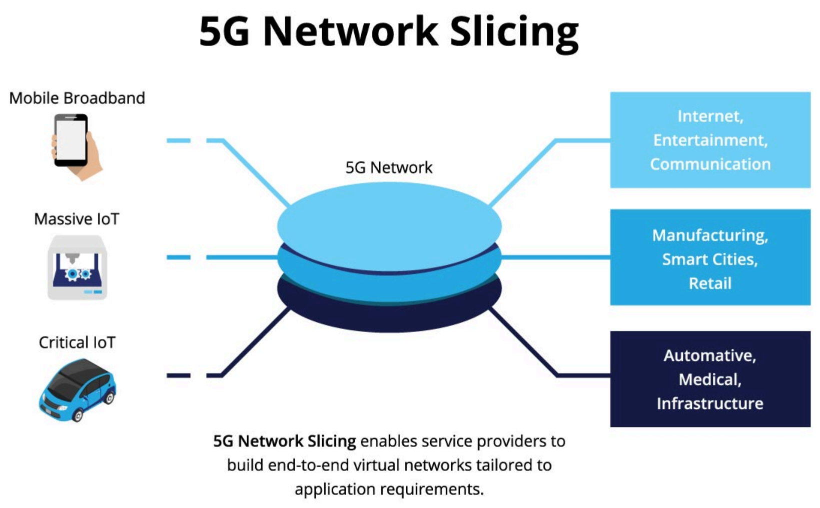

Figure F: 5G Network Slicing Architecture. A dedicated "Critical IoT" slice ensures zero-latency control for the robotic swarm, isolating it from high-volume "Massive IoT" sensor traffic.</td>
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<tr>
<td>Green Computing</td>
<td>To prevent the "electricity death spiral," the system treats energy as a variable cost rather than a fixed overhead:

- Energy-intensive AI tasks (like leaf-by-leaf analysis) are scheduled to run only when the HDB block’s solar energy output is at its peak. (11AM - 3PM)
- Data is processed locally on the rooftop "gateway" to reduce the energy cost of transmitting raw video data to the cloud.
- Automatically switching sensors to “Low Power Mode” during cloudy days to preserve battery.

This helps to optimize our system to save AC and lighting costs, turning fixed costs into a variable (and often free) resource, and allows our system to survive for extended periods of time without sunlight (cloudy days) to prevent crashing.</td>
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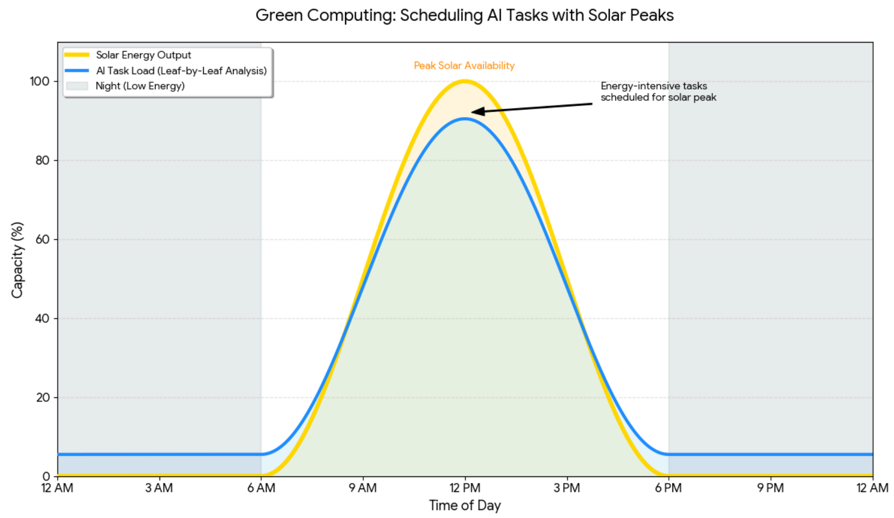

Figure G: Carbon-Aware Workload Orchestration. Energy-intensive AI training tasks (Blue) are scheduled to align with peak solar energy generation (Yellow)
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</tr>
<tr>
<td>Trust Technologies</td>
<td>
A blockchain ledger creates an immutable audit trail for every vegetable batch:

- Consumers scan a QR code to view the exact nutrient density and pesticide-free status, justifying a "Freshness Premium" over cheaper, untraceable imports.
- Prevents mislabelling of imported vegetables as "locally grown," securing the brand integrity of the Sovereign Food Mesh.

Doing so can help establish trust amongst customers and accept paying a little more for the added benefit. The SFA and government can quickly trace any safety issue to the exact rooftop and batch as well. In addition, having transparent records can have banks and investors more willing to fund rooftop farms.
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FOOD
[SECTION B]

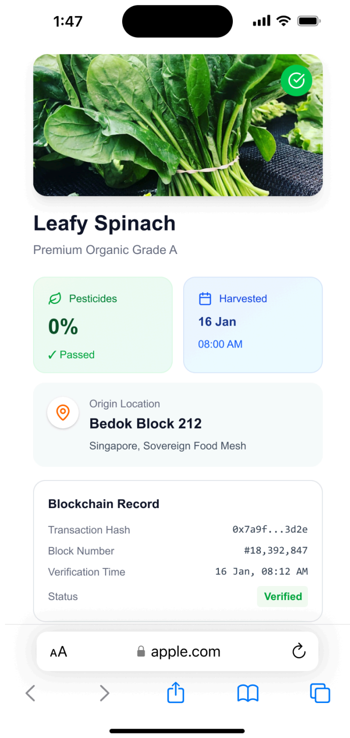

Figure H: Consumer view of the Digital Product Passport. Scanning the QR code retrieves immutable blockchain records of the produce’s harvest time and safety certification.

FOOD
[SECTION B]

Potential Market Demands (Local & Global)

Local Market Demand

1. Fragmented market demand between consumer preference and local production

As evidenced by an article by the Straits Times, with local produce priced higher than imported alternatives, consumers turn towards imported produce which are cheaper. This results in farms reducing their production output as they cannot consistently sell all of their produce. This signals to us that there is a fragmented market demand that could be solved through better alignment between consumer preferences and local production planning.

2. Farms attempting hybrid business models have a higher chance of success

Taking reference from a CNA article, it has been highlighted that local farms that have been able to remain viable in Singapore are able to do so due to diversifying their produce offerings and being able to carve a niche for themselves. Being able to diversify production according to consumer and seasonal behaviour can help address the issue of weak consumer demand by better matching market needs.

3. An aligned strategy towards Singapore's strategy towards Food Security

According to the Minister of Sustainability and the Environment, two of Singapore's four pronged strategies involve local production and stockpiling, reflecting the need for sustainable and resilient local food sources, coupled with the country's goal of increasing its current consumption of local fibre productions from 8% to 20% in 2035.

Global Market Demand

4. Countries are broadening supplier options as a response to increasing global supply chain uncertainty

With international trade risks, tariffs as potential disruptions are becoming a common occurrence, many nations are seeking to diversify their options towards food imports. As Singapore is well known as a premier global shipping hub, there is significant potential to be achieved if Singapore is able to further develop its capability to trade certain food resources to other countries to mitigate the impact of global supply disruptions.

FOOD
[SECTION B]

Challenges & Recommendations

To ensure the feasibility of the "Sovereign Food Mesh," we have identified key barriers and recommended technological solutions:

Challenge	Recommendation / Solution	Tech Pillar
High Energy Costs	Implement **Carbon-Aware Computing** to schedule intensive AI tasks (e.g., nutrient optimization) only when the building's solar output peaks, treating energy as a variable rather than fixed cost.	Green Computing
Consumer Skepticism	Use **Distributed Ledgers** to create an open-source audit trail. This allows consumers to scan a QR code and verify the proof of origin and safety (e.g. Zero pesticides, Harvested today, Nutrition Density), justifying a premium price point. This transparency provides a competitive advantage over cheaper and untraceable records from imported foods. Sometimes, suppliers can bluff about their harvest date and how long their product is in transit, which could lead to a series of issues like food poisoning. In 2023, Singapore had to recall imported eggs from Ukraine possibly due to this issue.	Trust Tech
Labor Shortage	Shift from "Man-in-the-loop" to **"AI-in-the-loop."** Computer vision automates pest scouting, while 5G-connected robots handle harvesting, allowing one technician to manage 50 blocks remotely.	AI & Connectivity
Scalability	Standardize an **API for Urban Farming**. Create a "Connectivity Plug" so any HDB block can be added to the national grid instantly, similar to adding a Wi-Fi router.	Connectivity

Conclusion

In conclusion, we are proposing a shift from 'City in a Garden' to 'City in a Farm.' By moving away from the struggling private-rental model and utilizing IMDA’s four tech pillars, we can transform food security from a commercial challenge into a distributed national resource. We stop treating food like a luxury product, and start treating it like the internet, which is connected, accessible, and running through the very infrastructure of our homes.

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