

KGAI4Ag: Knowledge-Guided AI for Agricultural Digital Twins

K. Guan^{1,2} · R. Carrasco³ · L.P. Koh³ · A. Banerjee¹ · L. Liu⁴ · S. Wang¹ · X. Luo³ · L. Shao³ · S. Redfern⁵ · J. Till¹

The Challenge

Singapore imports over 90% of its food — primarily from ASEAN nations. Extreme weather events, shifting climates, and fragmented data make food supply forecasting unreliable. Existing tools either rely on computationally expensive process-based models or on black-box AI that fails in heterogeneous tropical conditions. A new generation of tools is needed to bridge this gap.

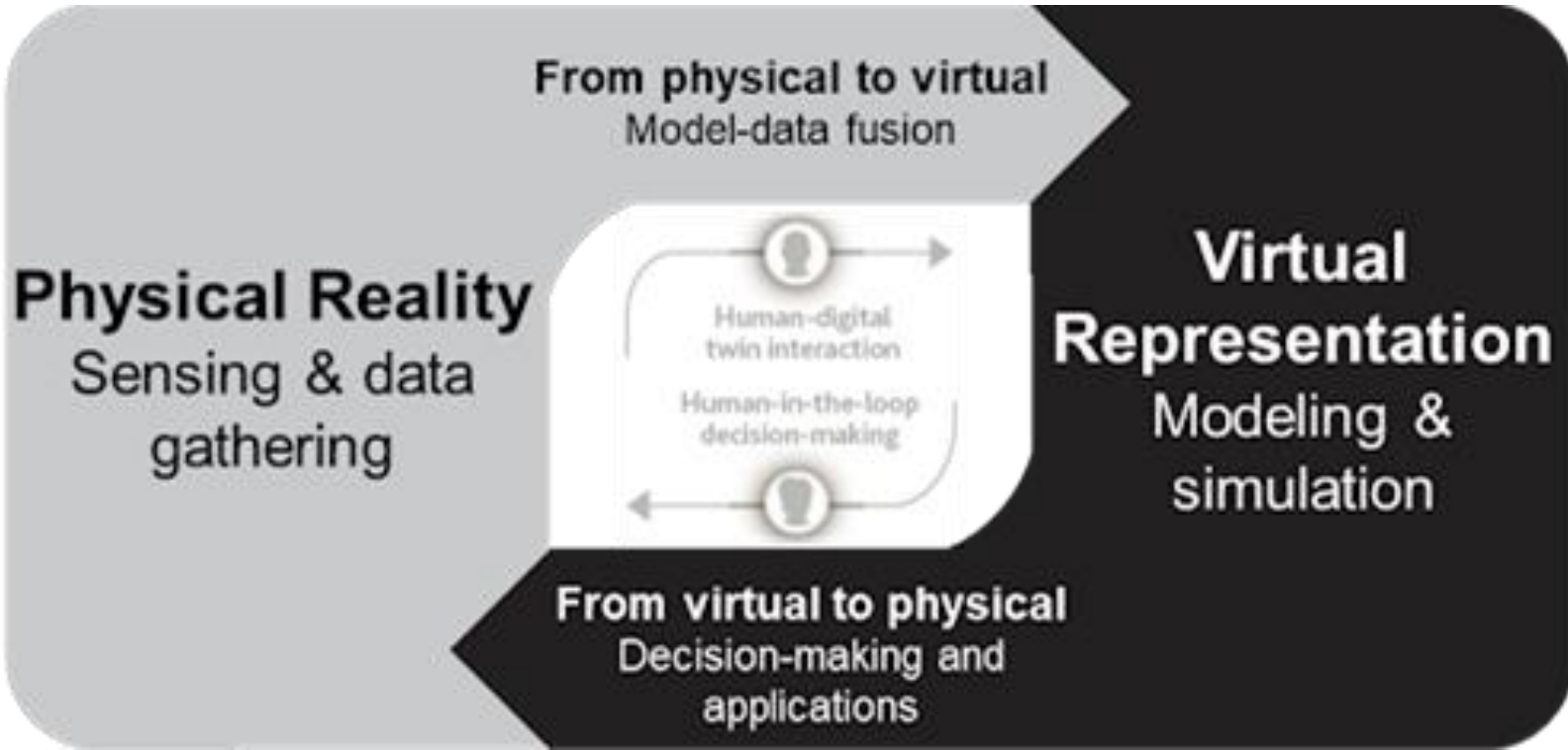
Our Approach: Knowledge-Guided AI (KGAI) + Digital Twin Technology

KGAI4Ag combines established scientific principles with advanced machine learning, embedding physical laws, ecological processes, and domain knowledge directly into AI architectures. This hybrid approach delivers interpretable, physically consistent predictions even with sparse tropical agroecosystem data.

Digital Twin technology provides a virtual representation of a physical agricultural system, which can range in scale from a single farm to an entire region. Based on data collected by ground sensors and satellites, it allows a wide variety of scenarios to be simulated rapidly for better planning and real-world decision-making.

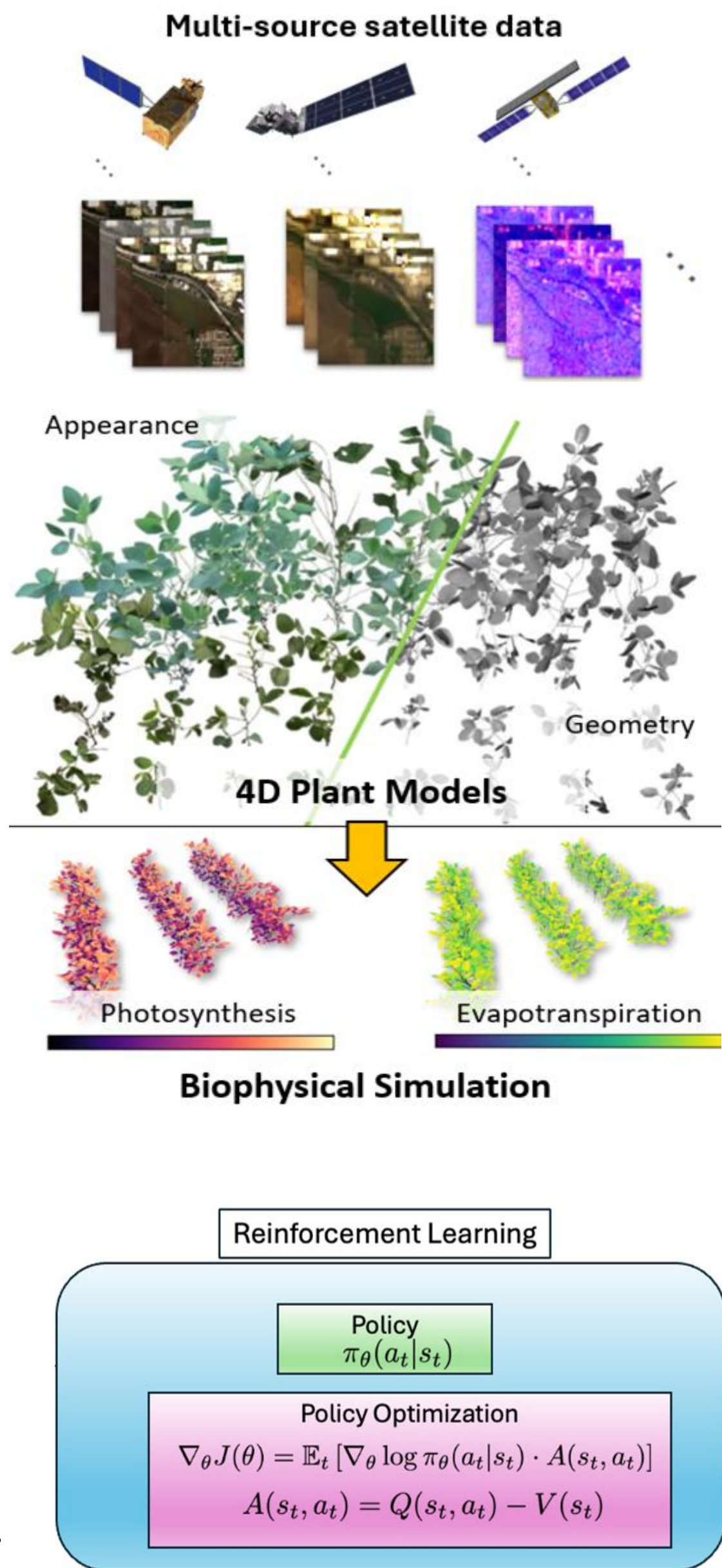
Foundational AI (FAI): Pushing the frontiers of AI methodology with new algorithms and architectures that can be applied broadly across agriculture and other scientific domains.

Use-Inspired Research (UIR): Applying KGAI to real-world problems by building digital twins for rice and agroforestry systems and forecasting tools that directly serve Singapore's food security needs.



Key Innovations

- Satellite & Field Sensing:** Ground sensors, drones, and satellites fused to produce daily cloud-free crop and soil maps at 30 m resolution across ASEAN.
- 4D Plant Modeling:** Dynamic 3D crop structural models that evolve through time, grounded in real field data to support biophysical simulation.
- Field-Level Digital Twin:** Physics-constrained AI integrated with the ecosys model to create virtual farm replicas that predict yield, carbon, and water outcomes.
- Regional Scaling — Bridge Model:** Novel upscaling framework extending field-level digital twin outputs to thousands of farms at >100× computational speedup.
- Trade Forecasting — DT-Trade:** KGAI-enhanced computable general equilibrium model for food supply chain forecasting and trade disruption early warning.
- AI Decision Support:** Reinforcement learning tools enabling farmers and policymakers to explore scenarios balancing yield, emissions, and economics.



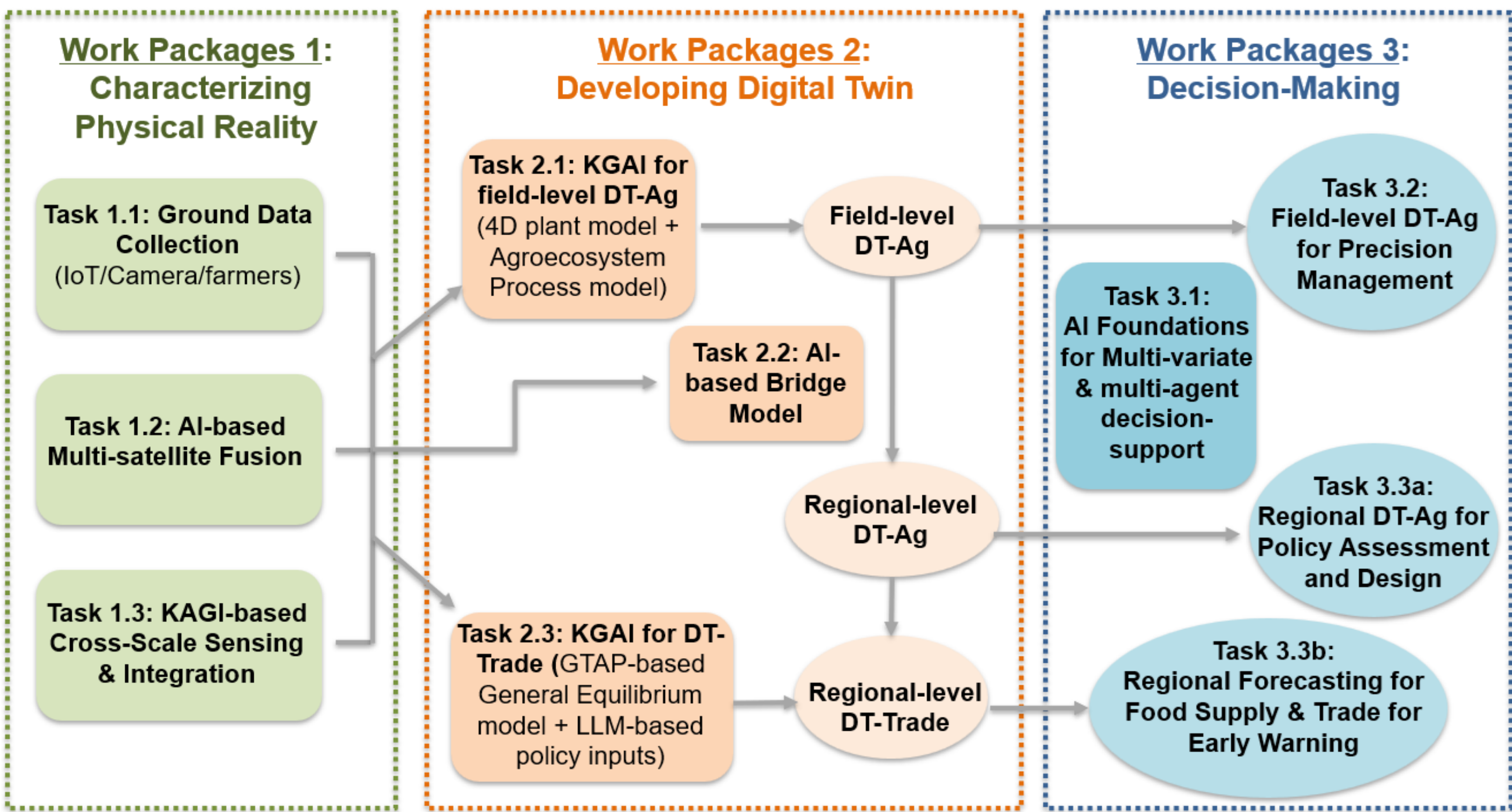
Pilot Crop Systems

The project focuses on rice and agroforestry as economically important crops that represent the two main types of agriculture in ASEAN (row crops and agroforestry). The tools built under KGAI4Ag will serve as templates that can be transferred to much broader cropping systems and geographies.

Row Crops — Paddy Rice (Vietnam → ASEAN) & **Agroforestry** (Indonesia → SE Asia)



Research Components



WP1 · Characterizing Physical Reality

IoT ground sensors, cross-scale sensing (field → regional), and AI-driven multi-satellite fusion to generate 30-m daily analysis-ready data cubes across ASEAN.

WP2 · Virtual Representation & Model-Data Fusion

Field-level digital twins integrating 4D plant models and biogeochemical modeling via KGAI; Bridge Model for 100× speedup in regional Digital Twin scaling.

WP3 · Decision-Making & Applications

Multi-agent reinforcement learning for farm management; Trade Digital Twin for food supply chain forecasting and early warning of trade disruptions.

Impact & Applications

Food Security: Early-warning forecasts for the Singapore Food Agency on import risk and supply chain disruptions from climate and trade shocks.

Green Finance & MRV: Agricultural decarbonisation and measurement, reporting & verification tools supporting carbon credit quantification across ASEAN.

AgTech Leadership: Transferrable digital twin templates positioning Singapore and ASEAN as a hub for agricultural AI innovation and policy.

Project Team & Institutions

Leading Institutions:

(2) Illinois Advanced Research Center at Singapore (Illinois ARCS) · (3) National University of Singapore (NUS) · (5) Nanyang Technological University (NTU)

Collaborating Institutions:

(1) University of Illinois Urbana-Champaign · (4) University of Wisconsin · AI Singapore · Cornell University · University of Maryland · University of Arkansas · University of Minnesota

