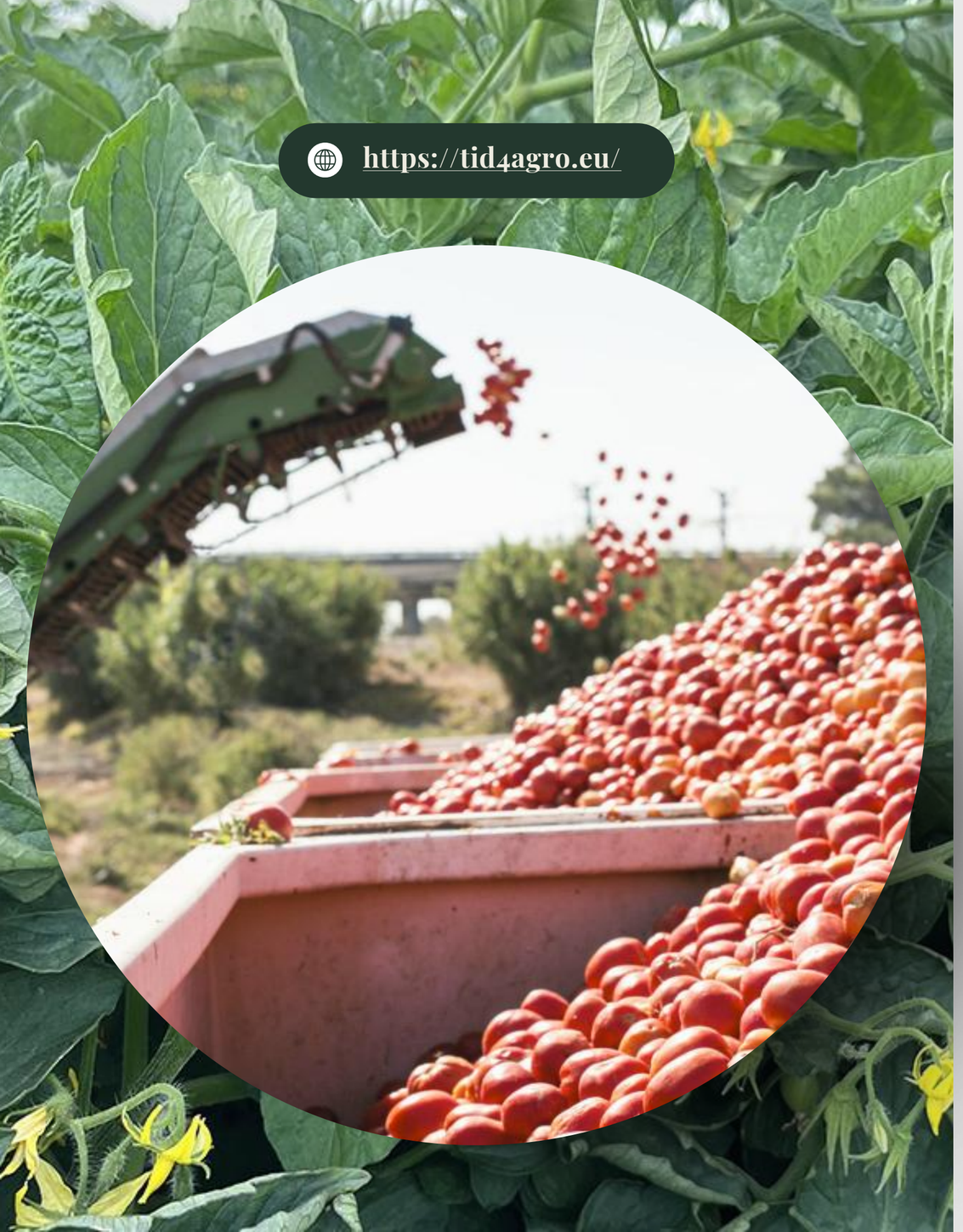


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TID4AGRO

Development of a platform as a tool for automating life cycle analysis supported by low-cost sensors

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E. Marquez[1]. **C. Campillo[1]**,

CICYTEX
CENTRO DE INVESTIGACIONES CIENTÍFICAS Y TECNOLÓGICAS DE EXTREMADURA

UEX
UNIVERSIDAD DE EXTREMADURA

1

What is life cycle analysis (LCA)?

Life cycle analysis (LCA) is a technique used to assess the **environmental impacts** associated with a **product, process, or service throughout its entire life cycle.** It considers all stages from **raw material extraction** to end-of-life, including **manufacturing, distribution, use**, and **end-of-life.**

ISO **14040**



Principles and framework

ISO **14044**



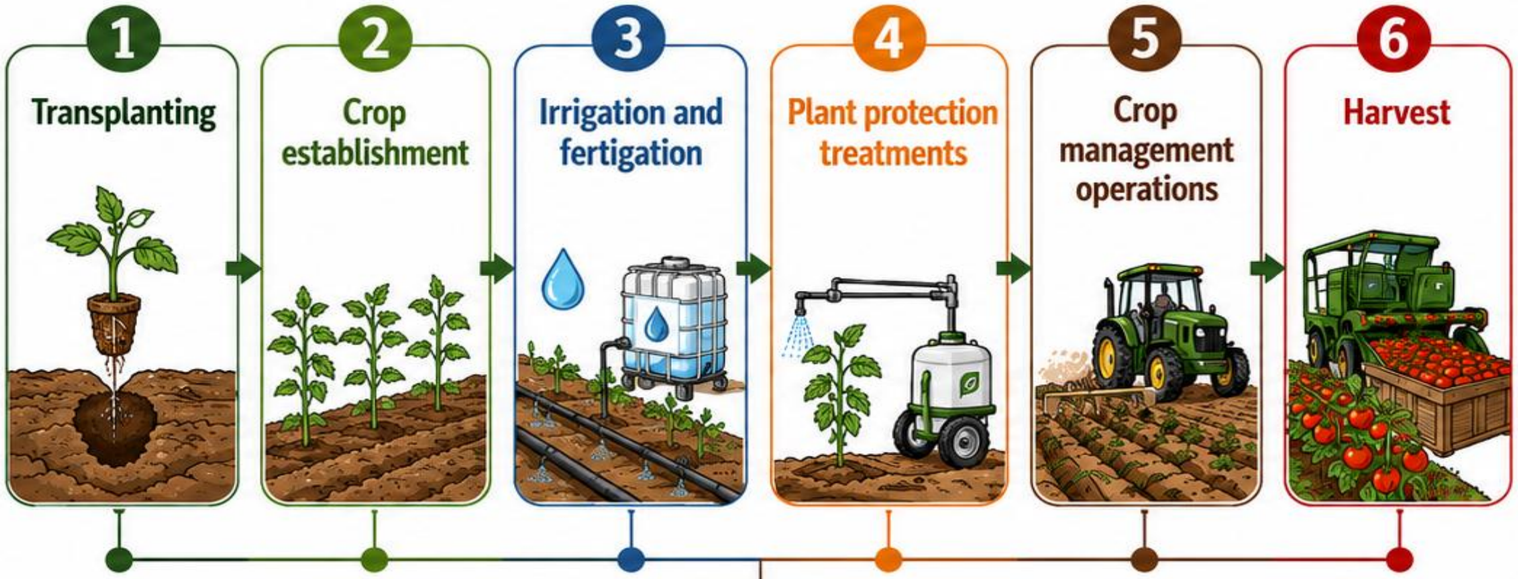
Requirements and guidelines

Life cycle assessment of industrial field-grown processing tomato

System boundaries: from transplanting to harvest

Main inputs

- Irrigation water
- Fertilizers
- Plant protection products
- Fuel and energy
- Irrigation system materials
- Labour and machinery



Functional unit

1 kg of fresh tomato at farm gate

Impact categories assessed

- Carbon footprint
- Acidification
- Freshwater eutrophication
- Freshwater ecotoxicity
- Water use
- Land use
- Fossil resource use
- Mineral and metal resource use

LCA integrates all crop inputs and operations to quantify their environmental impacts.

Improving LCA inventory data in processing tomato with low-cost sensors

From survey-based estimates to measured, traceable and reproducible primary data

1 Conventional data collection



- Irrigation, fertilisation and machinery operations are key hotspots
- High variability across farms and over time
- Difficult to quantify using conventional surveys
- Risk of missing or retrospective data

Key variables with high uncertainty

- Total irrigation water applied
- Actual liquid fertilizer used in fertigation
- Effective operating time of machinery and implements

2 Low-cost sensor monitoring



LoRaWAN — Water flow sensor



LoRaWAN — Fertigation sensor



LoRaWAN — Machinery operation sensor

Continuous field measurements

3 Digital LCA platform



- Sensor data
- Automatic processing
- Inventory variables
- LCA-ready dataset

Converted variables

- m^3 of irrigation water
- L of liquid fertilizer
- hours of field operations

4 Benefits for agricultural LCA

- Higher inventory accuracy
- Lower uncertainty
- Better temporal representativeness
- Improved traceability
- More reproducible inventories
- Integration into real-time digital LCA platforms
- Supports environmental decision-making

Main message

Low-cost IoT sensors transform key variables traditionally estimated through surveys into continuously recorded primary data, improving the quality of life cycle inventories on commercial farms.



Relevant hotspots in processing tomato: irrigation, fertilisation and mechanised operations.

Objective of the work

Development of a digital architecture for agricultural LCA in processing tomato

From field measurements to digital LCA inventories

1 Low-cost LoRaWAN sensors



Water flow sensor
on irrigation pipe



Fertigation tank sensor
in fertilizer tank



Machinery operation sensor
on tractor/implement

2 Continuous field data acquisition



3 Web-based LCA platform



4 Outcomes

- Higher accuracy
- Improved traceability
- Automated inventory data

To improve the accuracy, traceability and automation of inventory data in processing tomato production.



WORKFLOW: From Field Data to Environmental Impact Reports

1 CREATE FIELD RECORD

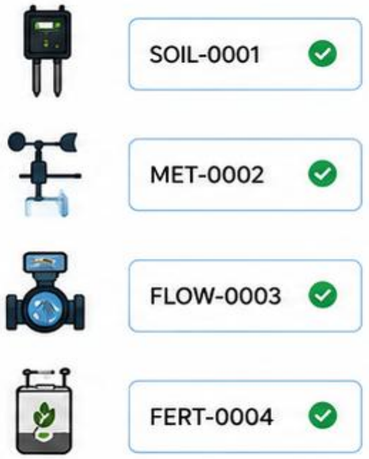
El agricultor o técnico crea un registro del campo en la plataforma e ingresa la información agronómica básica.



La información agronómica básica queda almacenada en la plataforma.

2 LINK SENSORS

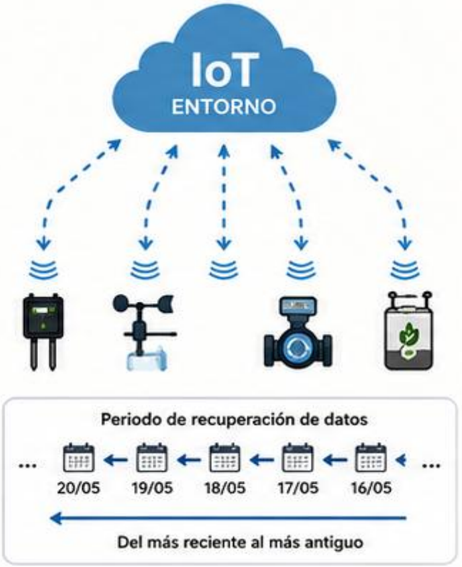
El usuario vincula cada sensor mediante un código único de identificación.



Cada sensor queda identificado de forma única y vinculado al campo.

3 RETRIEVE SENSOR DATA

La plataforma recupera los datos de los sensores desde el entorno IoT correspondiente.



Los datos se recuperan de los sensores hacia la nube en orden inverso desde los más recientes.

4 TRANSFORM TO LCA-RELEVANT VARIABLES

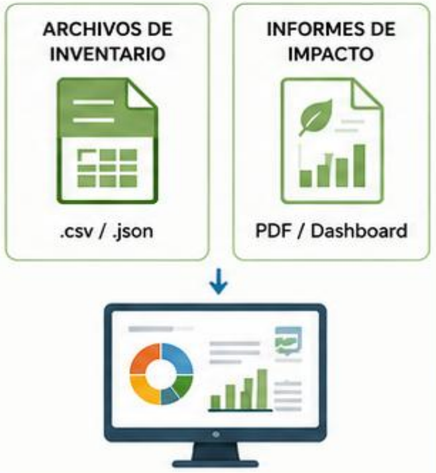
Los datos crudos se transforman en variables relevantes para el ACV, como:

- Agua de riego — $m^3\ ha^{-1}$
- Fertilizante líquido — $L\ ha^{-1}$
- Operación de maquinaria — $horas\ ha^{-1}$
- Otros insumos — $kg\ ha^{-1}$

Los datos de los sensores se limpian, agregan y convierten en variables relevantes para el ACV.

5 GENERATE OUTPUTS

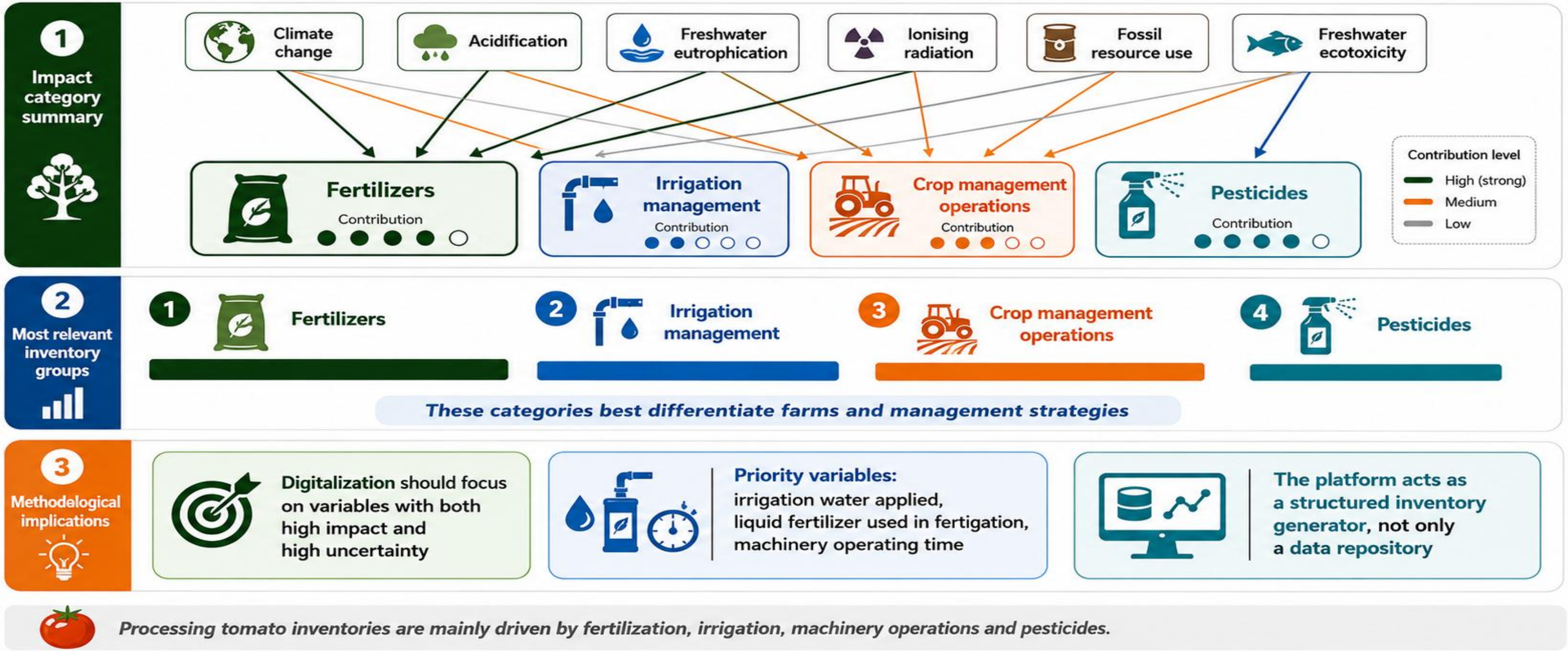
El sistema genera archivos de inventario listos para software e informes de evaluación de impacto que pueden usarse para interpretar el desempeño ambiental de cada campo.



Salidas listas para software de ACV y toma de decisiones sobre el desempeño ambiental del campo.

Priority inventory parameters in processing tomato LCA

Impact-tree synthesis used to guide sensor prioritization



Processing tomato inventories are mainly driven by fertilization, irrigation, machinery operations and pesticides.

Machinery operation and implement detection for agricultural LCA

From tractor sensor payloads to auditable field-operation inventories

1 Field setup: sensor on machinery and interchangeable implements



Interchangeable implements / operations

- Soil preparation
- Pesticide application
- Fertilizer distribution
- Harvest operation

2 Example sensor payload / data stream

LoRaWAN® payload example

TagID (implement)	= 2 (plow)
Location / plot	Plot A-12
Timestamp (UTC)	2025-05-20 08:45
Operating time (cum.)	02:30 h
Transmission frequency	Every 15 min



Location / plot

Effective time of use

The sensor records location, implement type and effective time of use.

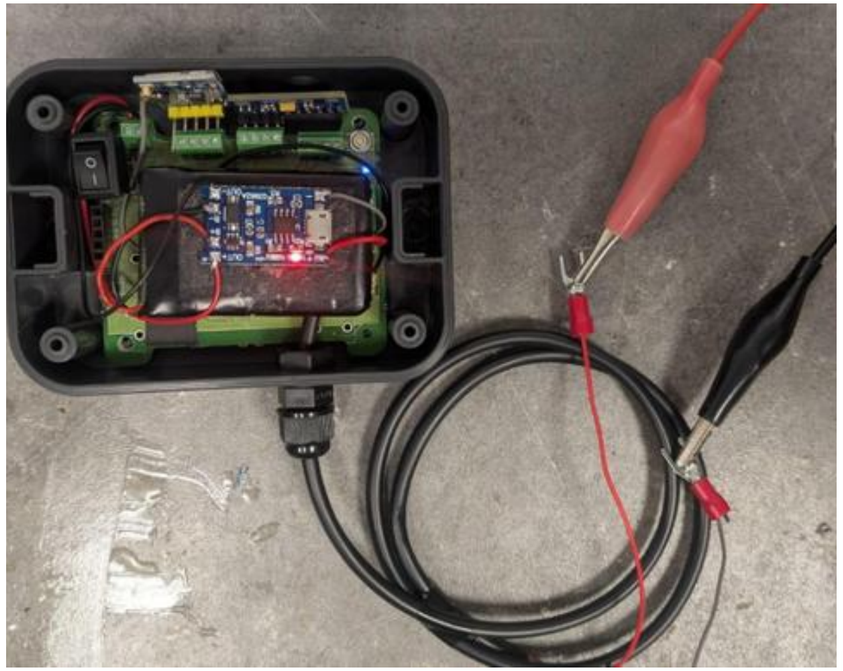
3 How data improve the LCA inventory

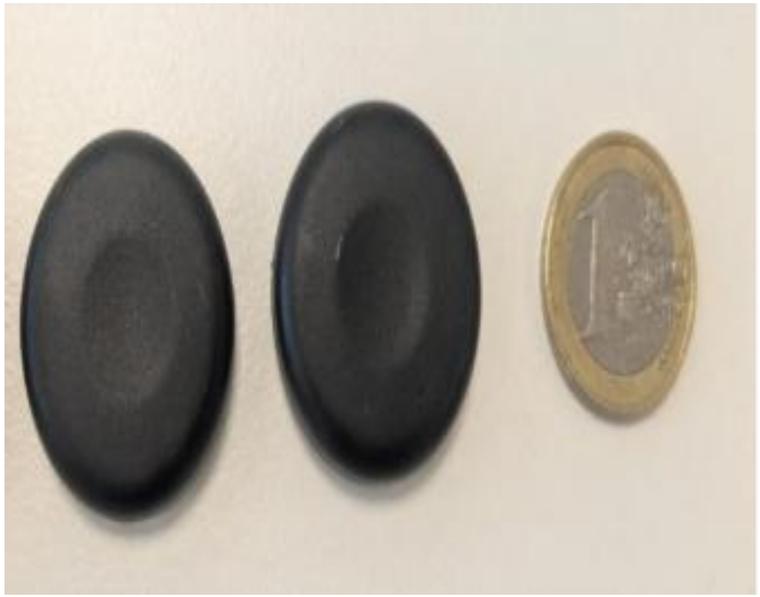
1 Recorded working time	Effective time per implement
2 Implement identification	Which implement was used
3 Plot allocation	Where the work was performed
4 Diesel use and labour time representation	Fuel and labour allocated by time and operation
5 LCA-ready machinery inventory	Traceable, auditable inventory for LCA and reporting

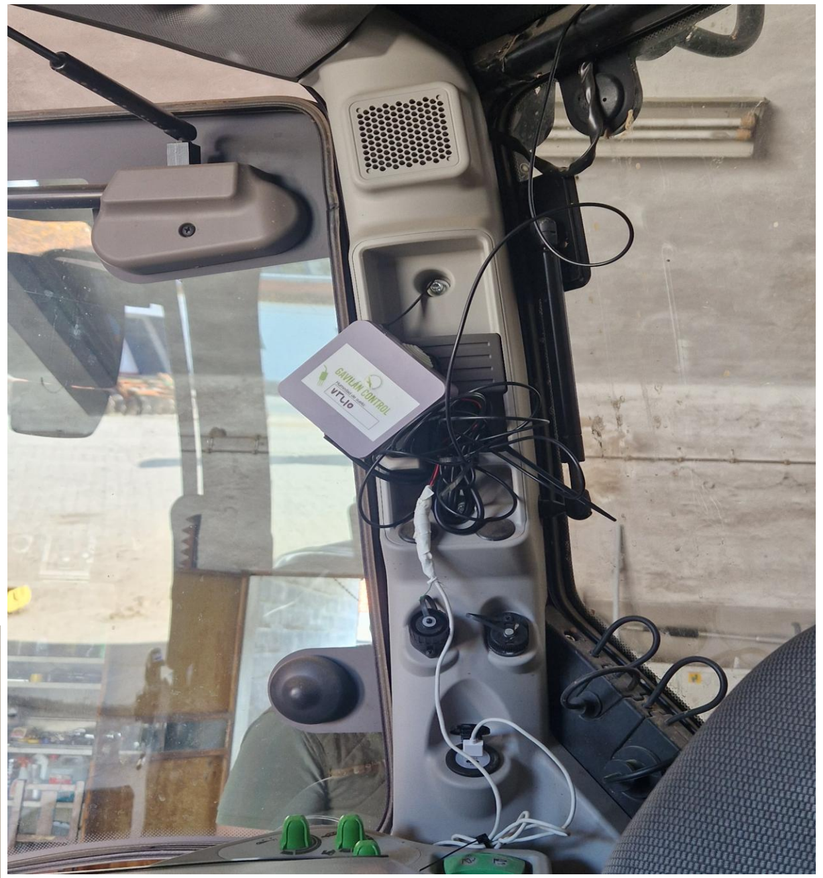
Fuel consumption still depends on tractor power, working conditions (soil, slope, weather) and implement load. Recorded time provides a more transparent and auditable basis than generic estimates.

- Recorded operating time reduces uncertainty compared with retrospective estimates.
- Implement detection allows the inventory to distinguish among specific field operations.
- Traceable payloads support sensitivity analyses and separation of real field variability from modelling assumptions.

Field operations are a common source of uncertainty in agricultural LCA.







machinery operation and implement detection



Real-time fertilizer quantification in fertigation systems

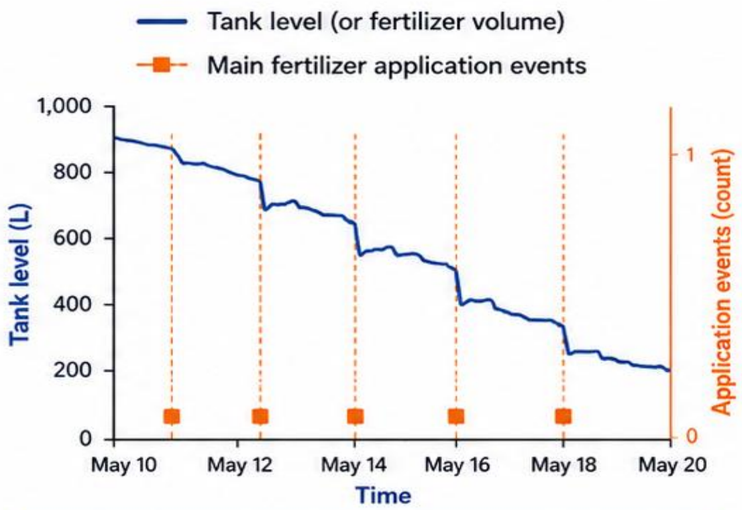
LoRaWAN monitoring of fertilizer tank depletion in processing tomato

1 Commercial-field setup



Low-cost LoRaWAN level sensor measures the fertilizer solution level in commercial tanks.

2 Tank depletion over time



Continuous monitoring detects real fertigation events.

3 From measurements to LCA inventory variables

1 Tank level change	LoRaWAN sensor data processed over time
2 Volume of fertilizer solution applied	Conversion from level change to volume (L)
3 Declared fertilizer composition	N, P_2O_5, K_2O, etc. from supplier label/analysis
4 Estimated applied nutrient units	kg N, kg P_2O_5, kg K_2O applied over time
5 LCA inventory flows	Export to inventory database / platform

LCA inventory database → Digital platform / data repository

Key results

The temporal pattern showed progressive tank depletion with clear drops linked to fertilizer applications.

Continuous data improve verification of fertigation events and reduce uncertainty compared with manual records.

This supports better nitrogen balance calculations and more precise fertilizer management, especially in nitrate-vulnerable areas.

Low-cost and appropriate for LCI needs: measures commercial fertilizer quantity directly.

Calibration of tank geometry and verification of concentration/density remain necessary.

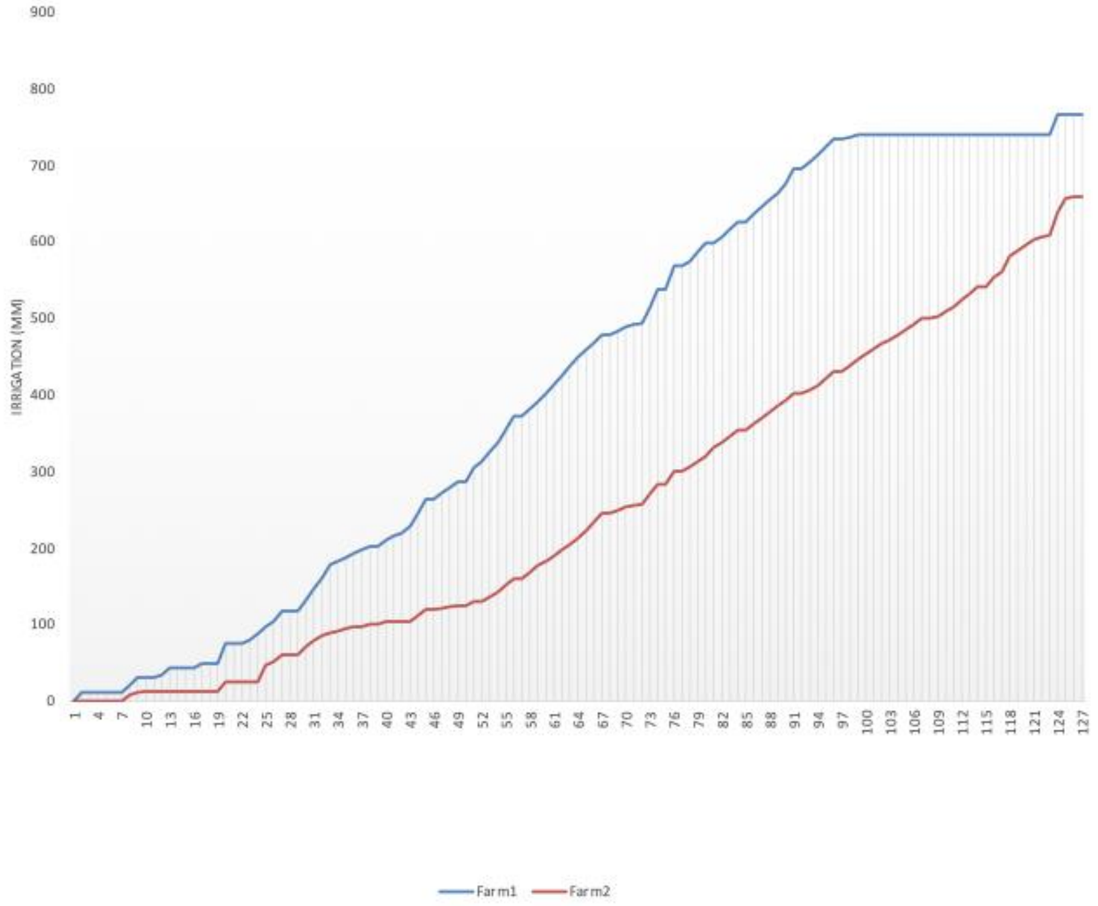
Coupling real-time tank level monitoring with declared fertilizer composition enables robust, continuous quantification of nutrients applied via fertigation.

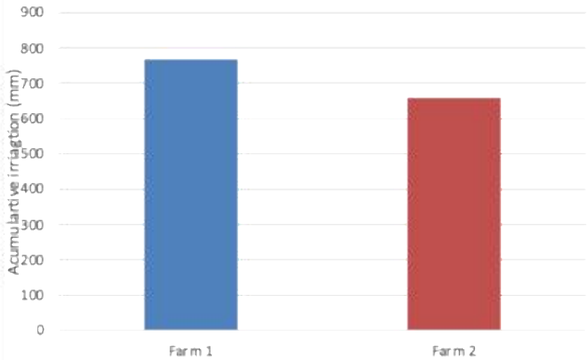
IRRIGATION

Irrigation Water measure







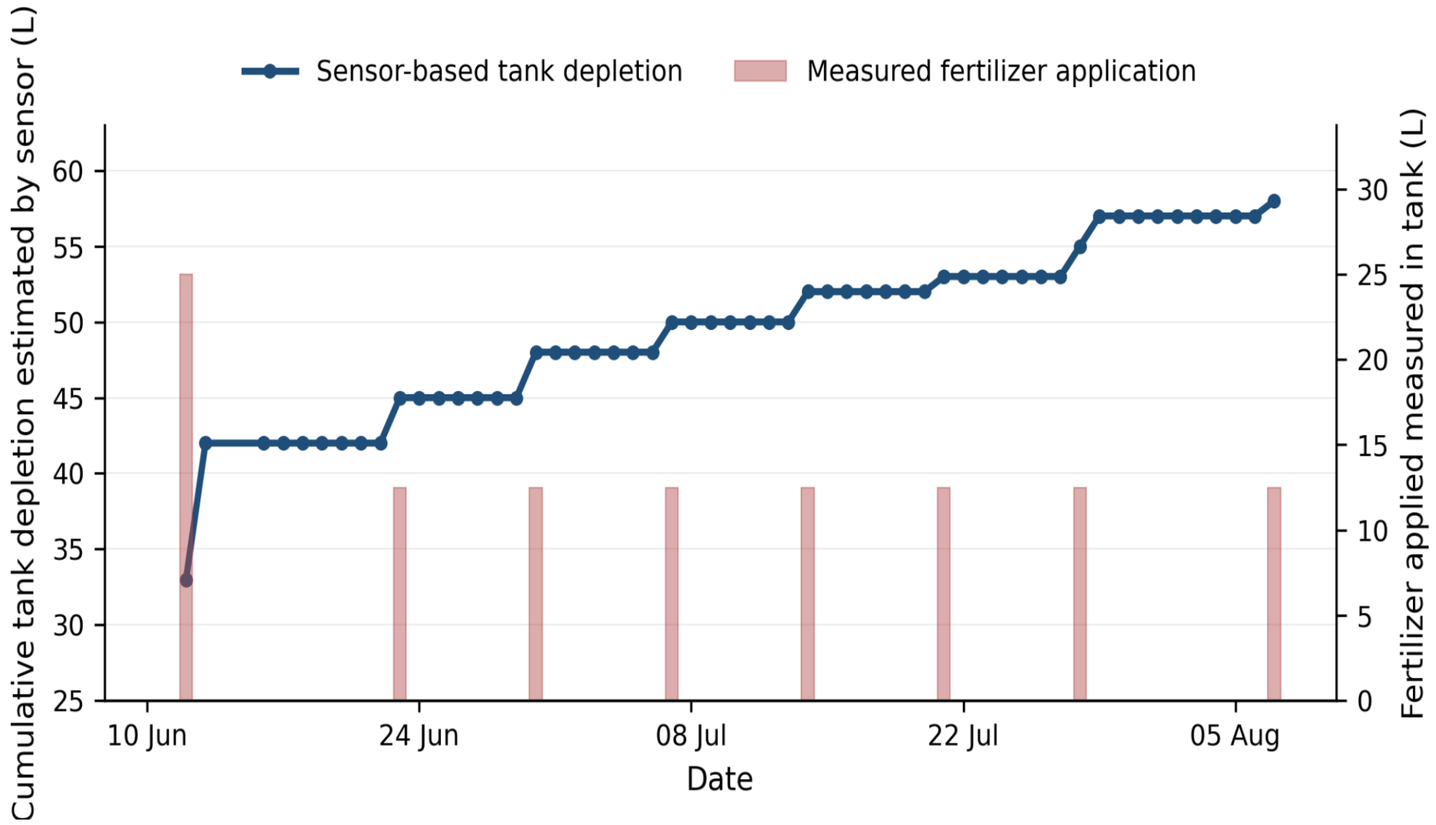


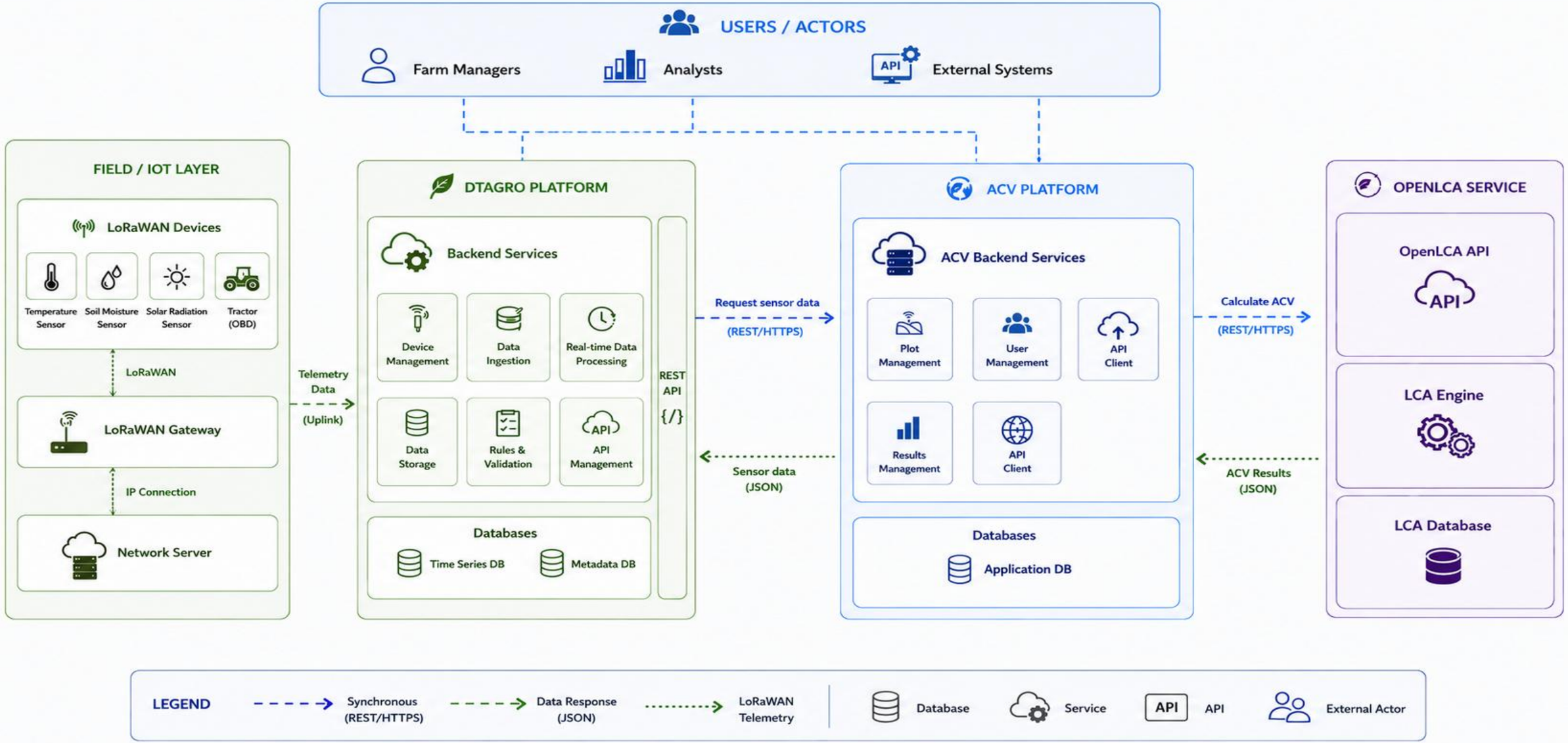
FERTIGATION

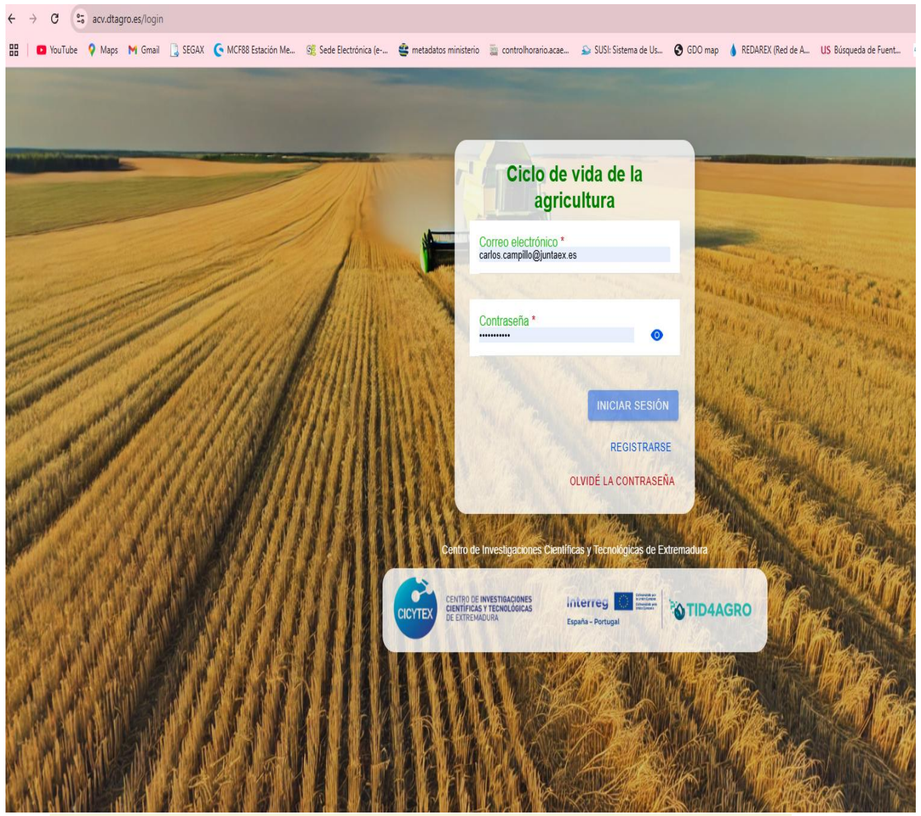
Tank NPK measure

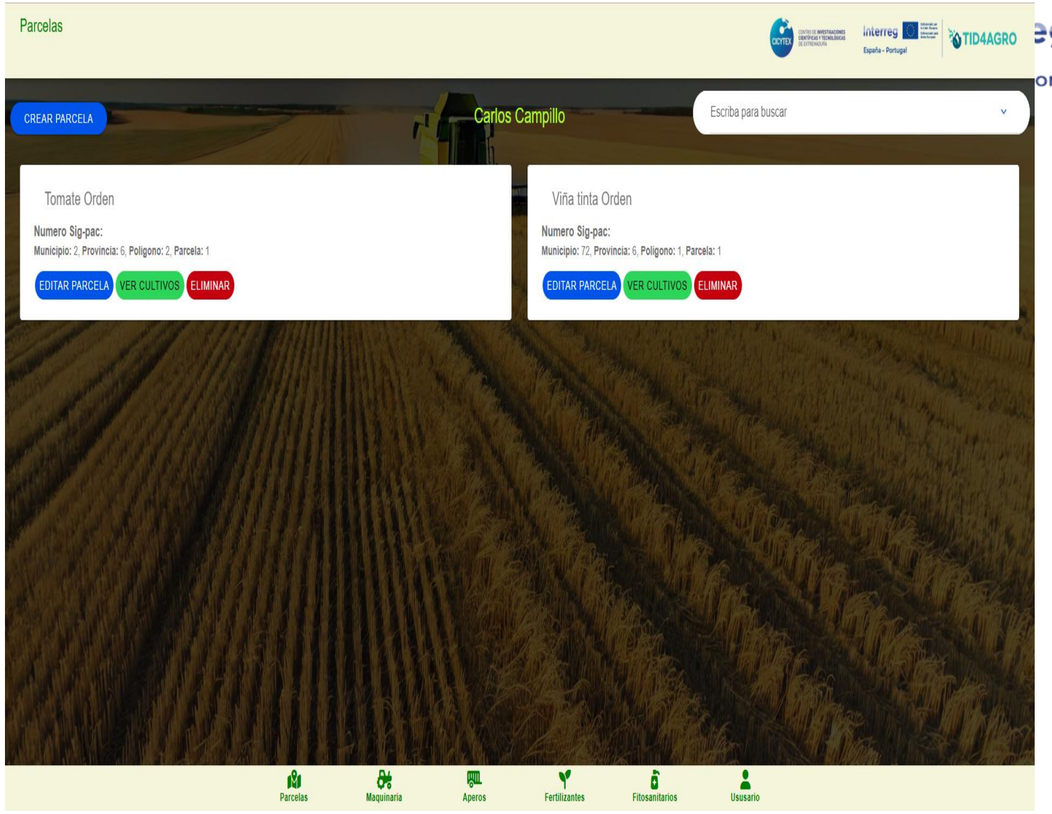




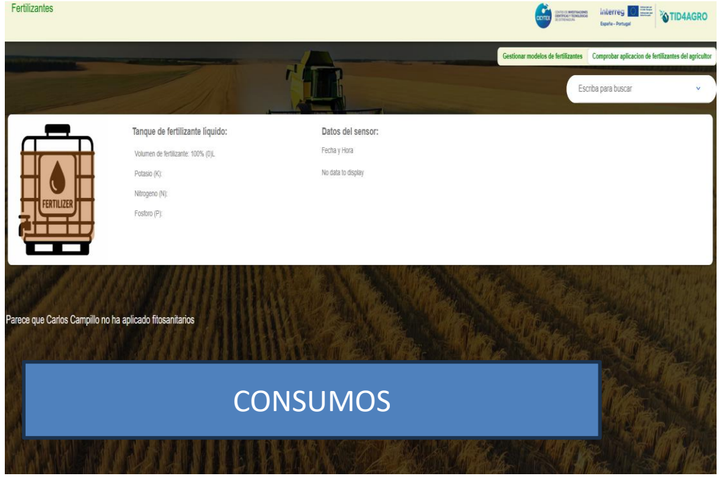



USERS / ACTORS
Farm Managers
Analysts
API
External Systems
FIELD / IOT LAYER
LoRaWAN Devices
Temperature Sensor
Soil Moisture Sensor
Solar Radiation Sensor
Tractor (OBD)
LoRaWAN
LoRaWAN Gateway
IP Connection
Network Server
Telemetry Data
(Uplink)
DTAGRO PLATFORM
Backend Services
Device Management
Data Ingestion
Real-time Data Processing
Data Storage
Rules & Validation
API Management
Databases
Time Series DB
Metadata DB
REST API
{/}
Request sensor data
(REST/HTTPS)
Sensor data
(JSON)
ACV PLATFORM
ACV Backend Services
Plot Management
User Management
API Client
Results Management
API Client
Databases
Application DB
Calculate ACV
(REST/HTTPS)
ACV Results
(JSON)
OPENLCA SERVICE
OpenLCA API
API
LCA Engine
LCA Database
LEGEND
Synchronous (REST/HTTPS)
Data Response (JSON)
LoRaWAN Telemetry
Database
Service
API
API
External Actor









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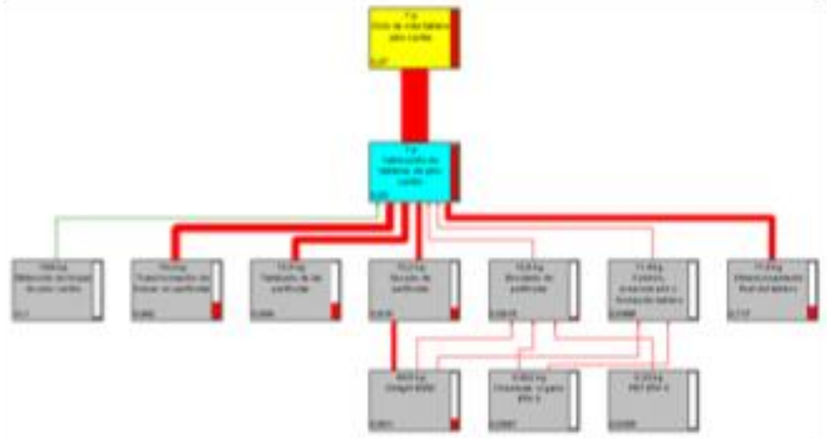
TID4AGRO



SCAN ME

https://acv.dtagro.es/






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SimaPro 9.6.0.[illegible] Fecha: 12/12/2024 Período: 14:47
Proyecto: maria pruebas

Cálculo: Analizar
Resultado: Evaluación del impacto
Producto: 1 kg Tomate ESCENARIO MEDIO (del proyecto maria pruebas)
Método: Environmental Footprint 3.1 (adapted) V1.01 / EF 3.1 normalization and weighting set
Indicador: Normalización
Skip category/fuzzy
Excluir proceso/fuzzy
Excluir emisión/fuzzy
Per impact only/fuzzy
Sorted on: Orden de categoría
Sort order: Ascendente

Orden de categoría	Unidad	Total	Tomate ESCENARIO MEDIO	Fertilizantes	Pesticidas T	Sistema de riego	Manejo de cultivo T
Acidification	mol H+ eq	4,77534E-06	0	3,41155E-06	1,17566E-07	2,68998E-07	9,73422E-07
Climate change	kg CO2 eq	5,68222E-06	0	4,12838E-06	4,77157E-08	5,14268E-07	9,56737E-07
Ecotoxicity, freshwater	CTUe	2,92531E-05	0	1,09987E-05	1,77963E-05	2,73766E-07	6,28299E-07
Particulate matter	disease inc.	5,10820E-06	0	4,43324E-06	7,24937E-08	1,88E-07	4,12493E-07
Eutrophication, marine	kg N eq	1,11964E-05	0	1,00999E-05	3,05099E-08	1,42157E-07	1,09315E-06
Eutrophication, freshwater	kg P eq	5,55197E-06	0	3,68308E-06	8,23988E-08	8,09466E-07	1,78321E-07
Eutrophication, terrestrial	mol N eq	5,59482E-06	0	4,09626E-06	1,77577E-08	1,58725E-07	1,31915E-06
Human toxicity, cancer	CTUh	1,23E-05	0	6,91566E-06	1,48401E-07	9,76132E-07	4,25998E-06
Human toxicity, non-cancer	CTUh	5,05946E-06	0	2,54955E-06	1,125E-06	1,43855E-07	1,29631E-06
Ionising radiation	kBq U-235 eq	6,72959E-07	0	4,44658E-07	9,54553E-09	1,84548E-07	1,19867E-08
Land use	Pt	2,27223E-05	0	2,30566E-07	1,34233E-09	4,28239E-08	2,18466E-05
Ozone depletion	kg CFC-11 eq	2,45139E-08	0	1,39066E-08	2,48944E-09	5,25668E-09	2,45657E-09
Photochemical ozone formation	kg NMVOC eq	6,09555E-06	0	4,27566E-06	3,99455E-08	5,45E-07	1,02659E-06
Resource use, fossils	MJ	1,02594E-05	0	6,60945E-06	1,04457E-07	1,95238E-06	1,59221E-06
Resource use, minerals and metals	kg Sb eq	6,9555E-06	0	5,75488E-06	5,74405E-08	1,89155E-07	7,1366E-07
Water use	m3 depriv.	0,00044206	0	1,4031E-06	6,33E-09	1,39635E-07	0,00044042

CATEGORÍA DE IMPACTO AMBIENTAL		UNIDAD DE REFERENCIA (RECOMENDADA)	FACTOR DE CARACTERIZACIÓN
CALENTAMIENTO GLOBAL	Fenómeno observado en las medidas de la temperatura que muestra en promedio un aumento en la temperatura de la atmósfera terrestre y de los océanos en las últimas décadas.	Kg. Eq CO_2 (CO_2 eq)	Potencial de Calentamiento Global (PCG)
CONSUMO DE RECURSOS ENERGÉTICOS	Energía consumida en la obtención de las materias primas, fabricación, distribución, uso y fin de vida del elemento analizado.	MJ	Cantidad consumida
REDUCCIÓN DE LA CAPA DE OZONO	Efectos negativos sobre la capacidad de protección frente a las radiaciones ultravioletas solares de la capa de ozono atmosférica.	Kg. Eq. CFC-11	Potencial de Agotamiento de la Capa de Ozono (PAO)
EUTROFIZACIÓN	Crecimiento excesivo de la población de algas originada por el enriquecimiento artificial de las aguas de ríos y embalses como consecuencia del empleo masivo de fertilizantes y detergentes que provoca un alto consumo del oxígeno del agua.	Kg. Eq. NO_3	Potencial de Eutrofización (PE)
ACIDIFICACIÓN	Pérdida de la capacidad neutralizante del suelo y del agua, como consecuencia del retorno a la superficie de la tierra, en forma de ácidos, de los óxidos de azufre y nitrógeno descargados a la atmósfera.	Kg. Eq. SO_2	Potencial de Acidificación (PA)
CONSUMO DE MATERIAS PRIMAS	Consumo de materiales extraídos de la naturaleza.	Tm	Cantidad consumida
FORMACIÓN DE OXIDANTES FOTOQUÍMICOS	Formación de los precursores que dan lugar a la contaminación fotoquímica. La luz solar incide sobre dichos precursores, provocando la formación de una serie de compuestos conocidos como oxidantes fotoquímicos (el ozono-O_3 es el más importante por su abundancia y toxicidad).	Kg. Eq. C_2H_4	Potencial de Formación de Oxidantes Fotoquímicos (PFOX)

Conclusions

Digital inventory generation for processing tomato LCA using low-cost LoRaWAN sensors

1. Inventory-data reliability



The reliability of agricultural LCA depends strongly on inventory precision. In processing tomato, the main critical gaps are irrigation, fertilizer use and field operations.

2. TID4AGRO platform



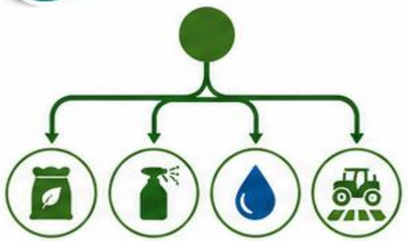
The TID4AGRO platform transforms farmer inputs and sensor data into standardized inventory variables compatible with LCA eoftware, reducing extensive post-processing.

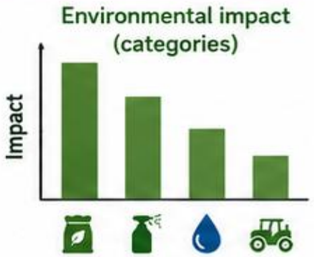
3. Low-cost LoRaWAN sensors



Low-cost LoRaWAN sensors are suitable for automating key inventory parameters under field conditions: pulse-based water metering, fertilizer-tank volume monitoring and machinery operating-time recording.

4. Sensor-prioritization criteria





Impact-tree analysis identifies fertilizers, pesticides, irrigation and crop management as the main categories to monitor in order to improve the environmental assessment of processing tomato systems.

5. Future work



Future work should focus on field validation across farms and seasons, uncertainty quantification, calibration protocols for the fertilizer sensor, and automated linkage between real-time inventory updates and environmental recommendations.



Main takeaway: better digital inventories lead to more accurate, traceable and actionable LCA of processing tomato production.

https://tid4agro.eu

https://acv.dtagro.es

¡Thank you very much for your attention!



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TID4AGRO