Sustainability Maturity Assessment

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Abbreviations and Acronyms:	
CSR	Corporate Social Responsibility
GDPA	Green Deal Performance Assessment
GDI	Green Deal Index
GDO	Green Deal Ontology
SCOR	Supply Chain Operations Reference
IOT	Internet of Things
LCA	Life Cycle Assessment
CEPA	Circular Economy Performance Assessment
EM	Energy Modeling
WM	Water Management
TME	Thermoeconomic Analysis
COP	Coefficient of Performance
KPI	Key Performance Indicator
AHP	Analytic Hierarchy Process
IDS	Industrial Data Space
AI	Artificial Intelligence
ML	Machine Learning
MLOps	Machine Learning Operations
APIs	Application Programming Interface

1. Executive summary

Within the CLARUS project, a decision-support tool has been created to help manufacturing companies evaluate and upgrade their sustainability maturity. The tool guides organizations through a structured evaluation of their processes from economic, environmental, and social perspectives, in alignment with the principles of Corporate Social Responsibility (CSR) and the EU Green Deal.

The tool aims to orchestrate CLARUS consulting services by identifying key areas for improvement and suggesting effective sustainability roadmaps. It allows companies to compare their sustainability performance with industry standards and competitors while receiving data-driven insights for long-term sustainability planning.

The methodology follows a **four-phase structure**:

1. **Evaluation Phase:** Companies fill a comprehensive survey to assess their current sustainability maturity with respect to supply chain and technological dimensions.
2. **Diagnosis Phase (AS-IS):** Based on survey responses, the tool performs a Green Deal Performance Assessment (GDPA) and calculates a baseline Green Deal Index, also known as the (GDI AS-IS – before the implementation of the AI TOOLKIT), leveraging the Green Deal Ontology (GDO) to structure and contextualize information.
3. **AI Modeling Phase:** Gathered data feeds into an AI TOOLKIT, which analyzes historical patterns to predict and optimize resource-related parameters.
4. **Strategic Planning Phase (TO-BE):** Based on the AI-predicted variables, the tool outputs a GDI (TO-BE), which provides a quantitative reflection of the improvement made by the application of the AI TOOLKIT.

In a food manufacturing context, the tool aims at assessing the Food Supply Chain function using the SCOR (Supply Chain Operations Reference) model, a standardized approach to evaluate and improve supply chain performance. The food supply chain is becoming more and more complex, requiring careful planning and management of raw materials, production, packaging, and transport flow. With the evolution of consumer preferences, higher attention posed to sustainability, and increasing competition in the food industry, the supply chain must adapt to these new needs. Technology, such as IoT and Big Data, can be used to optimize supply chain models and implement improvements. The sustainability maturity assessment aims to assess the current sustainability situation for food manufacturing companies and guide them in improving their sustainability through digital solutions.
To implement a Sustainability Maturity Assessment for the CLARUS project, also the Supply Chain function has been assessed, using the SCOR model.

We can define the Supply Chain system as a network of facilities that produce raw materials, transform them into intermediate goods and then final products, and deliver products to customers through a distribution system. The integration of food production into the supply chain, if well managed, can generate added value, giving security and integrity to both the producer and the consumer through the close coordination of activities along the supply chain.

The evolution of consumer preferences has led to an exponential growth in the offer and variety of available food products, also forcing the supply chain flow to adapt to distribution needs through the increase in delivery frequency and the search for a high service level. Thus, the food supply chain is a complex process that must guarantee and manage the approval of raw materials, moving from storage in the warehouse to the supply of the various production departments. At the same time, it must also manage packaging of the goods and ensure the correct transport flow throughout the distribution network. So, it is important to ensure a careful planning process. Within supply chain processes there are fundamental aspects related to technology. Internet of Things (IoT) and Big Data are relevant, through which it is possible to obtain a whole series of real-time information that can be used to optimize future Supply Chain models.

The SCOR (Supply Chain Operations Reference) model is a widely recognized framework developed by the Supply Chain Council (now part of APICS/ASCM). It provides a standardized approach to evaluate, improve, and communicate supply chain performance. The model breaks down supply chain management into five core processes: (i) Plan, (ii) Make, (iii) Source, (iv) Deliver, (v) Return.

2. Introduction

The industrial world is seeing a clear transformation driven by both sustainability and digitalization. In light of the sophisticated environmental challenges, manufacturing companies need to further develop their production models to be more resource-efficient and aligned with the principles of sustainable development, taking into consideration the fact that the continuous advancements in digital technologies are facilitating the collection, analysis, and leverage of data for smarter decision-making and resource-consumption optimization, which offers a unique opportunity for industries to gain a competitive edge through innovation and resilience besides meeting regulatory and social expectations.

Clearly, the transformation potential has gained more hype considering the European Green Deal**,** which sets a clear plan for a climate-neutral continent by 2050 [1]. The Green Deal urges industries to reduce their greenhouse gas emissions, enhance circularity, and adopt greener technologies across all processes. Furthermore, regulatory frameworks are currently promoting obligatory ESG (Environmental, Social, and Governance) disclosures, urging companies to measure and report their sustainability performance in a consistent and transparent manner, thus re-positioning sustainability as an essential pillar of strategic management, and encouraging organizations to adopt tools that can help them understand their current position and plan their way towards compliance and efficiency.

At the same time, Industry 5.0 sheds the light on the necessity of human-centric, sustainable, and resilient manufacturing systems. While Industry 4.0 prioritized digital automation, connectivity, and real-time data, Industry 5.0 emphasizes the integration of social and environmental values into technological advancement [2]. This paradigm shift requires organizations to rethink and redesign their operations and integrate sustainability goals into every level of decision-making.

In response to these evolving needs, the CLARUS project has developed a comprehensive sustainability decision-support tool tailored for food manufacturing companies. The tool is designed to fulfill three primary objectives as shown in Figure 1:

1. **Strategic assessment:** CLARUS researchers provide a structured methodology to evaluate the current sustainability maturity of industrial processes through qualitative and quantitative dimensions aligned with CSR and ESG frameworks
2. **Tactical guidance:** CLARUS consultants pinpoint sustainability gaps and spot potential improvement areas through sector-specific sustainability indicators
3. **Operational enablement:** CLARUS developers support strategic planning through AI-based modeling, which analyzes and predicts future resource parameters and suggests actions based on the company's target GDI

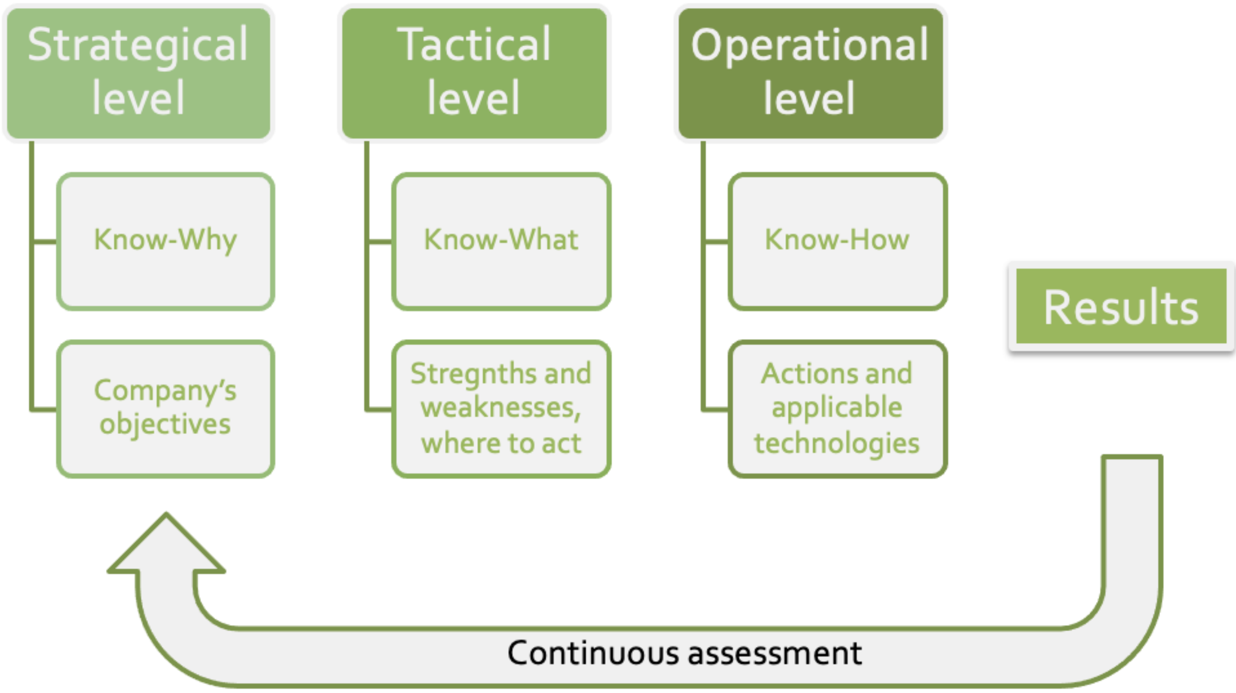

Figure 1 Primary Objectives of the CLARUS Road mapping Tool

By enabling the collection and analysis of targeted sustainability data, the tool empowers manufacturing firms to take concrete actions toward their sustainable transition. It bridges the gap between regulatory expectations and operational capabilities, ensuring that companies not only comply with ESG requirements but also make meaningful progress in reducing their environmental impact and enhancing social value. Through the integration of advanced analytics, domain-specific knowledge, and structured assessments, the tool represents a valuable asset in guiding industry toward a more sustainable and digitally intelligent future.

As a part of the CLARUS project, a Sustainability Maturity Assessment was carried out, which included an evaluation of the Food Supply Chain function using the SCOR model. A supply chain can be understood as a network of facilities involved in producing raw materials, converting them into intermediate and final products, and distributing those products to end customers [3]. The SCOR (Supply Chain Operations Reference) model, developed by the Supply Chain Council (now integrated into APICS/ASCM), is a widely adopted framework for assessing and enhancing supply chain performance. It offers a structured methodology to analyze and improve operations, organized around five key management processes: (i) Plan, (ii) Source, (iii) Make, (iv) Deliver, and (v) Return.

When properly managed, the integration of food production into the supply chain can generate added value, giving security and integrity to both the producer and the consumer through the close coordination of activities along the supply chain.

The food supply chain is a complex process that must guarantee and manage the approval of raw materials, moving from storage in the warehouse to the supply of the various production departments. At the same time, it must also manage the packaging of the goods and ensure the correct transport flow throughout the distribution network. The evolution of consumer preferences as well as the increasing presence of competing companies operating in the Food Industry, has led to an exponential growth in the offer and variety of available food products, also forcing the supply chain flow to adapt to distribution needs through the increase in delivery frequency and the search for a high service level.

Therefore, it became essential to ensure and rely on a careful planning process. Within supply chain processes, we can identify fundamental aspects related to technology, like Internet of Things (IoT) and Big Data, through which it is possible to obtain a whole series of real-time information that can be used to optimize Supply Chain models and implement improvements accordingly. Moreover, a growing attention has been posed to sustainability aspects in food supply chains, like the need to decrease food waste or develop more sustainable production processes. In this context, the adoption of technologies can be used to enhance and foster the sustainability in the food supply chain.

The purpose of this Sustainability Maturity Assessment for the CLARUS project is to (i) assess the current situation in terms of sustainability for manufacturing companies operating in the food industry; and (ii) guide and consult them in order to improve their overall sustainability thanks to the implementation of digital solutions.

3. Sustainability Maturity Assessment Model and Road Mapping Tool

The developed sustainability road mapping tool guides users through a step-by-step process that evaluates their sustainability performance across various dimensions (economic, environmental, social) and provides targeted recommendations for strategic improvement. The process combines expert input, ontology-driven reasoning, data sharing architecture, and AI-based forecasting.

Below are the six main pillars of the tool:

3.1. Survey

3.1.1. Purpose

The objective of the survey is to assess the current positioning of companies operating in the food industry, in order to identify the gaps to a target scenario.

3.1.2. Methodology

The survey consists of 3 sub-surveys designed to tackle (i) sustainability aspects alone, (ii) technology aspects alone, and (iii) technology with sustainability aspects simultaneously. The choice of articulating the survey into three alternative sub-surveys lays in the fact that we are interested in capturing any possible scenarios, including those companies that have a certain level of sustainability (or digital) maturity, but have not implemented any digital (or sustainable) solutions yet. In this way, the survey can be better suited to a more specific scenario. As a result, CLARUS solution could target and benefit any of the aforementioned scenarios.

Each sub-survey develops a set of questions for each step of the SCOR model. Results are organized following the «Maturity model» approach, to identify, for each company, the level of maturity concerning sustainability alone, technology alone, and technology with sustainability (results can also be analyzed on an aggregate level, e.g., by geography). Questions are answered on a 5-point Likert scale (e.g.: not at all/never; low/sometimes, medium, high/often, very high/always). When suitable/applicable, questions are developed on a 5-point scale based on percentage (e.g., "Do your suppliers combine the use of virgin materials with recycled ones?" Range of answers: 0% - between 1% and 10%, etc.). When a higher level of clarity is needed, examples are added to guide the interviewees and better detail the question. Also, when needed, the «N/A» option is offered to respondents. The survey is reported in the Appendix.

The survey is built following the steps of the SCOR-Model. The SCOR model contains:

•Processes

- Standard descriptions of management processes
- A framework of relationships among the standard processes

•Performance: Standard metrics to measure process performance

•Practices: Management practices that produce best-in-class performance

•People: Training and skills requirements aligned with processes, best practices, and metrics

(i) Plan process

It refers to the Demand and Supply planning, following two main sub-processes:

- Operational process: assess supply resources, aggregate and prioritize demand requirements, plan inventory, distribution requirements, production, material, and rough-cut capacity for all products and all channels

- Manage planning infrastructure: make/buy decisions, supply-chain configuration, long-term capacity and resource planning, business planning, product phase-in/phase-out, manufacturing ramp-up, end-of-life management, product-line management

(ii) Source process

It refers to two main activities:

- Sourcing/material acquisition (execution): as obtain, receive, inspect, hold, and issue material

- Manage sourcing infrastructure: vendor certification and feedback, sourcing quality, in-bound freight, component engineering, vendor contracts, initiate vendor payments

(iii) Make process

- Production execution: request and receive material, manufacture and test product, package, hold and/or release product

- Manage make infrastructure: engineering changes, facilities and equipment, production status, production quality, shop scheduling/sequencing, short- term capacity

(iv) Deliver process

- Delivery execution:

- Order management: enter and maintain orders, generate quotations, configure product, create and maintain customer database, manage allocations, maintain product/price database, manage accounts receivable, credits, collections and invoicing
- Warehouse management: pick, pack and configure products, create customer specific packaging/labeling, consolidate orders, ship products
- Transportation and installation management: manage traffic, manage freight, manage product import/export, schedule installation activities, perform installation, verify performance

- Manage deliver infrastructure: manage channel business rules, order rules, manage deliver inventories, manage deliver quality

(v) Return process

- Return execution:

- Source return: return of defective or excess goods to the supplier
- Deliver return: return of defective or excess goods from the customer

3.1.3. Scoring system

The maturity model

The SCOR model can be used in combination with the maturity model, which is an instrument that can be used by the companies for self-assessment. We used the SCOR approach to assess the maturity level of the company's supply chain (in terms of sustainability alone, technology alone, and technology with sustainability (corresponding to the 3 sub-interviews developed). We define five levels of analysis (corresponding to the five SCOR processes: Plan, Source, Make, Deliver and Return) and five stages of maturity (corresponding to the answers collected on a 1-5 Likert scale).

For each SCOR process, a final rate is evaluated as average of the survey results to assess the current maturity level for that process and that company. The maturity model can be used to define directions of improvement by comparing the "as-is" situation with the "to-be" (desired) situation.

3.2. Green Deal Performance Assessment

The Green Deal Performance Assessment (GDPA) is a quantitative tool developed to guide the identification of the most relevant environmental sustainability KPIs based on the responses collected through the structured survey mentioned earlier. By analyzing survey data, the GDPA determines key indicators that align with the objectives of the European Green Deal and provides a consistent approach to evaluating environmental aspects of products and processes. It incorporates recognized methods such as Life Cycle Assessment (LCA), nutritional-LCA, CEPA, and others, ensuring alignment with GRI standards and the specific requirements of the CLARUS project. The GDPA is built to be scalable, adaptable, and compatible with emerging AI and Data Space frameworks, making it a reliable starting point for data-driven environmental performance monitoring in the agri-food sector and related industries.

3.2.1. Objective

As thoroughly explained in D1.2, task 1.2 has focused on the identification and definition of quantitative environmental sustainability metrics, methodologies and KPIs for sustainability assessment of food manufacturing systems involved in the CLARUS project, to be integrated into a unique Green Deal Performance Assessment (GDPA) methodology. The GDPA methodology is defined as a quantitative metric able to deliver a final index: the Green Deal Index (GDI). The GDPA methodology has been built therefore as an overall quantitative methodology able to quantify different environmental sustainability performances of food processes.

According to the state-of-the-art quantitative methodologies to evaluate environmental sustainability metrics in food industries and according to the different requirements and perspectives to include in the GDPA development (i.e., Green Deal, GRI, and CLARUS pilot's requirements), the main characteristics of GDPA methodology are:

- Quantitative methodology
- Focused on the environmental performance of products and processes
- Coherent with the methodology requirements
- To be developed in accordance with AI and Data Space requirements
- Suitable for CLARUS
- Scalable and replicable outside CLARUS

According to these characteristics and requirements, the quantitative metrics, and methodologies available in the literature and selected to be integrated into GDPA as illustrated in Figure 2:

- **Life Cycle Assessment (LCA)** – for a comprehensive evaluation of environmental impacts across a product's entire life cycle
- **Nutritional Life Cycle Assessment (n-LCA)** – which combines nutritional value with traditional LCA to assess the environmental cost per nutritional benefit
- **Circular Economy Performance Assessment (CEPA)** – to measure resource efficiency and circularity in production and consumption processes
- **Energy Modeling (EM)** – for analyzing energy flows and identifying areas for efficiency improvement
- **Water Management (WM)** – to evaluate water usage and conservation strategies
- **Thermoeconomic Analysis (TME)** – to assess the economic efficiency of energy systems and resource use.

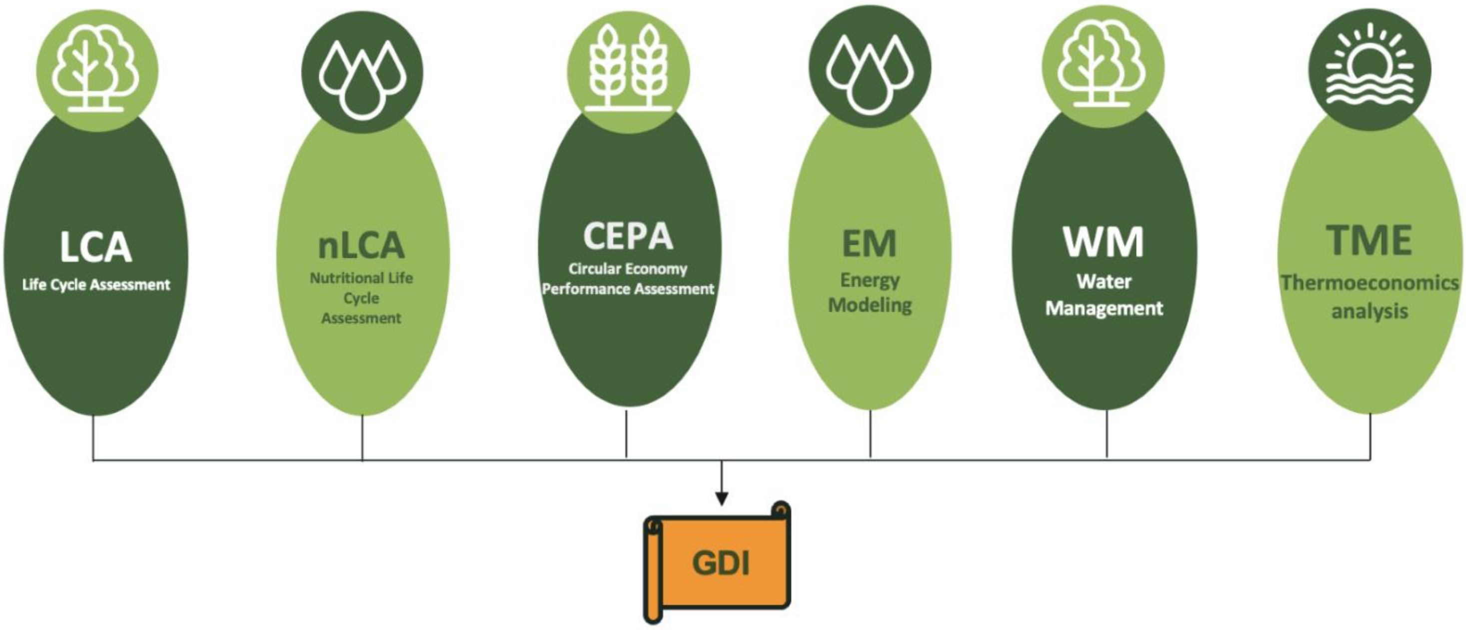

Figure 2 Available methodologies included in the development of GDPA

3.2.2. Environmental Sustainability Indicators aggregation

This phase revolves around evaluating environmental sustainability performances and identifying all the indicators that can be potentially calculated, starting from the metrics mentioned in the previous section. Starting with these indicators, and according to the survey's data and client's specific needs, a sub-set of indicators of interest to consider will be/is determined.

In general, the GDPA's scalability could be the key for the integration of categorically different sustainability indicators, which would be the key for a comprehensive GDI metric. The sustainability indicators could be:

- **Environmental**:
  - Energy consumption
  - CO_2 emissions
  - Water usage
  - Waste generated
- **Social**:
  - Training hours per employee
  - Accident rate
  - Workforce diversity index
- **Governance**:
  - ESG reporting compliance
  - Audit frequency
  - Supplier ESG score average
- **Digital Capability**:
  - Number of connected assets
  - Sensor coverage ratio
  - Data availability score

Although only environmental sustainability indicators were of interest to the pilots within the CLARUS project, but the comprehensiveness of the developed survey along with the scalability of the GDPA methodology would be the key for an all-round GDI metric as an output of the CLARUS consulting services. In Figure 3, a list of the final list of indicators selected for the ARDO pilot and assigned to different hierarchy levels (to be explained in the following sections) is provided as an example of the expected outcome.

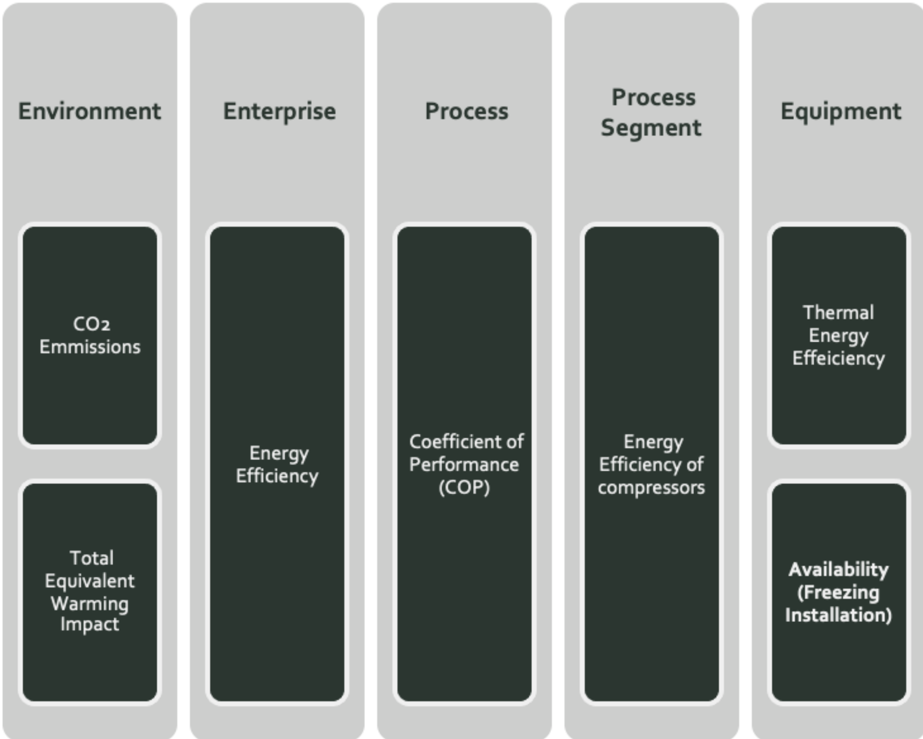

Figure 3 An example of a final list of indicators selected for ARDO pilot

3.3. Green Deal Ontology (GDO) Development

The Green Deal Ontology (GDO) is developed to create a semantic map that connects physical assets, such as equipment and sensors, with selected sustainability indicators, enabling traceability, full interoperability, and scalability of environmental performance assessment. Additionally, the GDO is pivotal for establishing a unified language across diverse case studies and potentially disparate industries. Briefly, as this outcome will be thoroughly explained in D5.4, GDO represents a set of representational primitives to model the environmental sustainability domain of knowledge created by the Green Deal Performance Assessment (GDPA) methodology, developed in WP1. The representational primitives will be classes, properties, and relationships necessary and useful to gather environmental sustainability data and allow the calculation of the Green Deal Index (GDI). The new Green Deal Ontology will allow for modeling knowledge about environmental sustainability data and performances in the food engineering domain.

The PO2/TransformON has been selected as the reference ontology for the Green Deal Ontology. PO2/TransformON is an available ontology created to solve the problem of data harmonization in the domains of food, feed, bioproducts, and biowastes engineering in a circular bioeconomy and nexus-oriented approach [5]. This ontology is based on the representation of a generic process according to the PO2 (Process and Observation Ontology) core model, which has then been further specialized to the food engineering domain with the vocabulary necessary to describe any biomass transformation process and to characterize the food, bioproducts, and wastes derived from these processes.

By providing context and purpose to data, the ontology allows for enhancement of knowledge interpretability and reusability. The ontology structure includes key classes such as *Equipment*, *Sensor*, *Indicator*, *Process*, and *Location*, with logical relationships like:

- measuredBy (Sensor, Indicator): the sensor measures an indicator
- monitors (Sensor, Equipment): the sensor monitors specific equipment
- contributesTo (Process, Indicator): a process contributes to an indicator
- locatedIn (Equipment, Location): equipment is located in a specific place.

Regarding the benefits of the GDO, it could be utilized in 2 different contexts:

- **Knowledge Reuse for Similar Processes** - Companies with similar processes to pilot cases can:
  - Discover relevant sustainability KPIs
  - Understand where input data is collected (e.g., equipment, process step)
  - Get insight into how processes impact sustainability

- **Methodological Guide for New Scenarios** - For companies with different processes:
  - Acts as a template to formalize new KPIs
  - Offers a structured approach to sustainability modeling
  - Promotes interoperability and comparability

To sum up, the GDO is intended to:

- Model environmental sustainability data and performance in the food engineering domain
- Formalize the necessary data for the computation of the sustainability indicators
- Allow standardization and replicability of the GDPA and GDI in other industrial contexts outside and beyond CLARUS
- Enables knowledge reuse, improving scalability and long-term value through the modeling of new scenarios

An example of the classes, instances, and relationships of GDO is provided in Figure 4.

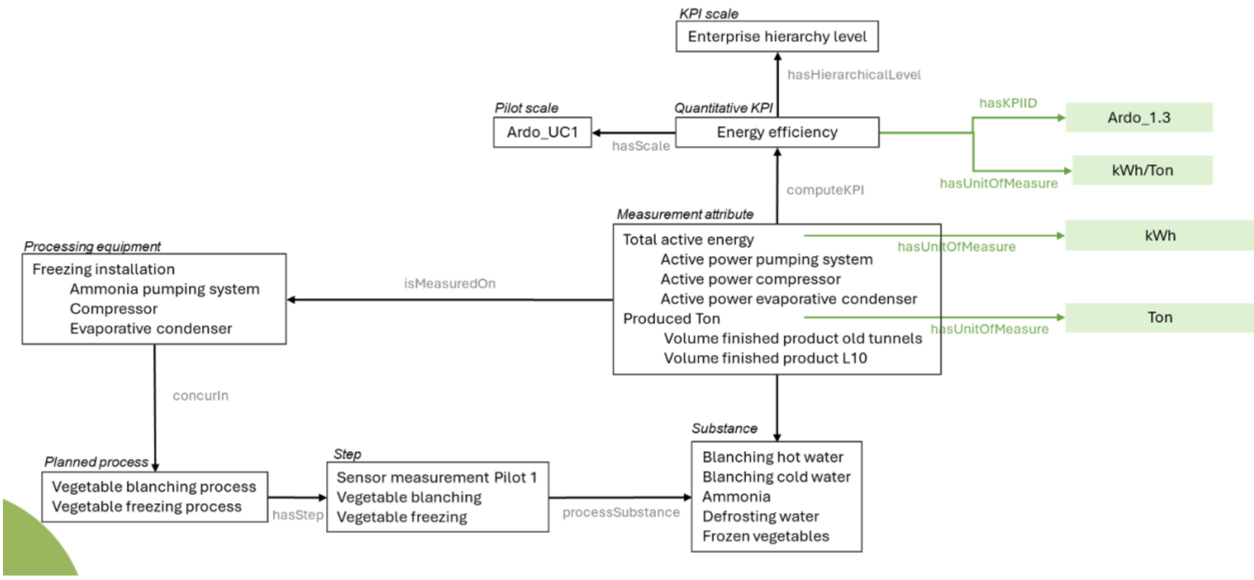

Figure 4 An example of GDO scheme - ARDO

Undoubtedly, such schemes can add a great value within CLARUS consulting services as it could help the clients clearly understand how similar/different processes were semantically modelled so they can relate to their own case, thus easily identifying the key performance indicators (KPIs) relevant to their operations, determine which sensors are needed for monitoring, and understand how each process contributes to environmental goals. This level of transparency and traceability supports more informed decision-making and smoother integration of AI models in sustainability-driven manufacturing.

3.4. Green Deal Index (GDI) Development

Following the explanation of both the GDPA and the GDO, it is important to clarify how both are jointly used to support the identification of relevant sustainability data and the calculation of key performance indicators (KPIs) as elaborated in Figure 5. While the GDPA provides a structured methodological framework to guide the assessment process, the GDO enables semantic linking between physical assets, processes, and sustainability indicators, thus helping consultants and company representatives work together on determining the most relevant indicators as well as having a clear idea about the types of equipment and associated sensors that would be needed to move forward. Their integration could also open the door for an automated selection and aggregation of indicators through AI-based tools and data models in the future. Starting from the current state of a company (AS-IS), this approach supports the simulation and evaluation of future improvement scenarios (TO-BE), ultimately enabling the calculation of the Green Deal Index (GDI), which represents the final goal of the assessment process.

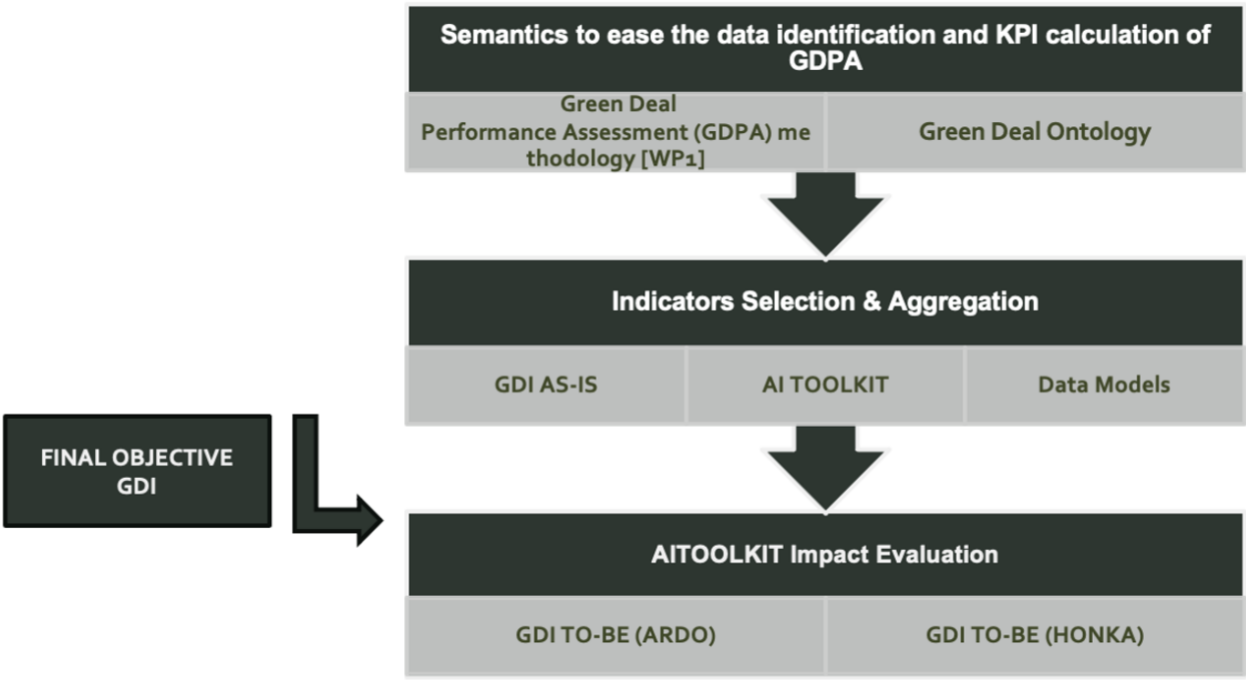

Figure 5 The relationship between GDPA, GDO, and GDI

3.4.1. GDI – AS-IS Aggregation Process

The Green Deal Index (GDI) is a comprehensive metric created to quantitively evaluate the sustainability performance of companies or production systems in alignment with the principles of the European Green Deal. Instead of focusing solely on single environmental indicators, the GDI aims to provide a holistic view of sustainability by aggregating various Key Performance Indicators (KPIs) that address environmental, economic, social, and operational dimensions. These KPIs may include metrics related to energy consumption, greenhouse gas (GHG) emissions, circularity, and resource efficiency. The GDI calculation process follows a sequence of steps: starting with the identification of relevant indicators through methodologies like the Green Deal Performance Assessment (GDPA) and semantic tools like the Green Deal Ontology (GDO), followed by the aggregation and weighting of these indicators using structured approaches such as the Analytical Hierarchy Process (AHP). The GDI allows benchmarking between the current state (AS-IS) of an enterprise and target scenario (TO-BE), which can be generated using the predicted values of the indicators through the deployment of the AI toolkit. By providing an integrative, interpretable score, the GDI supports strategic decision-making, fosters transparency in sustainability reporting, and facilitates the prioritization of actions to meet European climate and sustainability goals. Ultimately, the GDI not only helps companies monitor their environmental footprint but also empowers them to identify impactful areas for improvement, thus driving continuous progress toward greener operations.

In the next section, the GDI aggregation process will be briefly explained (to be explained in detail in D5.4):

The aggregation process, as illustrated in Figure 6, consists of structured steps that lead to the calculation of the final Green Deal Index, an indicator summarizing sustainability performance. The steps are:

1. **Identification of Indicators:** Indicators are selected using the Green Deal Performance Assessment methodology and supported by the Green Deal Ontology (GDO). These indicators represent various aspects such as environmental impact, resource use, digital maturity, etc.
2. **Selection of Relevant Indicators per Client:** Each client identifies the most applicable indicators for its context, ensuring that only relevant data is used.
3. **Grouping of Indicators:**

   Indicators are organized into **multi-levelled hierarchy** such as:

   - Environmental
   - Enterprise
   - Process System
   - Process Segment

- Equipment

  This helps in structuring the analysis across various levels of the production or decision-making system.

4. **Weighting Indicators (AHP):** At this stage, the Analytic Hierarchy Process (AHP) is used to assign weights to the indicators.
5. **Normalization (Distance to Target):** The performance of each indicator is normalized based on the distance between current and target values. This makes indicators comparable even if they use different units or scales.
6. **Data Collection:** This includes gathering the actual current values and target benchmarks for all selected indicators. These values feed into the normalization step.
7. **Calculation of Sub-Indices:** For each group (e.g., environment, process), a sub-index is calculated using the normalized values and the weights from the AHP.
8. **Final Aggregation to Green Deal Index:** All sub-indices are combined to form the final Green Deal Index according to the equation below, a single number representing the sustainability performance of the system.

GDI_AsIs = Σ (Weight_i × Indicator_i_normalized)

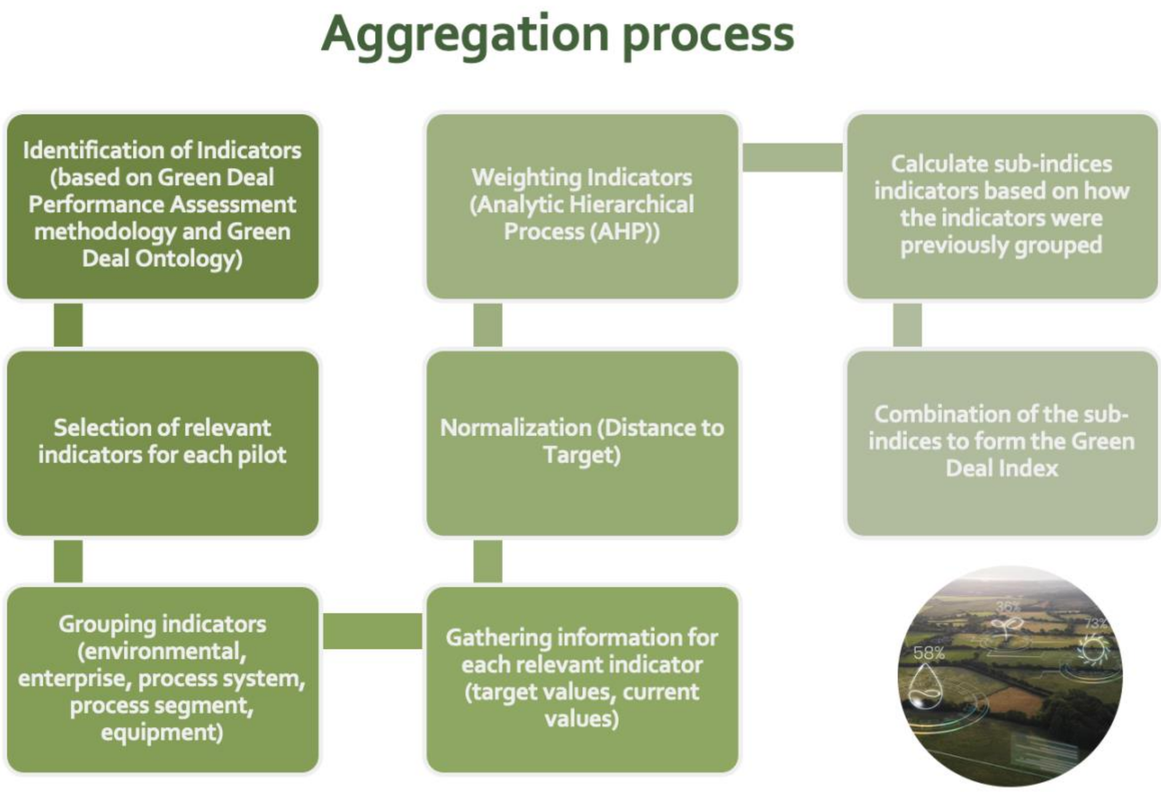

Figure 6 The GDI Aggregation Process

As mentioned in step 4, the aggregation process is supported with AHP process in which the client, with the assistance of the consultant, is asked to assign weights to different indicators and hierarchy levels (1 = equal importance, 3 = moderate importance, 5 = strong importance, 7 = very strong importance, 9 = extreme importance). This comes after the consultant's definition of the decision-making objective and the different hierarchical levels of indicators.

The Analytic Hierarchy Process (AHP) is briefly a structured decision-making method used to prioritize and evaluate multiple criteria based on expert judgments. In sustainability assessments, AHP can be employed to assign relative weights to different indicators—such as emissions, energy use, or digital maturity—based on their perceived importance [6]. By decomposing complex decisions into a hierarchy and applying pairwise comparisons, AHP provides a transparent and consistent way to aggregate expert input and guide data-driven evaluations.

	Compressor thermal energy efficiency	Freezing installation availability	Water pumps availability
Compressor thermal energy efficiency	1	2.80	4.40
Freezing installation availability	0.36	1	2.60
Water pumps availability	0.23	0.38	1

Figure 7 A demonstration of the AHP matrix the client is expected to fill – Equipment Level

The expected outcome of this process is a Graffana dashboard presenting the main insights, the composite GDI indicator and a breakdown of the impact of different indicators as shown in Figure 8.

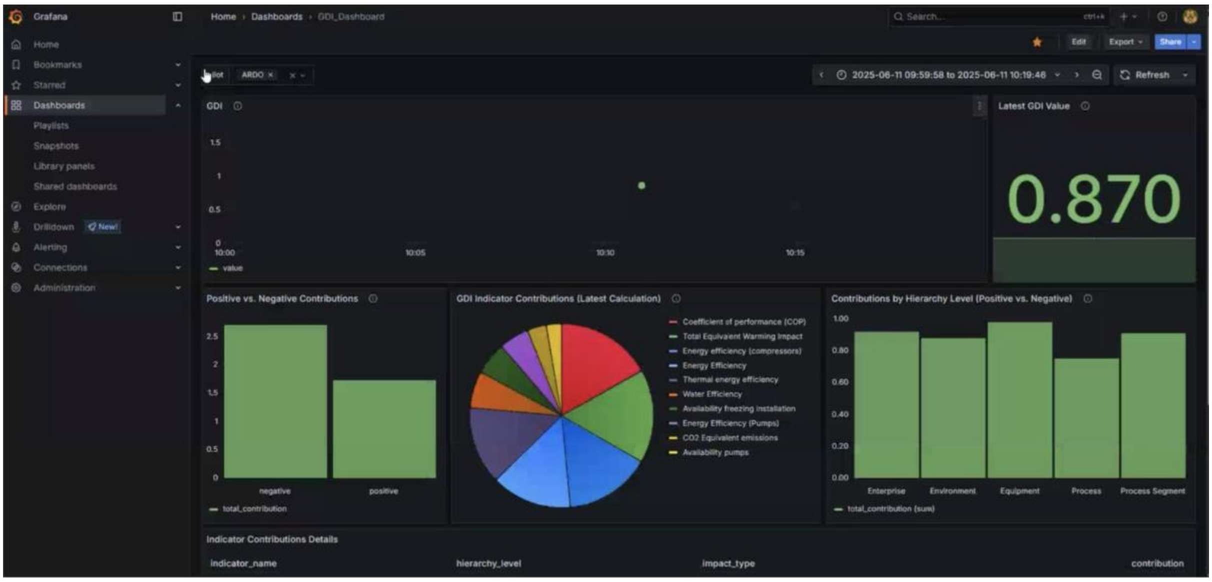

Figure 8 A Graffana dashboard presenting the outcome and main insights of the aggregation process

Based on the first iteration of the GDI aggregation process (GDI-AS-IS), which is computed prior to the application of the AITOOLKIT, a road-mapping table of potential improvements in the short, medium, and long term planning periods will be developed as demonstrated in Table 1

	Ease of Implementation	Margin of Improvement	Potential Impact
Improve KPI1	***	10%	High
Improve KPI2	****	5%	High
Improve KPI3	*****	10%	Medium
Improve KPI4	***	5%	Low

Table 1 Road mapping Table Example

To ensure a coherent CLARUS architecture, the relationship between different project outcomes will be explained. In this regard, the relation is represented in an iterative form where CLARUS Data Space feeds the CLARUS AI TOOLKIT with the needed data for training and validating the AI models. Then, the CLARUS AI TOOLKIT will optimize the processes and operations of the client. Afterward, the CLARUS client will provide the data to the CLARUS Data Space including metrics and KPIs. Finally, the process repeats itself while the overall performance of the client improves. In order to provide a governing element on the cycle, the CLARUS Green Deal Index (presented in Figure 9) will interact with each pillar of the project. In more detail, the CLARUS GDI will process and analyze the data in the CLARUS Data Space. This processing and analysis will be done by the CLARUS AI TOOLKIT. Finally, the CLARUS GDI will interact with the client to provide the indexing and ranking feature to drive the improvements towards Green Deal friendlier process and operations.

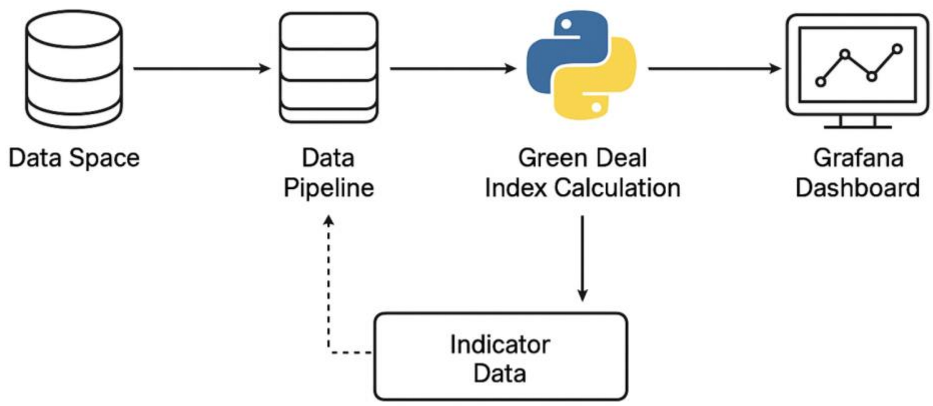

Figure 9 Overall CLARUS Architecture

3.5. Data Space

3.5.1. Objective

This phase of CLARUS is seen as the enabler infrastructure to execute and validate project objectives, and key baseline for the development activities, including data services (edge and cloud, as per client demand) and tools (mainly for data harmonization and AI analytics and results). Its main objectives include providing a centralized and secure data sharing, interoperability between different systems, feeding data to AI TOOLKIT, and ensuring data trust and compliance.

3.5.1. Data Requirement

Expectedly, based on the CLARUS use cases, there are multiple sources of data in different formats. So, once a data model is decided, this phase prioritizes the generation of the client's system map as demonstrated in Figure 10. The system map highlights the data flow between the client's users, cloud systems (if exists), and the field.

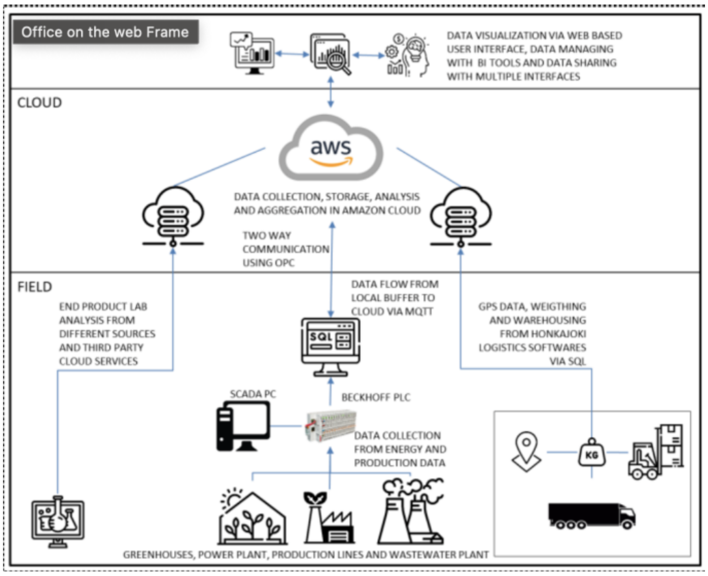

Figure 10 A demonstration for a system map - Honkajoki

Followingly, historical data are provided by the client as (i.e., excel worksheets containing data or a cloud server) to enable the initiation of the edge side data transformation and harmonization to combine multiple data sources into yearly historical files or a single dataset beside removing unnecessary data columns and rows with missing data. The final outcomes of the process are clean and clear datasets ready to be registered and transferred through the IDS connectors.

The data processing is performed using pandas and datetime libraries as well as math functions. The data processing processes depend on the types of datasets. The most common data processing processes are:

- **Column selection:** Columns with necessary data for training are selected to reduce memory size of datasets.
- **Timestamp conversion:** Timestamps are converted to ISO format.
- **Column renaming:** Columns are additionally renamed to allow users to examine the datasets.
- **Data classification & aggregation:** The raw datasets contain sensor readings at irregular intervals. Thus, in order to form complete datasets, which include synchronized sensor data, it is necessary to aggregate the raw data with specific intervals.
- **Dataset concatenation:** Individual sensor datasets are concatenated and synchronized by using timestamp columns.

3.5.2. Architecture

In this stage, the service prioritizes the development of the data architecture to structure and govern the full data lifecycle across CLARUS starting from data collection from manufacturing sources, to secure sharing, to analytics, and ultimately to sustainability-oriented outputs like the AI Toolkit and Green Deal Index. Within CLARUS, the reference architecture is The International Data Spaces Association (IDSA), created by the evolution of IDS (Industrial Data Space), which itself was an initiative lead by Fraunhofer ISST and promoted by the German Federal Ministry of Education and Research. IDSA is characterized by the focus on information ownership, with the aim of enabling clear and FAIR exchanges between data providers and consumers. To this end it suggests a reference distributed architecture that accomplishes this goal: the IDS Reference Architecture Model Version 4 [1].

The IDS Reference Architecture Model positions as an architecture that links different cloud platforms through policies and mechanisms for secure data exchange and trusted data sharing (through the principle of data sovereignty). Over the IDS Connector, industrial data clouds, individual enterprise clouds, on-premises applications and individual, linked devices can be connected to the International Data Space ecosystem.

The main goals of IDSA are research activities, standardization activities, and activities for the development of products and solutions for the market, while the list of the main strategic requirements deals with issues such as trust, security and data sovereignty, data ecosystems, and standardized interoperability.

The structure and functional design of the IDS reference architecture (reference model) is composed by five layers as shown in Figure 11.

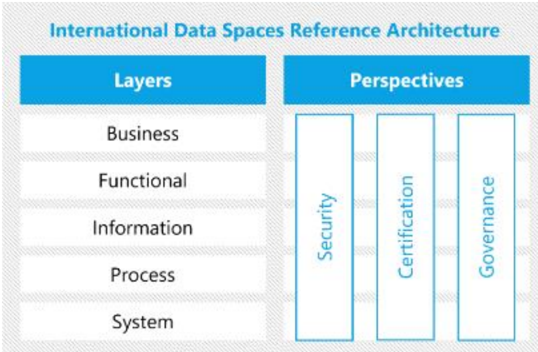

Figure 11 Structure of IDS reference Architecture

The Business Layer of the IDS defines the roles that participants in International Data Spaces can have, and the patterns of interaction between these roles. The Functional Layer defines the function requirements of the International Data Spaces and the features to be implemented, without considering the technological nature of the applications independently. The Information Layer specifies the information model of the reference architecture or the domain-independent common language representing the vocabulary of International Data Spaces. The Process Layer defines the specifics of the interactions between the different components of the International Data Spaces. It therefore deals with offering a dynamic vision of the reference architecture model, as well as the main processes and related sub-processes to the reference architecture. The System Layer contains the technical core components of IDS-RAM Reference Architecture, representing the reference implementation in terms of services and technologies. The main IDS reference implementation components are:

- Identity Provider (CA, DAPS and ParIS),
- IDS Connector,
- App Store and Data Apps,
- Metadata Broker,
- Clearing House,
- Vocabulary Hub.

3.6. AI TOOLKIT

3.6.1. Objective

The AI TOOLKIT in the CLARUS project is developed to support food manufacturing companies in enhancing their sustainability and operational efficiency through advanced data analytics and machine learning. It integrates various AI methods to analyze real-time and historical production data, enabling energy consumption forecasting, and resource optimization. By leveraging AI algorithms, the toolkit helps identify inefficiencies and environmental impacts within production processes, providing actionable insights for decision-making. This modular and user-friendly system facilitates the digital transformation of SMEs by simplifying complex data analysis and supporting sustainability goals aligned with Industry 4.0 principles.

3.6.2. Workflow

The development of the AI TOOLKIT follows a sequence of activities:

- Data Collection & Processing: Explained in the previous section
- Model (re-)training and validation: The MLOps infrastructure houses the training data. Various training experiments are automatically preset, and models are trained employing different structures and hyper-parameters. The models are then evaluated and those with superior performance metrics are chosen for deployment.
- Model packaging and deployment: Models are packaged and distributed using a docker image that uses FastAPI to offer model inference functions to outside services. The model and docker image are distributed separately, using MLFlow APIs to update the model and ensure that the latest, most efficient version is in use.
- Model inference: Based on the available training datasets, models are trained to detect anomalies and predict energy consumption and efficiency.
- Model monitoring for concept drift detection: Finally, model performance is monitored and in case the model performance deviates from target, models are re-trained to ensure long term performance.

3.6.3. Algorithm Selection

The current objective is to provide guide that companies can follow to integrate AI and to optimize the resource consumption of manufacturing systems.

The Guide designed consists of the following 9 steps:

- **System Definition and Initial Assessment**
  - **Initial assessment of the manufacturing system's performance and resource consumption:** Assess the company's current performance in terms of resource

consumption and identify areas for improvement, focusing on inefficiencies and comparative market analysis.

- **Define the system**: Identify the manufacturing plant, production line, facility, machine, or installation that from the initial assessment proved to be critical in terms of resource consumption.
- **Set clear objectives:** Determine the most critical resources to target for optimization, whether it is water, energy, CO_2 emissions, or a particular raw material. Prioritize these resources based on industry knowledge, considering factors such as current industry focus and exploration levels. For example, water optimization might be less explored compared to energy efficiency in the industry's current landscape. Additionally, it is important to set also quantitative objectives in a time-plan.

- **Specific Problem Identification**
  - **Data Collection and Analysis:** Gather relevant data on the identified system operation and analyse historical data to identify patterns, trends, and inefficiencies in the system's performance.
  - **Define the specific problems:** Identify root causes of energy, water, or other resource inefficiencies. To provide an example, the energy inefficiency within a production line, for instance, may stem from various issues such as maintenance gaps, material wastage, suboptimal scheduling, or inefficient resource consumption planning. Each specific problem should be analysed solely to ensure comprehensive understanding and targeted resolution.

- **AI Task Association**
  - Identification of the AI task for each specific problem, this can regard both triggering and reasoning tasks to be further elaborated later.

- **AI Methods and Algorithms Selection**

After identifying the role of AI for each specific problem, the next step is the selection of the potential methods to address the problem. The common AI algorithms are shown in Figure 12

- **AI Task-Related algorithms**: Tailor the algorithm selection for the specific AI task. For example, for optimization tasks, consider algorithms specifically correlated with optimization. For tasks where defining all associated algorithms is challenging, such as anomaly detection, a broader selection of ML algorithms may be appropriate.
- **Resource Type**: Specify the resource being targeted for efficiency improvement, such as material, water, CO_2, or energy.
- **Industrial Application**: Define the specific industrial context or application area of the specific problem.

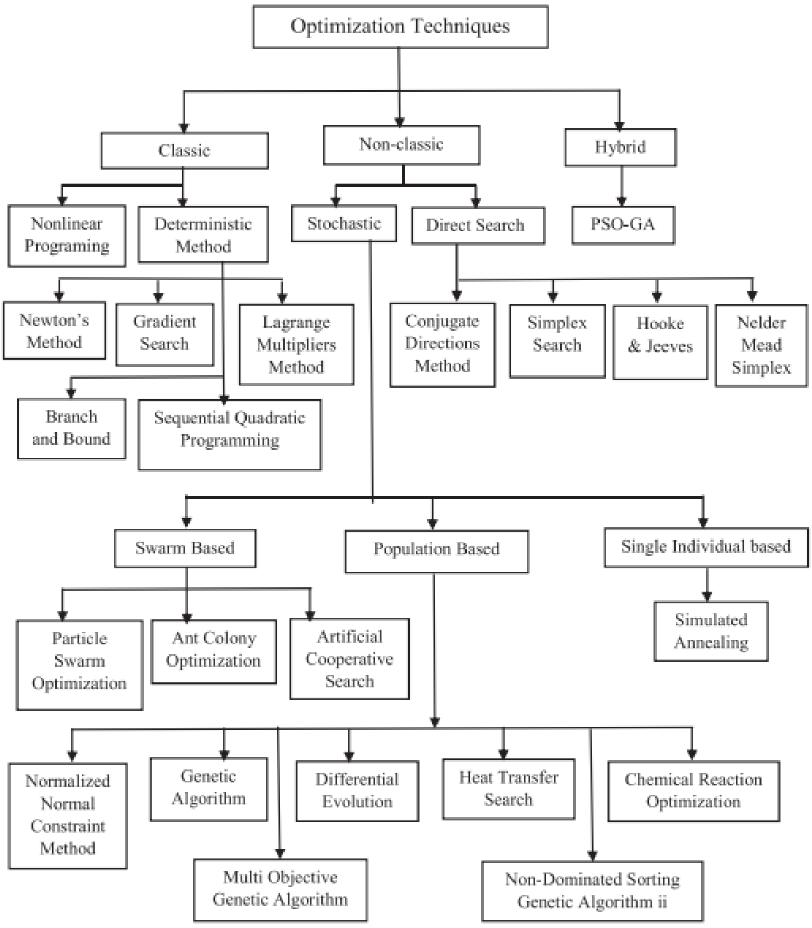

Figure 12 Common AI Optimization Techniques in the Food Manufacturing Sector

- **BUILD: Initial Algorithm**

This phase involves creating an initial version of the algorithm, the selection of one algorithm instead of another in the company will take into consideration several parameters, including the available data, domain expertise within the company, scalability, and robustness.

- **MEASURE: Algorithm Testing**

After building the algorithm, it needs to be evaluated using metrics and Key Performance Indicators (KPIs). The selected AI algorithm can be applied to a small scale or in a controlled environment to monitor the algorithm's performance and gather feedback from stakeholders to assess its effectiveness and identify areas for improvement.

The integration of the algorithm at full scale is not straightforward; it requires several actions that necessitate a comprehensive implementation plan. The main steps include:

- Definition of resources required and a timeline for the implementation

- Identification of key stakeholders, budget, and manpower allocation
- Infrastructure setup: To integrate an AI system, a company should have the infrastructure to support that such as hardware, software licenses, cloud computing resources, and data management systems.
- Collaborate with IT teams and software developers to ensure seamless integration and compatibility with existing infrastructure.

- **LEARN: Monitoring and Optimization**

Based on the measurements obtained in the previous phase, insights are gained to understand how well the algorithm is performing and where improvements can be made. This phase can involve modifications of the algorithm or even exploring alternative algorithms.

- Use real-time data analytics to identify opportunities for further optimization and fine-tuning of the algorithm parameters.
- Provide training and support to employees responsible for operating and maintaining the system.
- Transfer knowledge about the AI algorithm and its capabilities to ensure effective utilization and ongoing management.

After completing one cycle of the Build-Measure-Learn loop, the process iterates, with adjustments made to the model based on the insights gained in the previous iteration. This iterative approach allows for continuous improvement and optimization of the algorithm over time. At the same time, the company can learn and build an organization that is able to embrace this newly integrated technology.

- **Continuous Improvement and Innovation**

- Foster a culture of continuous improvement and innovation within the organization to drive further enhancements for resource efficiency.
- Stay informed about advances in AI technology and best practices in the food processing industry to explore new opportunities for optimization.

- **Evaluation and Reporting**

- Regularly evaluate the impact of the AI algorithm on the KPIs defined and overall system performance when possible.
- Prepare reports and presentations to communicate results, lessons learned, and recommendations to key stakeholders and decision-makers.

The steps can be summarized in Figure 13

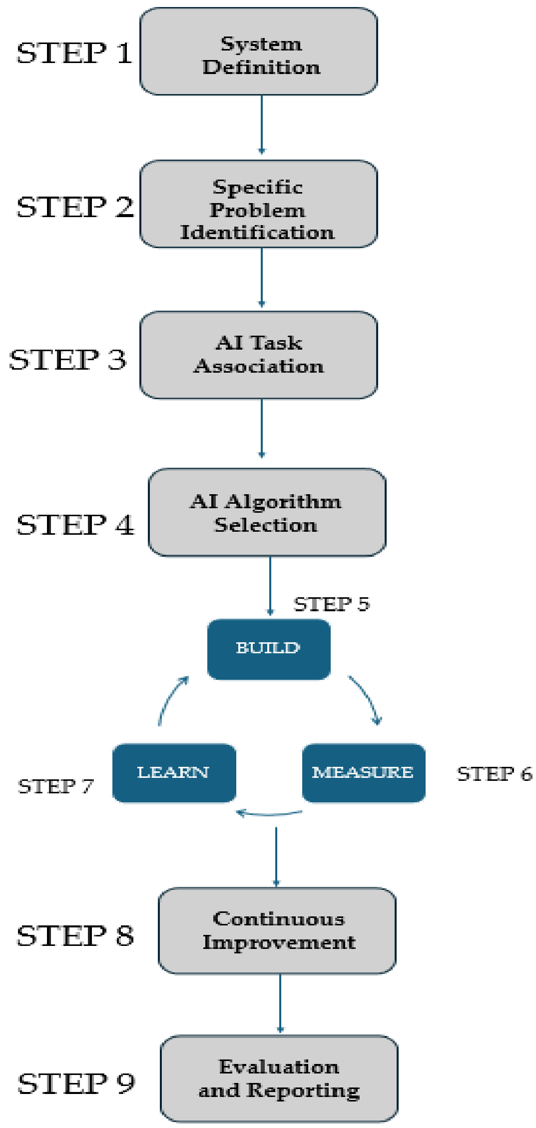

Figure 13 Algorithm Selection Workflow

3.6.4. Model Training & Validation

Training and validating machine learning models necessitate well-structured datasets which reflect the changes in all monitored variables over time, such as temperature, pressure, and other potentially relevant parameters. To streamline this extraction process, TimeScaleDB's advanced capabilities could be utilized for handling time-series data.

At the time of writing, the following machine learning tasks are considered:

- **Time series forecasting:** In the context of CLARUS, time series forecasting models can predict future values of critical variables, such as temperature, pressure, energy consumption, or generated energy, based on historical data. These forecasts can be used to anticipate potential system anomalies or maintenance needs, to schedule downtime optimally, and to adjust the system to optimize performance ahead of predicted changes in the environment or load. Possible machine learning models for time series forecasting include Recurrent Neural Networks (RNNs), including Long Short-Term Memory (LSTMs), and autoML frameworks for time series like PyCaret. The performance of these models can be evaluated using metrics such as Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE), which measure the difference between the model's predictions and the actual observed values.

- **Survival Analysis:** Survival analysis allows predicting the risk of occurrence of an event in different time windows from the current time, where the event could be a system failure. As time series forecasting, survival analysis can help in proactively scheduling operations to minimize the occurrence of these events, thus enhancing the overall operational efficiency and longevity of the production system. These models can be evaluated using metrics such as the concordance index (C-index) or log-rank test, which measure the model's ability to correctly rank the order of events, or the Brier score, which measures the accuracy of the model's probability predictions.

Undoubtedly, other models could be deployed to build the AITOOLKIT, following specific requirements of the client.

3.6.5. Model Expected Outcome

The expected outcome of the AITOOLKIT is a Graffana dashboard for every selected sustainability indicator as shown in Figure 14.

Figure 14 A demonstration for the expected AITOOLKIT outcome - ARDO

3.7. GDI (TO-BE) Computation

3.7.1. Objective

The objective of the Green Deal Index (GDI) TO-BE in the CLARUS project is to provide a comprehensive and standardized measurement of the environmental and sustainability improvement provided by the AI TOOLKIT. Specifically, it aims to evaluate how effectively the AI Toolkit supports companies in reducing their resource consumption, lowering emissions, and improving overall sustainability performance. By quantifying the impact of AI-driven interventions, the GDI TO-BE helps validate the real-world benefits of the AI TOOLKIT and guides continuous improvement towards achieving green and circular economy goals.

3.7.2. Visualization

Similar to the GDI (AS-IS), the aggregation process is performed following the same flow of activities and using the same input provided by the client, except for the current values of the selected sustainability indicators, which are collected following the deployment of the AITOOLKIT this time. Thus, another Graffana dashboard will be designed to compare GDI (AS-IS) and GDI (TO-BE)

Indicator	Value	Weight	Level	Value	Weight	GDI
Average material age until tipping	80.6%	0.72	Process	80.5%	0.64	76.6%
Number of containers downgraded CAT2	80.0%	0.28				
Thermal efficiency (KPI 2.4)	84.8%	0.24	Process Segment	60.8%	0.36	
Electric efficiency (KPI 2.5)	90%	0.06				
Protein Consistency (KPI 2.6)	85.0%	0.21				
Material age until tipping (KPI 2.7)	0.0%	0.20				
CO_2 Equivalent Emissions (KPI 2.8)	90.0%	0.29				

Figure 15 A demonstration for the GDI (TO-BE) Computation Process

As shown in Figure 15, the results will be visualised in a traffic lights system (TLS) following the scheme illustrated in Figure 16.

Figure 16 GDI Traffic Light System

4. Conclusion and Next Steps

The primary objective of this task was to design and deliver a sustainability road mapping tool to be made available towards the conclusion of the CLARUS project. This tool was intended not only as a static repository of project outputs but as a dynamic decision-support framework, enabling companies to assess their current performance, identifying areas for improvement, and planning the adoption of innovative solutions developed within the project. To this end, the work focused on the integration of the project's core components: the Green Deal Performance Assessment (GDPA), the Green Deal Ontology (GDO), the Green Deal Index (GDI), the Dataspace, and the AI TOOLKIT.

In light of the complexity of grouping different technical outcomes into a single actionable tool, a reverse-engineering methodology was adopted. This process began with the creation of a comprehensive survey instrument designed to capture a company's "as-is" situation in two critical domains: sustainability performance and digital maturity. The survey served as the starting point of a client-personalized deep analysis, allowing the tool to establish a quantitative and qualitative baseline from which targeted improvements could be planned.

Once the primary assessment framework was completed, the CLARUS team reversely revisited and analyzed all relevant project outcomes in a logical sequence. To complement the work carried out throughout the project course, each component (GDPA, GDO, GDI, Dataspace, and AI TOOLKIT) was examined deepening its role within a coherent transition pathway instead of isolated deployment and testing. This ensured that the road mapping tool could function as a step-by-step guide for companies seeking to operationalize the CLARUS methodology, from initial assessment through to full deployment of advanced digital and sustainability solutions.

Particular emphasis was placed on the GDI "to-be" state, which acts as a measurable indicator of the CLARUS solution's performance following the application of the AI TOOLKIT. Within this context, the impact of the AI TOOLKIT including its capacity to provide advanced analytics and predictive models for resource optimization was explicitly integrated into the tool's long-term planning capability. This alignment enables companies to not only understand their current position but to forecast the benefits of adopting CLARUS technologies, thus reinforcing the business case for implementation.

The result of this process is a comprehensive, integrated, and adaptable framework that supports companies of different sectors in building actionable, time-phased sustainability and digital transformation roadmaps. The tool bridges assessment and execution, combining short-term feasibility with long-term strategic impact. It provides both the analytical foundation and the operational guidance required for organizations to progress from their current operational baseline toward a high-performance, low-impact future, fully aligned with the objectives of the European Green Deal.

5. Annex

Details of the Survey

Sustainability (Tot: 19 questions)

PLAN (5 questions)

1) Do you have a Sustainability Department / Responsible within your organization?

Not at all / Informally, but without a clear role / Partially, with some assigned responsibilities / Yes, a formal role exists / Yes, a fully structured department

2) Is your product designed to facilitate recycling/reuse and/or regenerative agriculture (i.e., enhance soil health and biodiversity)?

Not considered at all / Considered in a few aspects / Considered in some aspects / Considered in most aspects / Fully considered in the product design

3) Is your organization committed to internal sustainability initiatives (e.g., employee training, increasing employees' environmental awareness)?

No commitment at all / Some initiatives, but limited impact / Moderate commitment with ongoing efforts / Strong commitment with structured programs / Fully embedded in company culture

4) Do you employ a Key Performance Indicator (KPI) system to specifically measure also sustainability aspects?

No, not at all / Limited KPIs, but not systematically tracked / Some KPIs, but not prioritized / A structured KPI system with sustainability metrics / A comprehensive KPI system fully integrated with decision-making

5) Are you delivering a sustainability report / (voluntarily) disclosure of sustainability data?

No, never / Rarely, on an ad-hoc basis / Occasionally, but not consistently / Regularly, but not comprehensively / On a regular basis, consistently and comprehensively

SOURCE (4 questions)

1) To what degree does your company source raw materials from sustainable suppliers?

Not at all / To a small degree / To a moderate degree / To a high degree / To a very high degree

2) Are you actively engaged in collaborative activities with your suppliers to improve sustainability in the supply chain (e.g., joint eco-friendly product development, reduction and recycling practices, etc.)?

Not at all / Limited collaboration, with minimal joint initiatives / Some collaboration exists, but not systematically applied / Strong collaboration with structured sustainability initiatives / Fully integrated partnership with suppliers, actively driving sustainability improvements

3) How often does your company perform sustainability audits of its suppliers and/or recurr to independent audits of sustainability of suppliers?

Never / Rarely, on an ad-hoc basis / Occasionally, but not consistently / Regularly, but not comprehensively / On a regular basis, consistently and comprehensively

4) Are you involved in supplier development plans or engaged in local community projects (e.g., supporting coffee or cacao farmers, improving labor rights)?

Not at all / Limited engagement, with small-scale or occasional initiatives / Some involvement, but not a core focus of the strategy / Strong engagement with structured supplier and community programs / Fully committed, supplier development and local community projects are a strategic priority

MAKE (4 questions)

1) Do you employ clean/renewable resources in your production system?

Not at all / To a limited extent / Partially, but not a priority / To a great extent, with clear initiatives / Fully reliant on clean energy sources

2) How important is reducing food waste in your company's operations?

Not important / Slightly important / Moderately important / Very important / Extremely important

3) How frequently does your company review production processes to identify opportunities for energy/water or material efficiency?

Never / Rarely / Sometimes / Often / Always

4) Are you committed to workers' health and safety measures?

No commitment at all / Some measures exist, but they are not a priority / Standard policies in place, but with room for improvement / Strong commitment with structured programs / A top priority, fully integrated with continuous improvement

DELIVER (4 questions)

1) To what extent does your company/your 3PLs invest in renewable energy sources for its transportation (e.g., electric vehicles)?

Not at all / To a small extent / To a moderate extent / To a great extent / To a very great extent

2) To what extent does your company/your 3PLs optimize logistics (e.g., cargo consolidation, vehicle routing optimization) to reduce transportation emissions?

Not at all / To a small extent / To a moderate extent / To a great extent / To a very great extent

3) How effectively does your company manage inventory to minimize waste in the distribution phase?

Not effective / Slightly effective / Moderately effective / Very effective / Extremely effective

4) Are you/your 3PLs committed to drivers' health and safety measures?

No commitment at all / Some measures exist, but they are not a priority / Standard policies in place, but with room for improvement / Strong commitment with structured programs / A top priority, fully integrated with continuous improvement

RETURN (2 questions)

1) How effectively does your company/your 3PLs manage the return, recycling, or responsible disposal of products and packaging to reduce environmental impact?

No formal process in place, disposal is not environmentally optimized / Some efforts exist, but they are limited and not systematically applied / A structured approach exists, but with gaps in efficiency or implementation / Well-established processes ensuring most products and packaging are properly recycled or disposed / Highly effective, fully optimized system with continuous improvement and circular economy initiatives

2) Do you employ circular economy principles in your food waste management (e.g., collecting food residuals for biofuel production)?

Not at all, no circular economy practices in place / Limited efforts with minimal impact/ Some initiatives exist, but not widely implemented / Well-structured programs supporting circular economy principles / Fully optimized system, maximizing waste repurposing and sustainability

<u>Leveraging Sustainability with Technology (Tot: 15 questions)</u>

PLAN (3 questions)

- To what extent does your company integrate sustainability goals into supply chain planning, supported by technology and to assess the sustainability impact of suppliers ?

Not at all / Low / Medium / High / Very High

- How often are technologies used in the planning phase to monitor and reduce environmental impacts within your supply chain (including, for example, demand forecast techniques to decrease food waste and to assess the sustainability impact of suppliers) ?

Never / Rarely / Sometimes / Often / Always

- How extensively is technology applied to plan for sustainable sourcing options (e.g., packaging, ingredient origin, production methods) and how significantly is data from the planning phase used to inform sustainable practices across other SCOR phases (e.g., source, make, deliver) ?

Not at all / Low / Medium / High / Very High

SOURCE (3 questions)

1) How frequently are digital tools or platforms used to evaluate the environmental and social impact of suppliers?

Never / Rarely / Sometimes / Often / Always

2) How significantly does the use of technology in the sourcing process help in achieving overall sustainability targets for your supply chain?

Not at all / Low / Moderate / High / Very High

3) To what degree does your organization incentivize suppliers to adopt sustainable practices through technology-driven programs and use digital platforms to collaborate with suppliers on sustainable sourcing initiatives?

Not at all / Low / Medium / High / Very High

MAKE (3 questions)

1) To what extent are sustainable practices (e.g., renewable energy) incorporated into production or manufacturing processes through the use of technology?

Not at all / Low / Medium / High / Very High

2) To which extent do you employ technologies to improve sustainability of your production processes (e.g., use of machinaries to decrease CO_2 emissions or water/energy usage, reduce waste...)

Not at all; no sustainability-focused technologies in use/To a limited extent; a few technologies implemented with minimal impact/To some extent; moderate adoption, but not a key priority/To a great extent; well-integrated technologies with clear sustainability benefits/Fully implemented; advanced and continuously improving sustainable technologies

3) How often are real-time monitoring systems used to ensure compliance with environmental standards during production?

Never / Rarely / Sometimes / Often / Always

DELIVER (3 questions)

1) How significantly do digital tools or platforms assist in coordinating with distribution partners to achieve sustainability goals?

Not significant / Low / Moderate / High / Very High

2) Are you or your 3PLs employing sustainable vehicle routing optimization to improve sustainability (e.g., CO_2 emissions) in transportation?

Not at all; no optimization in place/ Limited use, with minimal impact on sustainability/ Some optimization strategies, but not a key priority/ Well-integrated routing optimization with clear sustainability benefits/ Fully optimized, advanced systems ensuring maximum efficiency and sustainability

3) Do you use technologies (such as energy-efficient systems, automation, or AI) to improve the sustainability of your warehouses/distribution centers?

Not at all; no sustainability-focused technologies in place/Limited implementation with minor improvements/Some technologies are used, but not comprehensively/ Well-integrated technologies with clear sustainability benefits/ Fully optimized, continuously improving with advanced technologies

RETURN (3 questions)

1) To what degree does your company use technology to improve the efficiency of reverse logistics operations for sustainability?

Not at all / Low / Medium / High / Very High

2) How frequently are digital tools employed to assess the condition of returned products for reuse or recycling?

Never / Rarely / Sometimes / Often / Always

3) How significant is the role of technology in facilitating the recycling or composting of returned food products?

Not significant / Low / Moderate / High / Very High

Digital Technologies (Tot: 24 questions)

PLAN (4 questions)

- We integrate pricing and promotions data into our demand planning tools.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- Our technology supports collaboration with external partners during planning.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- We use automated alerts to adjust plans when raw material prices change.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- We evaluate risk scenarios (e.g., climate or geopolitical) using tech-enabled models.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

SOURCE (5 questions)

1) Our procurement process is supported by supplier evaluation software.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

2) We use mobile apps for quality checks during sourcing at farms or suppliers.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

3) Our suppliers are connected to our ERP system for automatic order processing.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

4) We use blockchain to certify organic or fair-trade food sourcing.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

5) We use supplier performance data to dynamically reallocate sourcing volumes.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

MAKE (5 questions)

1) We monitor temperature and humidity in production using IoT sensors

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

2) Our production line uses computer vision to inspect product quality.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

3) We apply real-time analytics to monitor yield efficiency during food processing.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

4) Our facility uses automated allergen control systems.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

5) We use augmented reality (AR) for operator training on production equipment.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

DELIVER (5 questions)

1) We use cold chain monitoring tech to track product temperature during transit.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

2) Our delivery trucks are equipped with real-time GPS and delivery updates.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

3) We use predictive algorithms to anticipate delivery delays and reroute accordingly.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

4) Our order management system integrates with last-mile delivery apps.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

5) We offer customers digital proof of delivery and condition (e.g., photos, signatures).

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

RETURN (5 questions)

- Customer return data is integrated with quality assurance systems.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- Our digital return portal allows customers to report issues with food freshness.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- We use blockchain to trace returned items back through the supply chain.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- Our tech helps us evaluate the cost-effectiveness of returns vs. Disposal.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

- We visualize returns trends over time using BI tools to reduce future occurrences.

Never / Strongly Disagree/ Disagree/ Neutral/ Agree/ Strongly Agree

6. References

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