# Development of the Green Deal Performance Assessment Methodology (GDPA) for food manufacturing

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**Abstract**

The need to support more sustainable products and practices in the food industry is nowadays clear for academia and practitioners. This is mainly due to the growing global population requiring increasing amount of energy, materials, and nutrition to guarantee wellness and equal opportunities. The methodology reported in this paper has been developed within the research context of "CLARUS - Optimizing Production and Logistic Resources in the Time-critical Bio Production Industries in Europe" project funded by HORIZON-CL4-2021-DIGITAL EMERGING-01. The paper proposes the identification and definition of quantitative environmental sustainability metrics, methodologies, and KPIs for the sustainability assessment of food manufacturing systems involved, to be integrated into a unique Green Deal Performance Assessment (GDPA) methodology. The GDPA methodology has been defined as quantitative metrics able to deliver a final index: the Green Deal Index (GDI), to be later integrated with data and Artificial Intelligence (AI) technologies to provide businesses with a fully autonomous sustainability evaluation tool.

**Keywords**

Green Deal, Food manufacturing, Life Cycle Assessment, Sustainability

## 1. Introduction

The downgrading of the environment and the depletion of natural resources, driven by consumerism phenomena and globalization, is worldwide pushing the interest on Sustainable Manufacturing paradigm and on climate crisis ([1], [2] [3]). In fact, the interest of several industries in the implementation of sustainable operations and practices is nowadays evident [4]. It is moreover clear for academia and practitioners that food industry needs to update its current operations to face new sustainable requirements and norms due to its size and massive consumption and waste of natural resources. The food industry is fundamental for humanity because it realizes products that provide energy and nutrition to people. It represents one of the main sectors requiring a long-term vision to manage sustainability ([5], [6]).

The need to guide the sector toward a Green Transition is pushed by a strong emphasis on improving the environmental and social sustainability of its activities, products and processes, leveraging also on Digital Transition.

In an attempt to provide an answer for the ongoing environmental concerns, CLARUS project aims to connect Sustainable Paradigm in the food industry and AI-based applications, trying to develop a platform with high communications and processing capabilities, aiming for the use of standardized open protocols and data models that will allow resource consumption assessment and traceability for processes in the food industry. The focal point of CLARUS proposal is therefore the "Sustainability Data" of food production and consumption, intended as the source of information strictly related to food industry sustainability (e.g. materials and energies consumed, waste produced, emission and pollution, water consumption, logistics optimization, etc.), whose correct collection, analysis and tracing can lead to enormous benefits for the natural resources management within food manufacturing systems and food supply chains. At the same time, Digital Transformation of food

12th International Conference on Interoperability for Enterprise Systems and Applications (I-ESA24), April 10th 12th, 2024, Chania, Crete, Greece
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companies represents an enabler of Sustainability.

Transformation thanks to the benefits smart technologies can offer in terms of data management and elaboration. Although the choice to digitize manufacturing processes for food companies is increasingly clear and linear, it does not seem to be the same for achieving better sustainability standards. In general, there is confusion within industrial sectors in correctly identifying the actions to be taken for an efficient Green Transition. For this reason, CLARUS proposal is strictly connected with the European Green Deal [7] program in order to develop and define a unique quantitative and standard methodology, the Green Deal Performance Assessment (GDPA) methodology, to support the elaboration of a green-friendly food industry structure and culture, that can generate business in a sustainable way and with a much smaller impact on the environment. The GDPA methodology will be a data-driven methodology models/metrics for environmental sustainability assessment, efficiency, and manufacturing digital adoption. This methodology will be tested for the optimization of production resources and the minimization of waste stream, and energy consumption within the CLARUS pilots. Referring to CLARUS pilots, the project will be tested and validated being applied to two companies within the food processing industry. The first, Honkajoki, is currently Finland's leading processor of animal by-products. In this use case, CLARUS focuses on the deployment of data and AI technologies to facilitate the optimization of logistics operations to maximize the added value of the incoming materials [8]. The second, Ardo, is Spain's leader in fresh-frozen plant-based foods. CLARUS aims to utilize innovative AI techniques to leverage energy consumption and production monitoring data to achieve a significant reduction of the energy costs associated mainly with electricity (cooling installation) and water consumption [8].
Starting from this, CLARUS ambitions is not only to contribute to resource and logistic optimization methods with the two pilots' solutions but aims to generate a more general contribution to the manufacturing green transition, integrating green ICT aspects at every stage of the development of the CLARUS ecosystem, creating a Green Deal Index (GDI), including environmental, logistic and economic KPIs, and, based on this, a Roadmap of AI-based environmental sustainability improvement for food companies.

## 2. Sustainability evaluation methodologies in food industry

In general terms, sustainability encompasses the economic, social, and environmental pillars, each of which addresses multiple factors. The focus of the CLARUS European Project is directed towards the environmental perspective of sustainability in the framework of the Green Deal compliance. Related to this, current measurements are based mainly in CO2 emissions, which is very relevant in most cases but can sometimes be misleading and insufficient.
The analysis of the food industry is not trivial because it needs to bring together sustainability, food quality, and food security: indeed, a push toward sustainable production must not come at the price of reducing the quality of nutrition that is required to sustain a healthy population. Considering the entire supply chain, food production brings a strong environmental burden, and its impacts are distributed along the whole life cycle of the food products. The necessity to measure and improve sustainability performances in food sectors is, therefore, a must in nowadays societies.
The main important factors to consider analysing the sustainability of food products are: (i) hunger; (ii) food waste; (iii) environmental impacts; and (iv) food quality. The necessity to measure and improve sustainability performances in food sectors is, therefore, a must in nowadays societies. Scientific literature proposes a heterogeneous mix of quantitative and qualitative tools to evaluate environmental sustainability performances in manufacturing systems. Several methodologies, metrics, and approaches have been also developed for sustainability assessment of food manufacturing systems and processes through performance indicators. Among many, Material Flow Analysis and System Dynamics, thermodynamics and thermoeconomics, Life Cycle Assessment and exergetic Life Cycle Assessment are particularly well suited to analyze the magnitude of resource consumption and depletion in the food industry, as well as the efficiency of resources transformations within food manufacturing processes. There is a lack in the current scientific and industrial knowledge of exhaustive sustainability metrics, methodologies and indicators that involves the European Green Deal requirements to be applied in the food industrial environment.

Given the heterogeneity of the resource flows involved in the food production processes, these methodologies are suitable for assessing the exhaustion of consumed resources and the calculation of environmental impacts in the food industry.

According to the state-of-the-art of quantitative methodologies to assess 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 industry's requirements), the main characteristics of GDPA methodology are:

- Quantitative methodology; as the absence of quantitative indicators would make the attainment of the environmental sustainability goals subject to high uncertainty;
- Focused on the environmental performance of food products and processes;
- To be developed in accordance with AI and Data Space technical requirements and with Pilots' requirements;
- Convenient for CLARUS;
- Scalable and replicable outside CLARUS.

The research methodology of the work is based on 5 main steps, as briefly described below:

1. State-of-the-art analysis: a scientific literature review together with a search in industrial environments have been conducted to assess the state of the art in the field of quantitative metrics, methodologies and KPIs to evaluate environmental performances in food industries.
2. Identification of the main gaps: the main gaps have been identified according to the literature analysis to try to overcome some of the limits present in this research field.
3. Definition of the methodology requirements: the requirements to be addressed in the Green Deal Performance Assessment methodology has been identified.
4. Selection of the main methodology/metrics to include in GDPA methodology: the most suitable available quantitative methodologies and methods to assess environmental sustainability performances have been selected.
5. Integration of the methodology/metrics and development of GDPA methodology.

In accordance with the analysis carried out, a list of quantitative methodologies selected from available literature to be integrated into the proposed tool is provided below:

- Life Cycle Assessment (LCA)
- Nutritional-Life Cycle Assessment (n-LCA)
- Circular Economy Performance Assessment Methodology (CEPA)
- Energy Modeling (EM)
- Water Management (WM)
- Thermoeconomics analysis (TME)

A brief explanation of these six methodologies is provided in the next section, highlighting the link with the GDPA methodology. A selection of the related impact indicators have been done to be potentially integrated in the GDI.

## 2.1 Life Cycle Assessment (LCA)

A standardized methodology that can be deployed to analyze and evaluate the environmental impacts of resource consumption in food processes is the Life Cycle Assessment (LCA) [9] . LCA methodology, very spread and common-used, is the analysis of a product's life cycle from an environmental sustainability perspective. It is a methodology that computes the overall environmental impact of a product, process, or human activity from raw material extraction, through production and use, to end-of-life (e.g. disposal, reuse, reconditioning) and waste management. The LCA framework consists of four different phases: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation of the results [11]. Including different feedback loops between its various phases, LCA cannot be considered a linearly proceeding process. Insights from the impact assessment are used in refining the inventory analysis and insights from both of these phases may feedback to the scope definition, e.g., in the setting of the boundaries of the product system. The LCA is an iterative process. LCA is integrated into GDPA for analyzing environmental load indicators in the CLARUS project. Taking the life cycle inventory as a starting point, the impact assessment translates the physical flows and interventions of the product system into impacts on the environment using data, knowledge and models from environmental science. Provided below the list of indicators extracted from LCA methodology to be integrated in GDPA:

**Table 1**

**Indicators extracted from LCA methodology**

| **Methodology** | **Indicator extracted** |
|---|---|
| Life Cycle Assessment (LCA) | Abiotic Depletion |
| | Global Warming |
| | Photochemical Oxidation |
| | Eutrophication |
| | Total Waste Produced |
| | Acidification |

## 2.2 Nutritional-Life Cycle Assessment (n-LCA) and Thermoeconomics analysis

A Nutritional-Life Cycle Assessment (n-LCA) and Thermoeconomics analysis are elaborated together since they are integrated together in GDPA methodology for the computation of exergy nutritional LCA based indicators.

In the document "Integration of environment and nutrition in life cycle assessment of food items: opportunities and challenges", Food and Agriculture Organization of the United Nations overviews LCA techniques adopted in the context of food items, suggesting potential enhancements and recommendations for further research [12]. The main concepts are nLCA (nutritional Life Cycle Assessment) and nFU (nutritional Functional Unit), which are fundamental for describing the relationship between environmental impact and the nutrition potential of food items [12]. The solution facilitates the differentiation between nutrients to encourage and nutrients to limit and elaborates how to establish the nutritional quality of food items. Furthermore, an analysis of impact categories is executed to highlight the way the choice of various nFUs affects the outcomes of LCA in terms of both human health and environmental impact. The main result of the analysis is a decision tree that supports the choice and development of an nLCA.

This research spots the light on the importance of analyzing food items from a nutritional point of view to enable the computation of their environmental impacts incorporating specific functional units. In other words, the nutritional dimension of food (energy density, nutrient density, content of good/bad nutrients, etc.) is of primary significance and the specific approach of nLCA is clearly more convenient when analyzing food items. Definitely, this approach would benefit all stakeholders: policymakers can define development paths that are peculiar to the food industry, customers can take into account both the sustainability and the nutritional quality of the food they consume, and food companies can upgrade their processes and gain market share by being more transparent.

Referring to the customer's benefit, the research has proposed the concept of the Nutrient Rich Foods (NRF) score as a tool to assess the nutritional quality of food. NRF can provide either nutrient to encourage or both nutrients to encourage and to limit, thus offering a comprehensive overview of the nutrition's quality [12]. Then, exergy analysis is another emerging topic in the context of sustainability assessment in the food industry. Exergy analysis mostly focuses on drying technologies and heating processes, but the principles of this kind of analysis can be extended to other industrial processes. Provided below the list of indicators extracted from nLCA and Thermoeconomics analysis methodologies to be integrated in GDPA:

**Table 2**
**Indicators extracted from nLCA and Thermoeconomics methodologies**

| Methodology | Indicator extracted |
|---|---|
| Nutritional-Life-Cycle Assessment (LCA) | Abiotic Depletion |
| | Global Warming |
| | Photochemical Oxidation |
| | Eutrophication |

| | |
|---|---|
| | Total Waste Produced |
| | Acidification |
| | Nutrient Content – Protein Quality |
| Thermoeconomics analysis | Total Exergy per line/product |

## 2.3 Circular Economy Performance Assessment Methodology (CEPA)

The circular economy (CE) represents a paradigm shift destructing the building blocks of the old linear economy, which relies on mass production and mass consumption. This economic model that imposed a disposable lifestyle has now reached its limits [13].

Beyond the activities, including recycling, reuse, and reduction processes, circular economy emerged as a challenge to the linear economy model where resources are extracted to produce disposable products [14]. The basis of the CE is prioritizing renewable inputs, using the product with maximum efficiency, and recycling by-products and wastes in goods and service processes [15]. With the implementation of the CE, a transition to a low-carbon economy can be achieved. For instance, an analysis of seven European countries indicated that switching to a CE would decrease each country's greenhouse-gas emissions by about 70% and increase its workforce by approximately 4% [16]. As such, a CE is key to the sustainable development of nations.

The European Union, through the Circular Economy action plan [17](Feb 2021) and a first package of measures, the European Green Deal, already cited before, is boosting sustainable products, empowering consumers for the green transition, reviewing construction product regulation, and creating a strategy on sustainable textiles. Since this importance in the European framework, the circular economy principles will be integrated amongst the quantitative metrics in the GDPA methodology, through the Circular Economy Performance Assessment (CEPA).

The CEPA methodology, developed and tested by POLIMI in European Project H2020 FENIX, is composed of three different sub-methodologies related to three different fields of analysis: (i) a Circularity Product Assessment (CPA), (ii) a Circularity Cost Assessment (CCA), and
(iii) a Circularity Environmental Assessment (CEA). The first sub-methodology is considered and selected to be integrated into CLARUS GDPA to evaluate the circularities of natural resource flow in food processes. CEPA methodology facilitates computing the circular share of resource flows exploited during the product life cycle and obtaining an exhaustive index (KPI) about the circular percentage share of the product with respect to total resources used (Circularity Product Indicator, CPI).

Material Flow Analysis (MFA) represents the main principle underlined the CEPA methodology development. In brief, MFA is a systematic assessment of stocks and flows of materials within a system defined in space and time [18]. In accordance with the physical law of conservation of matter, the results of an MFA can be controlled by a simple material balance comparing inputs, stocks and outputs of a process, which arguably makes the method attractive as a decision-support tool in resource management, waste management and environmental management. Provided below the list of indicators extracted from CEPA methodology to be integrated in GDPA:

**Table 3**
**Indicators extracted from CEPA methodology**

| Methodology | Indicator extracted |
|---|---|
| Circular-Economy Performance-Assessment methodology (CEPA) | Material Circularity Indicator |
| | Energy Circularity Indicator |
| | Resources Circularity Indicator |
| | Circularity Product |
| | Indicator Circularity-Yield-Vector Indicator |
| | Water Circularity Indicator |
| | Circularity Function |

### 2.4 Energy Modeling (EM)

Industrial Energy Efficiency can be seen as "using less energy to produce the same amount of services or useful output" [19]. Energy Efficiency could be also viewed as the enhancement of the ratio between the useful output and the energy input into the same process. Such ratio improvement is approached by the decreasing of the denominator, thus opening the door for two benefits. Firstly, the diminishment of detrimental exhausts of Green House Gases and other substances due to energy consumption in the atmosphere enhances the entity's sustainability from the ecological perspective. On the other hand, the elimination of operational costs is directly associated with energy billing, up levelling the sustainability of a company from an economic perspective.

The main steps that will be carried out through GDPA methodology on CLARUS pilots will be:

- Analysis of the production process energy consumption and mapping of the consumption
- Development of an energy model
- Calculation of ENKPIs
- Optimization of energy consumption

Provided below the list of indicators extracted from EM methodology to be integrated in GDPA:

**Table 4**
**Indicators extracted from EM methodology**

| Methodology | Indicator extracted |
|---|---|
| Energy Modelling (EM) | Total active power per line |
| | Total reactive power per line |
| | Total apparent power per line |
| | Power factor per line |
| | Electrical Efficiency |
| | Total Thermal Energy |
| | Thermal Efficiency |

### 2.5 Water Management (WM)

Water has multiple uses in the food industry such as cleaning, sanitation, and manufacturing purposes. Apart from being utilized as an ingredient, it may be incorporated for different other operations including growing, unloading, fluming, washing, brining, ice manufacture, and in sanitation and in hygiene programs [20], which justifies the water quality's detrimental impact upon both quality and safety of products and operations in food production systems. Undoubtedly, the underestimation of water management's importance is generally the main reason behind various problems, such as mismanagement of water, equipment operation, and maintenance issues; loss of revenue; food safety; and product quality [20].

This brings to the surface new concepts including water circularity and waste hierarchy. The concepts of Circular Economy and the waste hierarchy can be applied also to the case of water systems, defining new concepts for water circularity. The absence of a wastewater management framework in the food industry urges the development of a model to propose the most practical and convenient technologies to be deployed in the case of food effluents, which are generated mainly by washing activities. An organic analysis allows to define a set of indicators required for the determination of the level of pollutants in wastewater, supported with some visual indicators, before the application of any water treatments. On the other side, a physical and chemical analysis enables the definition of drinking water requirements and threshold value set by legislation.

Provided below the list of indicators extracted from WM methodology to be integrated in GDPA:

**Table 5**
**Indicators extracted from WM methodology**

| Methodology | Indicator extracted |
|---|---|
| Water Management (WM) | Chemical-Oxygen-Demand (COD) |
| | Biochemical-Oxygen-Demand (BOD) |
| | Total Organic Carbon |
| | Turbidity |
| | Colour |
| | Taste odor |
| | Temperature |
| | PH |
| | Hardness |
| | Chlorine |
| | Nitrite |
| | Waste water treated |
| | Amount of sludge % |
| | Pollutant removal |

## 2.6 Literature gaps

The analysis of the literature showed that there are different methodologies available for sustainability assessment in the food industry. The well-developed and commonly used is Life Cycle Assessment. However, some resources spot the light on the necessity of a more food specific framework for sustainability assessment, which is the nutritional LCA. This methodology is practically a synthesis between traditional life cycle assessment and techniques for the analysis

of food nutritional quality. Unfortunately, there are few demonstrations of the application of nutritional LCA to food items, beside the absence of a general framework that suggests how to incorporate food quality indices in an LCA. Another gap in the literature is the lack of specific methodologies to assess the food processing stage, as LCAs follow a "cradle-to-grave" approach and highlight the agricultural stage as the most impactful phase for most impact categories, so the footprint of the processing activity is in the background. Furthermore, the methodologies proposed in the past literature raised questions regarding the selection of impact categories: many of the analyzed papers considered a whole set of midpoint and endpoint impact indicators, which require extensive data collection and many calculations (e.g. CEPA). The others, such as Water Management and Energy Modeling, deal with very specific aspects, as energy efficiency, water quality.

This implies the importance of taking all indicators into consideration, in order to do a complete analysis of the whole environmental burden of a product. Furthermore, addressing the literature's gaps,

The GDPA methodology will address the gaps highlighted above, integrating in the point of strengths of the methodologies analysed and building a GDI that will consider in an holistic way the impact indicators highlighted before. In particular, the proposed methodology GDPA will:

- Give specific indications on how to include nutrition in the framework of the Life Cycle Assessment;
- Use a few impact categories and justify their selection;
- Introduce exergy analysis for the evaluation of the processing stage and comparison between products;
- Explain how to put together impacts, nutritional quality, and food processing to compare different food items;

Since that, the overall scheme of GDPA is provided in Figure 1:

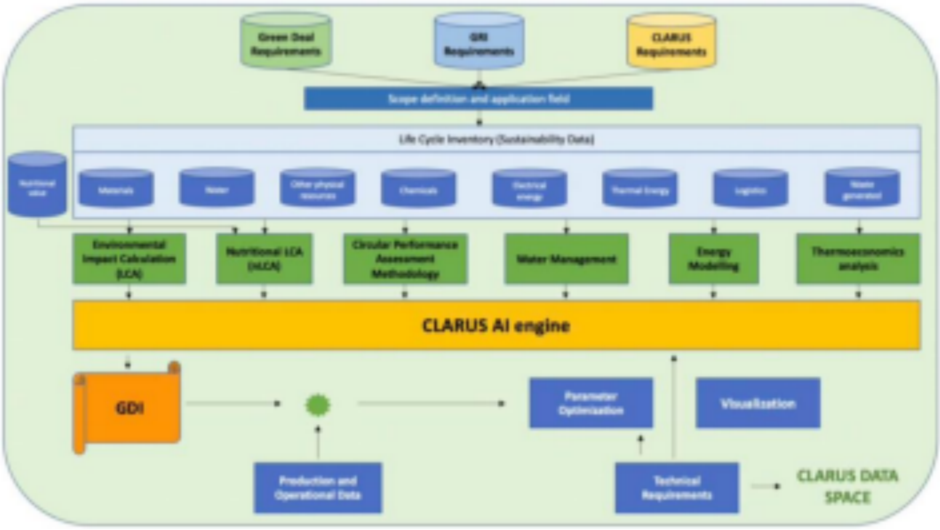

**Figure 1**: Overall View of GDPA Methodology

The interrelationships between the GDPA methodology, Data and AI technical requirements in the CLARUS European project are emphasized in Figure 2. To elaborate, the relation is represented in an iterative form where CLARUS Data Space provides the CLARUS AI Tools kit with the required data for training, testing, and validating the AI models. Then, the CLARUS AI Toolkit will optimize the processes and operations in the pilots. Followingly, the CLARUS pilots will provide the data to the CLARUS Data Space including metrics and KPIs. Finally, the process repeats itself while the overall performance of the pilots enhances.

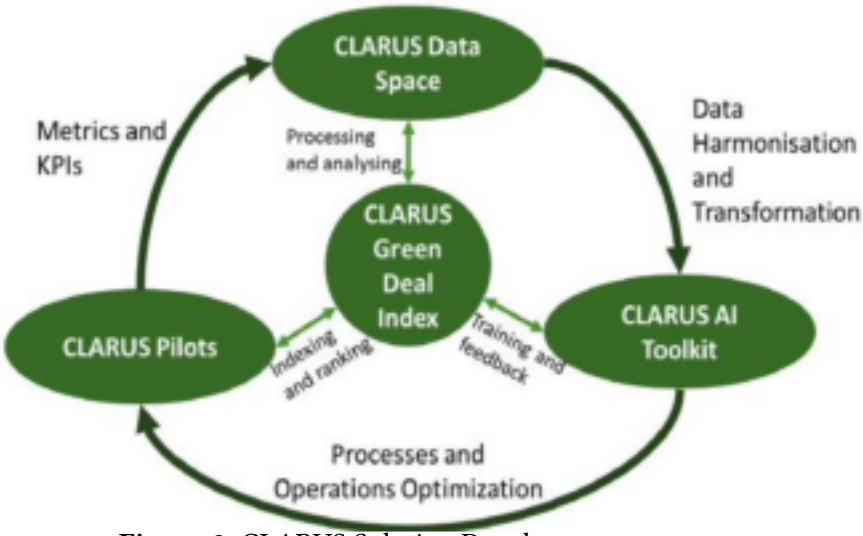

**Figure 2**: CLARUS Solution Development

The relation with GPI, in the center of the figure, is continuous and consists in a bi-directional exchange of processing and analysis data with the CLARUS Data Space, training and feedbacks with the AI Toolkit, and indexing and ranking with the CLARSU pilots. The road to GDI development, therefore, requires a strong interrelation between the expected characteristics of the GDPA methodology, and what is being developed in the context of Data Space and AI toolkits.

## 3. Conclusion

CLARUS project aims to connect Sustainable Paradigm, in the framework of the Green Deal compliance, in the food industry and AI-based applications, to develop a platform with high communications and processing capabilities, aiming for the use of standardized open protocols and data models that will allow resource consumption assessment and traceability for processes in the food industry.

From a sustainable perspective, the analysis and improvement of the food industry are difficult, for the very high complexity of the impacts to be considered. The methodologies and metrics available in the past literature are not sufficient and comprehensive to give an holistic framework of performances and environmental impacts. They in fact analyse the environmental impact from different points of view and have strengths and weaknesses to overcome. Some of them, as LCA, are very know and common-used, others, as nLCA are more specific for the food sectors, but less applicated. Others deal with very specific aspects, as energy efficiency, water management, circularity. This is why, CLARUS aims to provide an overall quantitative methodology (GDPA) and a final index (GDI) that offers a broader view, taking into consideration all the environmental aspects of the food manufacturing, including water consumption reduction, energy savings, waste generation reduction. This GDI would be applicable to differently sized entities (e.g., companies, cities, countries, or processes) providing a complete measure of the compliance with the Green Deal.

Till this point, the GDPA methodology is developed at a theoretical level taking into consideration the relationship with the development of the solutions required for the data stream (Data approach) and the optimization of environmental sustainability performance through the use of artificial intelligence algorithms (AI approach).

To conclude, this paper presents a quantitative environmental sustainability methodology (and related indicators) for the environmental sustainability assessment of food manufacturing systems to be later integrated with Data and AI technologies, first within the CLARUS project, then outside.

The development of the GDPA methodology and GDI need a strong interrelation with Data Space, AI toolkits and Pilots' requirement, through the incorporation of Green ICT principles into the assessment tools. This will enable the measurement of Key Performance Indicators (KPIs) related to the training models and the overall ICT infrastructure of the CLARUS platform, providing a holistic assessment of impacts in accordance with the food industry's requirements.

## Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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