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Data architecture framework for improving consumer awareness in food shopping experience

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Abstract

Nowadays, consumers are often influenced by retailers who prioritize economic objectives over the well-being of individuals and society. To address this issue, there is a need for tools that can help consumers make more informed and sustainable purchasing choices. This paper proposes a data architecture framework that can enable consumers to have a more aware and sustainable purchasing experience, particularly regarding food choices. The framework empowers consumers' experience by providing access to integrated enabling technologies that promote sustainable, nutritionally complete, customized purchase choices and eating habits. Under the NEXT CART project's framework, this paper aims to provide technological solutions that can help optimize and digitize the food supply chain, making it more environmentally, socially, and economically sustainable.

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1. Introduction

The food supply chain (FSC) is a complex network that connects various players involved in food production, processing, distribution, and consumption. It is an essential part of the global socio-economic system, affecting human health, environmental sustainability, and economic development. The FSC involves many stakeholders, including farmers, processors, distributors, retailers, consumers, policymakers, and regulatory bodies, each playing a crucial role in ensuring the smooth flow of food from farm to fork [1]. The efficiency, resilience, and sustainability of the FSC play a significant role in addressing contemporary challenges such as population growth, climate change, resource scarcity, and changing consumer preferences [2]. Studying the dynamics of FSCs requires a multidisciplinary approach, drawing insights from agriculture, economics, environmental science, logistics, sociology, and public health [3]. This interdisciplinary perspective helps to understand the complex interactions and trade-offs inherent in food production and distribution systems. Technological advancements and globalization have transformed the structure and functioning of the FSC, facilitating the integration of diverse markets and enabling the efficient distribution of perishable goods across vast geographical distances. However, these developments have also introduced new challenges related to food safety, traceability, sustainability, and equitable access to nutritious food [4].

Food losses and waste are significant challenges the food supply chain faces, occurring at various stages from production to consumption. At the consumer stage, food waste is a prevalent issue with far-reaching implications for sustainability and food security [5]. Studies estimate that a substantial portion of food produced for human consumption is lost or wasted, with a significant share occurring at the household level [6]. Factors contributing to consumer-level food waste include overbuying, improper storage, and excessive portion sizes, often driven by socioeconomic factors, cultural norms, and consumer behavior [7]. The consequences of food waste extend beyond the economic losses, encompassing environmental degradation, resource use inefficiency, and social inequalities. Expired food in landfills generates greenhouse gases, contributing to climate change, while the resources used in producing wasted food, such as water, land, and energy, represent a squandered investment [8]. Addressing consumer-level food waste necessitates a multifaceted approach encompassing education, policy interventions, technological innovations, and collaborative efforts across the FSC. Educating consumers about food storage, portion management, and waste reduction strategies can foster more sustainable consumption habits [9].

Nutrition is a critical dimension of food products within the supply chain, encompassing their composition, quality, and impact on human health. The nutritional profile of food items is influenced by agricultural practices, processing methods, storage conditions, and transportation logistics [10]. Agricultural practices such as soil quality, crop selection, and farming techniques determine the nutrient content of crops and livestock. Additionally, post-harvest handling and processing can affect the nutritional integrity of food products, with factors such as temperature, humidity, and exposure to light impacting vitamin retention, protein denaturation, and lipid oxidation [11]. Furthermore, the packaging and storage of food products can influence their nutritional quality over time, with improper storage leading to nutrient degradation or contamination. Ensuring food products' nutritional adequacy and safety requires robust quality control measures, adherence to regulatory standards, and traceability throughout the supply chain. Moreover, consumer demand for healthier food options encouraged product formulation and labeling innovation, emphasizing transparency, sustainability, and health-promoting ingredients. Promoting nutrient-rich diets and reducing harmful additives are essential priorities for public health initiatives addressing malnutrition, obesity, and diet-related diseases. Consequently, collaboration among stakeholders across the FSC is critical for optimizing the nutritional value of food products while balancing economic viability, environmental sustainability, and social equity.

Currently, retailers prioritize economic objectives over consumer, environmental, and societal well-being [12]. Developing purchasing tools supporting consumers in making sustainable and healthy choices is challenging. This paper proposes a data architecture framework and entity-relationship diagram that can be used to create a purchasing support tool for consumers. This architecture empowers consumers to make more informed purchasing decisions, focusing on sustainable food choices. The proposed framework takes a bottom-up approach, where consumers are supported by an integrated system of enabling technologies that promote sustainable, nutritionally complete, and personalized purchasing choices and eating habits. This paper presents technological solutions for digitalizing and optimizing the food supply chain for environmental, social, and economic sustainability.

The paper is structured as follows: Section 2 examines the literature gap and explores the primary levers and drivers affecting consumers' purchasing decisions in the retailing stage of the FSC. Section 3 introduces the data structure and elucidates the relationships among the main tables used to discretize the four main layers of influence

on consumer habits. Section 4 delves into the obtained results.

2. Literature review

There are efforts to educate consumers about the impact of food on the environment and its nutritional properties. However, these efforts lack clear and precise indicators. For example, certifications [13] do not provide information on the energy, water, and labor resources that go into producing food, nor do they quantify the environmental impact, such as carbon emissions. Nutritional indicators, such as the Nutri-Score, only provide information on the product's nutritional value not on specific dietary requirements or the impact on the consumer's health [14]. A purchasing support system integrating the different dimensions of food can better inform the consumer of the effects of his purchasing choices. The literature and industrial case studies report several technological solutions to support retail sales [14], [15]. According to [15], the applications of technology in retail follow the different stages of the path-to-purchase (P2P) cycle described by [16]. These stages are: (1) need appearance, (2) search information, (3) alternative valuation, (4) purchase, and (5) after-sale. In this cycle, the phases (3) and (4) are the targets of mature technologies such as self-laser handheld scanners based on UPC Barcode, NFC solutions for automatic payment, Wireless LAN systems for recording purchases at the point of sale [17], and laser/RFID-enabled screen product-consumer interface [18].

The retailer is revolutionizing the shopping experience by introducing a virtual store concept that incorporates the benefits of e-commerce, resulting in cost and time savings. This approach aims to overcome consumer resistance [19] and influence their shopping behavior by fulfilling their cravings [20] and needs [21]. Shopping platforms are now incorporating Augmented Reality (AR) and Virtual Reality (VR) to enhance the consumer experience. This integration allows consumers to recognize and immerse themselves in VR Stores [22] during the research phase and evaluate alternatives using mobile eye-tracking [23]. However, these technologies do not highlight the efforts of supply chain actors such as traveled distance, processes, operations, and externalities. This can create a disconnect between consumers and the food production and distribution environment, leading to an unbalanced judgment and possibly affecting their final purchasing choice. This business model aims to enhance the consumer experience by providing virtualization, personalization, individualization, and forging an emotional connection.

Tab. 1 categorizes the current state of P2P supporting technology solutions. Although there is a mature technology available, it is mainly focused on the sales needs of retailers and not on the benefits that individuals and communities can obtain from it.

Apart from P2P supporting systems, consumers are often guided by visual indicators such as qualitative labels when making choices. These labels provide information on various aspects such as nutritional values, the number of production processes, environmental impacts, and calorie intake. However, the use of informative labels in the industry is poorly implemented, and end consumers are often the only ones who use the information they contain. Several studies in the literature have examined the use of informative labels in retail settings.

In [24], a survey was conducted to evaluate the effectiveness of five different front-of-pack (FoP) nutritional label formats in India. These labels were easy to comprehend and highly ranked by the participants. These labels were also found to influence purchase intentions more effectively as compared to informative labels such as multiple traffic lights, monochrome guideline daily amounts, and Nutriscore. In conclusion, the survey participants found nutrition FoP labels to be more useful in encouraging healthier food choices than informative label formats. They identify nutrition FoP labels as more useful in influencing healthier food choices than informative label formats. A study was conducted to evaluate the preferences of Belgian consumers for vegetables under a proposed Eco-score in European food labeling [25]. [26] examine the impact of different FoP nutrition labels on perceived visual attention and nutritional quality perception. Three label types are assessed: directive (Nutriscore), semi-directive (monochromatic Guided Daily Amount, GDA), and non-directive (multiple-traffic lights, MTL).

Tab. 1. Technology-powered solutions for improved shopping experience. A literature review’s findings.

| | Goal/Purpose | | | | | | | Technology Feature | | | | Technological Solution | | | | Shopping Experience | | | P2P Cycle Phase | | | | | | | |
|-------------------------|-----------------|-------------|--------------|-------------------------|--------------------|---------------------|---------------------|--------------------|------------------------|------------------------|------|------------------------|--------------------|-----------------------|-----------------|---------------------|-----------------|----------------------|-------------------|------------|------------------|------------------|--------------------|------------------------|----------|---------------|
| | Sales Marketing | Educational | Traceability | Supply chain visibility | Operations Control | Impact transparency | Nutritional Advisor | Display / Totem | Software & Mobile apps | Hybrid in-store system | RFID | Wireless Sensors | Augmented/ Virtual | Robotics & Automation | Digital Screens | Mobile App | Cloud Computing | Eye-Tracking Glasses | In-Store Shopping | e-Commerce | Virtual Retailer | Need Recognition | Information Search | Alternative Evaluation | Purchase | Post-Purchase |
| [27] | ☑ | | | | | | | | ☑ | | | | | | | | | ☑ | | | | | | | ☑ | |
| [15] | | | ☑ | ☑ | ☑ | | | ☑ | | ☑ | ☑ | | | | | ☑ | | ☑ | | | | | ☑ | | | |
| [28] | ☑ | | | | | | | | ☑ | ☑ | | | | | | | | ☑ | | | | | | ☑ | | |
| [20] | ☑ | | | | | | ☑ | | ☑ | | | | ☑ | | | | | | | ☑ | | | | ☑ | ☑ | ☑ |
| [19] | ☑ | | | | | | | | ☑ | | | | ☑ | | | | | | | ☑ | | | | ☑ | ☑ | ☑ |
| [29] | ☑ | | | | | | | | ☑ | | | | ☑ | | | | ☑ | | ☑ | | | | | ☑ | ☑ | ☑ |
| [30] | ☑ | | | | | | | | ☑ | | | | | | | | ☑ | | ☑ | | | | | ☑ | ☑ | ☑ |
| [31] | ☑ | | | | | | ☑ | | | | | | ☑ | | | | | ☑ | | | | | | ☑ | ☑ | ☑ |
| [22] | ☑ | | | | | | | ☑ | | | | ☑ | | | | | | | | ☑ | | | | ☑ | ☑ | ☑ |
| [23] | ☑ | | | | | | | | ☑ | | | ☑ | | | | | | ☑ | | | ☑ | | | ☑ | | ☑ |
| [18] | ☑ | | | | | | | ☑ | | | | | ☑ | | ☑ | | | | ☑ | | | | | ☑ | ☑ | ☑ |
| [32] | ☑ | | | | | | | | ☑ | | | ☑ | | | | | | | | ☑ | | ☑ | | ☑ | ☑ | ☑ |
| [21] | ☑ | | | | | | | | ☑ | | | | | | ☑ | | | | | ☑ | | | | ☑ | ☑ | ☑ |
| [33] | | ☑ | | | | | ☑ | | ☑ | | | | | | ☑ | | | | ☑ | | | | ☑ | ☑ | ☑ | ☑ |
| [34] | ☑ | | | | | | | | ☑ | | | ☑ | | | | | | | | ☑ | | | | ☑ | ☑ | ☑ |
| [35] | | ☑ | | | | | ☑ | | ☑ | | | | | | ☑ | | | | | ☑ | | ☑ | ☑ | ☑ | ☑ | ☑ |
| [36] | | | ☑ | | | | | | ☑ | ☑ | ☑ | | | | | | ☑ | | ☑ | | | | ☑ | ☑ | ☑ | ☑ |
| NEXT CART Project | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | | ☑ | | | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | | | ☑ | ☑ | ☑ | ☑ | ☑ |

The results of this study showed that Nutriscore tends to require the least visual attention, leading to exaggerated perceptions of nutritional quality for unhealthy products. On the other hand, GDA labels were found to provide the most accurate estimates. While MTL labels required less visual attention, they did not enhance visual efficiency. These findings emphasize the importance of considering consumers' ability to process nutritional information when designing public policies. In [37], a study investigated the impact of environmental impact labels (eco-labels) and nutrition labels on sustainable purchasing behavior. The study explored whether nutrition labels influenced healthier purchasing when presented alongside eco-labels. Participants were randomly assigned to view products with environmental labels only, nutrition labels only, both labels, or no labels. The results show that environmental labels alone or with nutrition labels significantly reduced the environmental impact on consumer’s perception compared to cases where no labels are available. The study findings support the effectiveness of environmental labels in encouraging sustainable purchasing behavior and contribute to increasing consumers' awareness of their role in promoting more sustainable FSC operations.

This paper aims to demonstrate how incorporating enabling technologies in the food retailer sector can change the consumer experience along the P2P cycle by promoting FSC visibility. Increased visibility on the environmental and social impacts of food and nutritional properties and needs can transform shopping into an inclusive, conscious, and educational experience. The development of a new educational P2P model aims to promote FSC redesign towards a sustainable and resilient agri-food industry, in line with the bottom-up approach triggered by educated and aware

consumers. Therefore, this paper identifies and addresses two main issues in the agri-food industry and FSCs: the lack of consumer food education and supply chain sustainability. These issues are interdependent and affect the food production and distribution ecosystem's economic, environmental, and social sustainability. Furthermore, they are responsible for social externalities concerning public health, territorial and industrial development, resource consumption, and the deprivation of natural ecosystems. To communicate the nutritional, environmental, and economic externalities to different food industry stakeholders, this paper integrates the content of available and novel labels [38] and proposes a comprehensive data framework enabling a novel food shopping experience.

This novel data architecture provides comprehensive visibility over different dimensions and layers of the food industry. These include the industrial layer, the consumer layer, the nutritional layer, and the waste dimension. These layers underpin the need for stakeholders like production and logistic managers, consumers, healthcare policymakers, and environmental managers to make more informed decisions.

3. Methods and Materials

The data framework architecture is based upon integrating four main layers, namely the *Industrial*, *Consumer*, *Nutritional*, and *Waste* dimensions. Fig. 1 draws the data structure's Entity Relation (ER) diagram. This section introduces and describes the proposed data framework's dimensions, tables' features, and main relationships.

3.1. Industrial Layer

The Industrial layer models and defines the industrial actors involved throughout the FSC processes responsible for raw material processing into finished products, packaging, storage, and transportation operations. To make the data structure adaptable to every type of FSC, the actors that are considered include consolidation, processing, warehousing, and selling nodes/facilities. The data architecture is fed by mapping processes at each node (NodeID) and for each ProductID. ProductID refers to the individual order from a specific distribution path (RouteID). Thus, as mentioned in [32], the supply chain impacts are scaled down to the individual product batch. This strategy is necessary because the individual EAN code does not allow for tracing the product's supply chain, as with the aforementioned smart label. The virtualization of a food batch enables tracking and quantifying a set of performance punctual indicators like the power consumption by processing lines, the energy required for refrigeration and storage, the food miles, the GHG emissions from transportation, and material handling efforts. This *Industrial* layer comprises nine tables and more than 120 attributes to describe the FSC's processes and stages and make the practitioners more informed and aware. This layer can be exploited by simulation tools and digital twins able to virtualize the industrial operations and provide estimates of impact and economic/environmental externalities as illustrated in [38] and [39].

3.2. Consumer Layer

The Consumer layer is responsible for modeling the consumer's behavior and nutritional requirements by defining their user profile in terms of calories needed and micro-macro-nutrients. This information is generated through calculations based on dietary restrictions due to allergies (AllergenID) or special diets (DietID), the user's basal metabolism (ConditionID), and their weekly routine (ActivityID).

Since users usually shop for themselves and their family unit (GroupID), the Group's requirements can be used as a reference value. Each family group contains a certain number of consumer profiles that contribute to quantifying the total calorie requirement into macronutrients and the associated vitamin and mineral profile. The information contained within this layer is cross-referenced with the nutritional properties associated with each *ProductID*.

The Consumer layer includes seven tables encompassing over 90 attributes to profile the consumer effectively. Each UserID is associated with anthropometric measures and all activities contributing to the individual's caloric requirements. The Routine table assists consumers in listing the activities typically comprising their week. These activities, identified by *ActivityID*, are based on the normalized value of the Metabolic Equivalent of Task (MET), representing the energy per kilogram of body weight expended during any activity.

This data layer records consumer purchases to monitor and quantify the macro-micro-nutrients acquired by the consumer group within a specific timeframe. All attributes listed in the *PurchasesHistory* table can be accounted for by utilizing the *ReceiptID* and *GroupID*.

3.3. Nutritional Layer

Each *ProductID* in our database has a unique nutritional profile that includes information about the food item itself as well as any processes or treatments it has undergone. These profiles also include claims such as low sugar content, which can be used to filter and categorize products in our database. This layer also associates each product with compatible diets and potential allergens. To make the vast number of *ProductIDs* in our database more accessible, we assign each a food category and a legal, conventional, or descriptive name according to prevailing regulations. This ensures that each product is affiliated with a single food category (*CategoryID*), streamlining certain data queries. Our database uses data from official nutritional tables to determine the nutritional content of each product, and this information is linked with specific user conditions such as gender, age range, and health status to provide a clinical framework for computing individual caloric requirements [40]. Thanks to the information stored in the *DietID* field, each product is associated with compatible diets such as celiac, halal, and vegan. Finally, the *Nutrients* table in our database contains 36 different nutrients (such as carbohydrates, sugars, fats, proteins, vitamins, and minerals) within the *NutrientID* attribute. In total, 78 attributes are organized into nine tables to build the *Nutritional* layer.

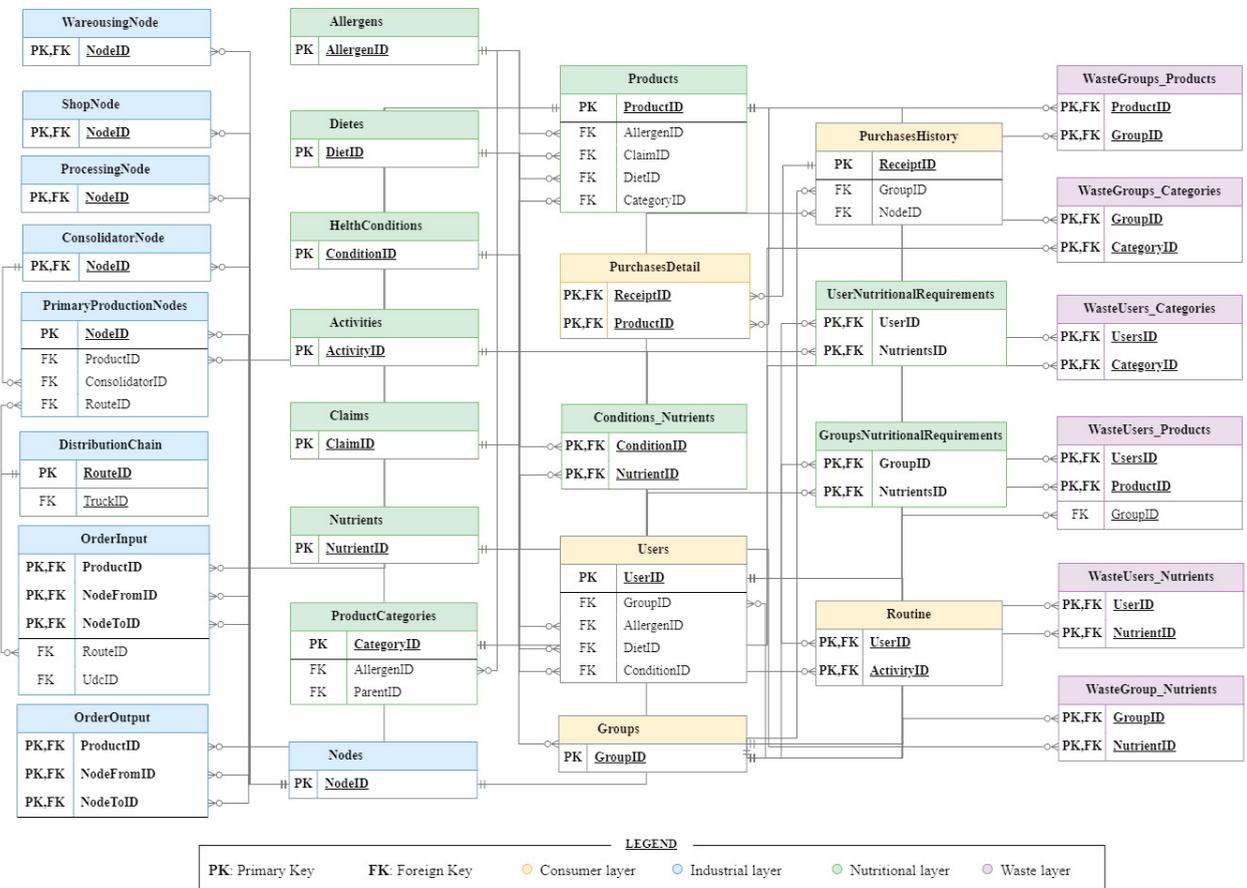


Fig. 1. Entity Relation Diagram

3.4. Waste Layer

In order to raise consciousness among consumers, this layer takes into account the waste generated downstream of the purchase. A report is generated within the PurchasesDetail table whenever a user purchases a product. Based on user feedback, this table quantifies the waste generated by each previously purchased item. The responses to the inquiries allow the system to quantify waste in terms of unconsumed products, energy consumption, water footprint, land use, cost, and wasted micro-macro-nutrients. Additionally, the tables within this layer enable the generation of statistics on individual ProductIDs and their respective categories, calculated for individual users and user groups. The waste layer is comprised of six tables, with more than 110 attributes associated with them.

4. Applications and discussion

The proposed data framework improves stakeholders' awareness of food industry impacts and externalities and informs consumers to incentivize more conscious purchasing from a nutritional and environmental perspective. It paves the way for several applications concerning practitioners and customers as exemplified in Tab. 2. Its prime intention is to make the environmental impacts and pollution release during food production, conservation, and delivery tasks accountable and visible to the purchaser. Such visibility is also attractive to practitioners who might trigger tailored sustainability transition strategies (e.g., reducing virgin packaging material, installing photovoltaic panels, enhancing machine utilization, and minimizing traveling). Based on personal attitudes and habits, the consumer could be informed of the chosen item's fit with undertaken diets or targets, such as in the case of sports. The purchaser might be also warned about the expected waste generated from the products' basket, considering the waste trend and the potential metabolic surplus.

Tab. 2. Examples of competence questions addressed by the data framework.

| Data layer | Stakeholder | Query | Indicator |
|-------------|---------------------|---|---------------------------------|
| Industrial | Consumer | What is this item's carbon footprint? | kg eq. CO2/Packaged Unit |
| Industrial | Consumer | What is the product's water footprint? | lt. water/Packaged Unit |
| Industrial | Line manager | What are this lot's labor and energy costs? | Labor time/batch; kWh/batch |
| Industrial | Logistic manager | The transportation cost out of the total distribution cost? | €/shipment ; food miles |
| Industrial | Retailer | How fair prices are according to expected shelflife and thermo-hygrometric stresses occurred along supply operations? | %quality decay; €/Packaged Unit |
| Consumer | procurement manager | Whether my shopping basket is fair and tailored to my targets? | %calories; %nutrients; etc. |
| Consumer | Sporty | How healthy are the portions of prepared meals? | %GDA; gr./portion |
| Nutritional | Family chef | Is this product allowed for my diet? | %fats; Allergens; % cholesterol |
| Nutritional | Consumer | Will my shopping cart generate a nutritional surplus? | %Nutrients required |
| Waste | Purchaser | How much waste is expected from the purchased basket? | Wasted €; Wasted kg. |

This data framework can benefit from integrating FSC digital twins and simulation tools able to virtualize production and distribution processes, track simulated food lots, and estimate economic, logistic, and environmental indicators when primary data are unavailable. Such details are printed upon a multi-dimensional QRCode that univocally assesses the performance associated with each food order [32].

Whilst this data framework can feed queries for indicators' evaluation, a set of user interfaces can facilitate the consumer's choice during the shopping experience, driving more fair and sustainable products with simple infographics dashboards. The communication and integration of the four data layers occur at the retailer to enable aided-shopping opportunities overcoming the current informing labels usually applied (see Fig. 2).

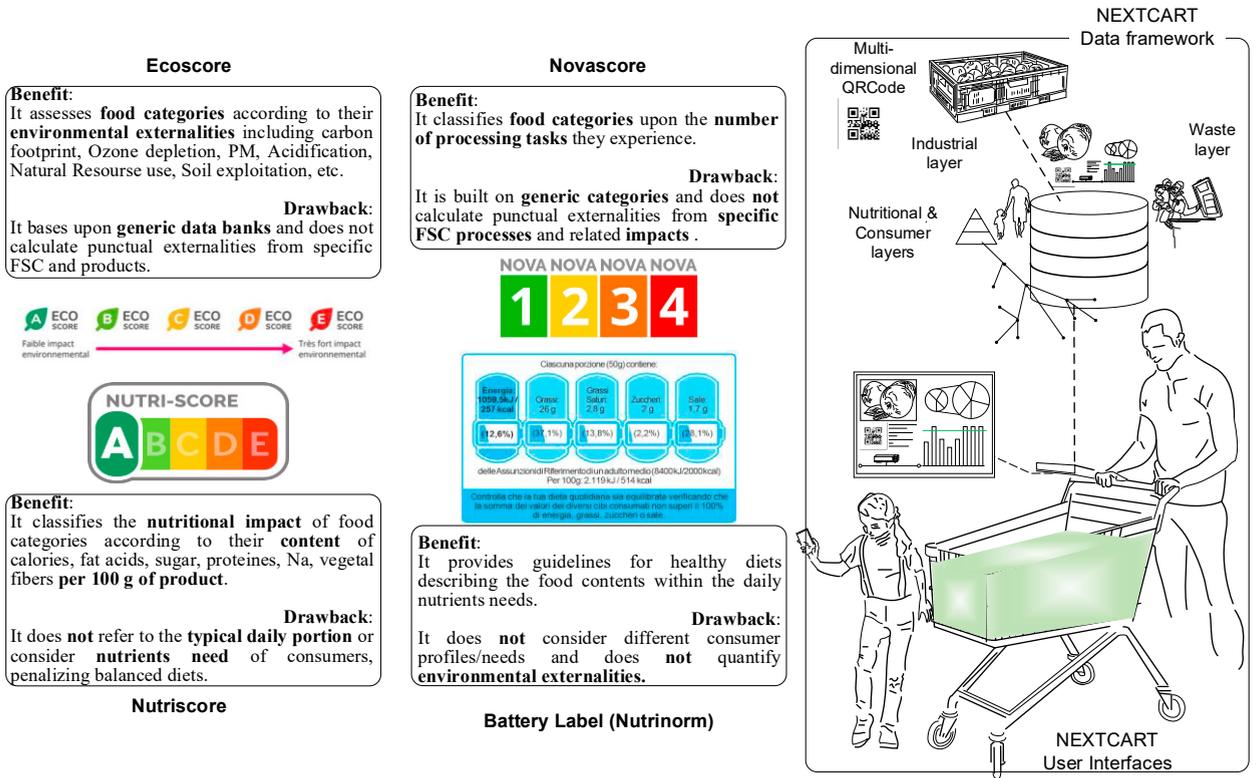


Fig. 2. NEXTCART data framework application: comparison with current labels.

5. Conclusion and future steps

In order to spread awareness among the food industry’s consumers, establishing a P2P system that encompasses four main knowledge domains is essential. These domains include: Industrial, Consumer, Nutritional, and Waste layers. This paper introduces a new data framework that integrates these data layers. The industrial layer helps map and measure the impact of the supply chain on each food order or batch. The *Consumer* layer profiles the final customers and their associated group, defining their needs and habits. The *Nutritional* layer provides information on food content and properties, helping consumers make choices that fit their health status, diets, and well-being goals. Lastly, the *Waste* layer quantifies unfair waste habits and trends.

This data infrastructure is the basis for implementing a P2P system that empowers consumers to understand their purchasing decisions’ social, economic, and environmental implications. Such a data framework is designed to work with digital twins and simulation tools, which can virtualize food industry processes and estimate impacts and performance where primary data is unavailable. As the challenge is to communicate effectively with the consumers, future project’s steps will focus on designing and prototyping advanced and easy-to-access data lake architectures and user-friendly mobile interfaces together with cart-embedded dashboards able to aid the consumers through the shopping experience and drive a bottom-up transition toward a more sustainable food industry.

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