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# Methods and tools for reducing food waste in the household environment

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# Abstract

The total quantity of food waste in the European Union has been estimated at around 89 million tonnes per year of which about 42% is thrown out by households. Furthermore, it has been esteemed that the 60% of the latter would be avoidable by increasing users' awareness and encouraging them to adopt better eating habits, which also allow reducing the health and obesity problems.

For this reason, several attempts have been dedicated by the scientific and industrial world to the reuse of food industries wastes, the development of systems for a more efficient waste management and the launch of campaigns to attract interest of citizens on this issue. However, methods and tools able to support consumers to prevent the waste are still lacking.

In this context, the goal of the present research work, carried out in collaboration with the Indesit Company, consists in the study and development of an integrate system able to reduce the household food waste and improve the end-users lifestyle in terms of health and wellbeing.

In particular, a web application and a set of related services have been developed to guide the user in the proper storage of food, support him/her in the purchase planning and suggest the recipes that better satisfy his/her energy and nutritional requirements and need ingredients close to expire.

Such result was possible thanks to the development of a smart fridge equipped with a NFC reader that allows reading specific NFC tags that the user can configure according to the food information. This allows having an updated stocks inventory and tracking the products expirations.

The potentialities of the system has been evaluated from the usability, environmental and economic point of view. Finally, the system integration in a wider smart ecosystem allowed also evaluating its interoperability.

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# Introduction

In the last years, international efforts and studies are dedicated to the sustainability issue in order to understand the hottest spots, identify common drivers and define approaches and methodologies to increase the global wellbeing from an environmental, economic and social point of view. The residential sector and its dwellers are some of actors involved in this challenge.

They are called to face the energy consumptions reduction, but also the food waste issue. Indeed, the total quantity of food waste is continuously increasing and it is often generate by households. For this aim, the consumers' behaviour has been investigated by researchers in order to understand everyday practices around food and waste. The results of such studies prove that the main causes of the household food waste are related to the preparation of abundant portions, the incorrect planning of purchases, and the exceeding of the products expiration date.

Despite these evidences, the most of the attempts of the scientific world focuses on the reuse of food waste coming from food industries and the development of more efficient waste management systems, neglecting the importance of the role of consumers. Therefore, methods and tools oriented to the prevention of food waste that help consumers in overcoming their careless attitude towards this theme are not sufficiently deepened. On the other hand, their development is often entrusted to the industrial sector, which is often technology-oriented and loses sight of the users' needs, habits and expectations. In particular, new systems have to make people aware of the economic and environmental impact of waste and support them in the food management. Indeed, the development of strategies to prevent the food waste remains the first step to achieve ambitious goals in terms of sustainability, rather than focusing on waste itself.

In addition, the developed countries are also dealing with the overeating phenomenon, which is responsible of the overweight and obesity problems and the relative risks to health. Indeed, it consists in an excessive consumption of food that exceed the energy requirements of the organism. Based on these evidences, the new initiatives and solutions related to the food care are called to address both

the attitude to waste food and the diffusion of bad eating habits. However, the current technologies usually face the two issues separately.

In this context, the present research work focuses on the development of a smart system that aims to improve the consumers' eating habits and reduce the food waste overcoming the current state of the art. From a technical and functional point of view, it is based on two important pillars such as the expiration date traceability and the proper information management. Indeed, the combination of these two aspects allows designing new services able to support users in improving their lifestyle in a non-intrusive way. In particular, the collaboration with the Indesit Company, which is an Italian company that produces household appliances, allowed developing a smart fridge able to track the entry/exit of products in terms of typology, quantity and characteristic dates (i.e., purchase, opening, and expiration). On the other hand, the study of the information flow, the creation of a proper information model and the definition of specific algorithms allowed the development of a web application that interacts with the fridge and supports users in the food purchase, storage and preparation. In particular, the proposed system aims to reach the following main objectives:

- To reduce the impact of the inadequate storage conditions by suggesting to the user the most proper fridge compartment according to the products typology;
- To avoid the purchase of an excessive amount of food by supporting the creation of the shopping list according to the stocks and analysing the historical data to provide efficacious warnings to the user. For this reason, the suggestion of the supermarkets special offers could encourage users to adopt this tool by allowing them to save money;
- To help consumers in selecting the most appropriate recipes according to the ingredients available at home or close to expire, the daily energy requirements and the last meals consumed as well as the possible food allergies.

The latter objective is an ambitious goal also from a scientific perspective. Indeed, it aims to find the right trade-off between different aspects such as helping the user in maintain a balanced diet, limiting to throw away edible food and avoiding that food exceeds its expiration date.

Furthermore, to encourage the researchers to invest their efforts in the study and development of new technologies able to address the food care issue and the actors of the Food Supply Chain (FSC) to collaborate in order to reach a common goal, the potentialities of the proposed system has been assessed from several points of view. In particular, the benefits in terms of environmental impact and costs has been preliminarily esteemed by taking into account the weekly eating habits of a typical Italian family. In addition, the interoperability of the system has been evaluated by proposing its integration in a wider smart ecosystem, which is the subject of an European project that aims to help people in changing their behaviours and improving their health conditions and wellbeing. For this reason, an information model that efficiently integrates the system has been created and a methodology that ensures a proper high–level information management to identify the most proper Dos messages (i.e., actions to do) to send to the user according to his/her lifestyle has been developed.

Henceforward an overview of the thesis is given. As anticipated, the thesis topic is the study and development of an ICT tool able to support consumers to address the food waste challenge and follow daily food-related best-practices. In particular, C*hapter 1* illustrates the context by introducing the concept of food waste, providing an estimation of its extent and impacts, analysing the main causes at different level of the FSC and proposing possible solutions, describing the correlation with the obesity phenomenon and the relative concerns worldwide and, finally, treating the relevance of the consumer role. *Chapter 2* investigates the literature and the Internet of Things (IoT) market to provide an overview of the existing initiatives and ICT solutions. It also summarizes the driving forces and barriers related to the success of the current methods and tools. *Chapter 3* presents the methodology adopted to design and develop the system. It highlights the importance to analyse the user needs for the definition of system requirements and to create an accurate information model for the design of an efficient system architecture and satisfactory services. *Chapter 4* describes the system architecture and the relative functionalities. In particular, the structure of the database, the smart fridge operation and the features of the web application are presented in detail. *Chapter 5* evaluates the system from several perspectives. Indeed, it describes the performances of the system by means of the validation of the algorithm that suggests the most proper recipe to the user and the results of the usability analysis that has been carried out by involving a sample of 10 users.

Furthermore, it illustrates the results of the Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) analysis that allowed evaluating the benefits of the system respectively from an environmental and economic point of view. *Chapter 6* aims to demonstrate the system interoperability by describing the creation of a data model that integrates the proposed system in wider smart environment. Furthermore, it presents the approach adopted to elaborate the data, to identify the users profile and to define how intervening to help users to improve their behaviours. The implementation of such approach is an ongoing activity, however, some preliminary results of its first steps are presented.

Finally, the last section summarizes the outcomes of the thesis, highlights its strengths and weaknesses and introduces the future works that have to be undertaken.

# *Chapter 1*

# The food waste

The food care, at each step of the supply chain, is assuming a worldwide relevance both at research and industrial level since it is one of the most important pillars of the sustainable and healthy society. However, this theme is a huge challenge that involves a lot of stakeholders. Several aspects have to be taken into account to guarantee and improve people well-being preserving the environment and limiting costs.

For example, the first steps of the supply chain (e.g., agriculture, livestock, etc.) should work in harmony with the natural environment instead of not to give to the land the proper rest, to use chemicals fertilizers and other pollutants, to concentrate an unnatural number of animals in one place, etc. Therefore, all actors involved in these stages are called to reduce the environmental impact and to guarantee the food genuineness. However, the food supply chains, especially upstream, mainly consist of small and medium-sized enterprises that not always succeed to face huge investments to improve environmental care and quantify the related financial effects.

From another point of view, to support decision making and influence buying behaviour, stakeholders and consumers need to be informed about sustainability of the companies, products, and processes. Therefore, food supply chains need to be transparent. In particular, the transparency of a supply chain is defined as "the degree of shared understanding of and access to product-related information as requested by a supply chain's stakeholders without loss, noise, delay, or distortion" [1]. However, in the majority of cases, the environmental information provision mainly focuses on the single business unit even if the impacts are caused by the supply chain. This is due to the fact that to create transparency is perceived by businesses as costly in the short run since in many cases its benefits will only occur in the long run. It is a barrier to the implementation of systems that reduce the environmental impact. Another problem is the tacit character of producing in a sustainable way; it implicates that the compensation of sustainability efforts in pricing is problematic.

Another aspect that plays a key-role in the food care issue is the food traceability, which becomes mandatory to guarantee the food safety and satisfy the consumers' expectation. It can be defined as "the part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing is correct animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control, traced upward, and tracked downward at any time required" [2]. For this reason, the main efforts focus on the development of technologies able to ensure an accurate information flow through the supply chain without an excessive increase in costs [3].

However, in this context, a more critical scenario is emerging: the paradox between food waste and hunger [4] [5]. According to the estimations of international organizations, there are 795 million undernourished people in the world today [6]. It means that one in nine people do not get enough food to be healthy and lead an active life. In particular, 6.3 million children under the age of five died in 2013 and about 45% of all deaths are linked to malnutrition [7]. Therefore, more than half of these early child deaths are due to conditions that could be prevented or treated with access to simple, affordable interventions. And yet, food availability is enough to feed the population of the world. This highlights the global economies imbalance and pushes the industrialised countries to deal with the high amount of food wasted every day as well as the growing relevance of the obesity problem. For this reason, in order to identify the causes and, consequently, propose valid solutions, it is essential, first of all, to define the food waste concept. There is not a standard definition in literature, therefore, the international organizations and several research studies tried to provide one.

The first definition of food waste was given by the Food and Agriculture Organization (FAO): "wholesome edible material intended for human consumption, arising at any point in the FSC that is instead discarded, lost, degraded or consumed by pests" [8]. During the years, it has been reviewed and integrated and, in a recent study of FAO, a new distinction between food loss, food waste and food wastage has been introduced [9]:

- **Food loss** – a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills,

knowledge and management capacity of supply chain actors, and lack of access to markets. In addition, natural disasters play a role.

- **Food waste** – food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Often this is because food has spoiled but it can be for other reasons such as oversupply due to markets, or individual consumer shopping/eating habits.
- **Food wastage** – any food lost by deterioration or waste. Thus, the term "wastage" encompasses both food loss and food waste.

Furthermore, the food wastage can be both edible and inedible according to the following definitions [10]:

- **Avoidable –** food and drink thrown away that was, at some point prior to disposal, edible (e.g., slice of bread, apples, meat).
- **Possibly avoidable** – food and drink that some people eat and others do not (e.g., bread crusts), or that can be eaten when a food is prepared in one way but not in another (e.g., potato skins).
- **Unavoidable** – waste arising from food or drink preparation that is not, and has not been, edible under normal circumstances (e.g., meat bones, egg shells, pineapple skin, tea bags).

## 1.1 How much food is lost or wasted?

To provide an accurate global estimation of food waste is not a simple issue. It is hindered by the limited availability and heterogeneity of data, however, several attempts has been carried out adopting different approaches and methods. A review of them has been carried out within the European project FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies) [11]. In particular, some studies focus on quantitative and qualitative data coming from literature, statistics and questionnaires as well as assumptions. Other ones exploit standard approaches on quantitative techniques to estimate the level of wasted food [12].

Taking into account the studies carried out by the Swedish Institute for Food and Biotechnology (SIK) on request from the FAO, approximately one-third of all food produced globally for human consumption is lost or wasted, around 1.3 billion tonnes per year [13]. Food is wasted at different stages of the FSC, both in

medium- and high-income countries and in low-income countries. As shown in Figure 1, food loss and waste in industrialised countries are as high as in developing countries, but different waste-generation patterns exist around the world:

- In developing countries, it mostly occurs upstream of the food supply chain (i.e., agriculture, postharvest, animal production, processing, distribution, etc.);
- In industrialised countries, it mostly takes place at retail and consumer stage.

Therefore, the main difference between developed and developing countries is the amount of waste at the end of the food supply chain. In Europe and North America, this waste amounts to 95-115 kg per capita per year, while in Southeast Asia and Sub-Saharan Africa, only 6-11 kg per person of food is wasted by consumers [13].

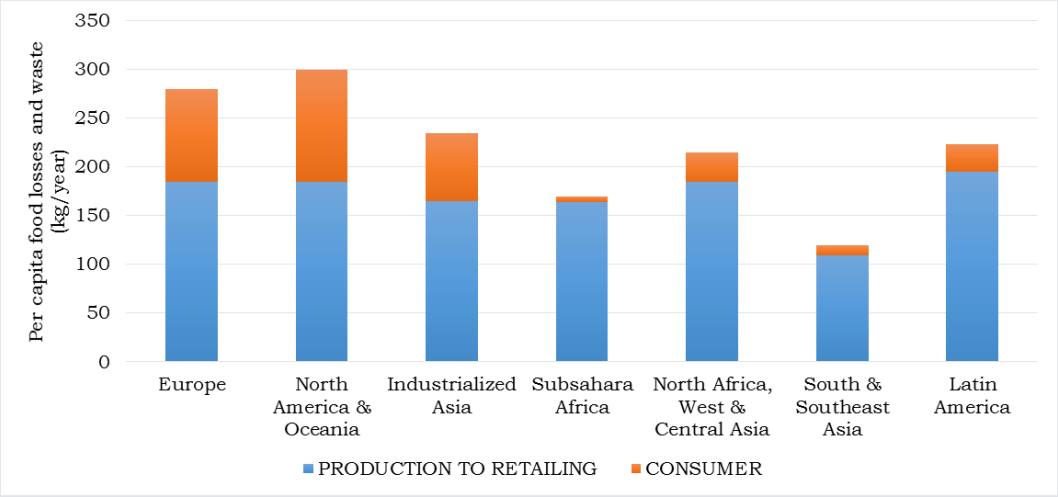



*Figure 1 – Per capita food losses and waste, at consumption and pre-consumptions stages, in different regions [13]*

Going into more detail, the left chart of Figure 2 illustrates the amounts of food wastage by phase along the food supply chain and highlights a high responsibility of the consumption phase (22%) as well as upstream stages of the FSC (54%) [9].

An in-depth analysis of the food supply chain phases by regions (right chart of Figure 2) confirms that upstream losses occurring at agricultural

production phase appear homogenous across regions and downstream wastage occurring at consumption level is much more variable. Indeed, the latter is about 31–39 percent of total wastage in middle and high-income regions and 4–16 percent in low-income region [9].

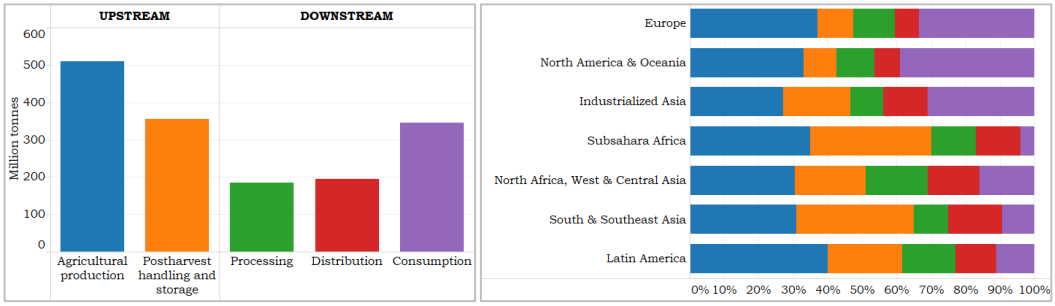



*Figure 2 – Food wastage, at world level, by phase and by region of the food supply chain [9]*

Focusing on the European Union, the total quantity of food waste has been estimated over 100 million tonnes per year [14]. About 40% of waste is thrown out by households, of which 60% would be avoidable. Without additional prevention policy or activities, food waste is expected to rise to over 120 million tonnes by 2020.

Looking only at household waste and using various national data sources, the Barilla Center for Food & Nutrition (BCFN) found that the amount wasted per person per year is: 110 kg in Great Britain, 109 in the United States, 108 in Italy, 99 in France, 82 in Germany and 72 in Sweden [15].

In Italy, according to the study of Prof. Segrè and his research group, nearly 12 billion of euros of food – which could feed 636000 people – are thrown away annually, 20 millions of tonnes of edible food is wasted every year and 250 kilograms of food is thrown away by supermarkets every day [16].

## 1.2 Environmental, economic and social impact of food waste

Everyone knows that food waste is one of the challenges that the world have to deal with, but few really knows the extent of the problem and its impacts. It is often seen as an injustice or a moral obligation because of the paradox with the hunger that involves low-income countries. Sometimes, people realize that

reduce household waste allow them to save money. However, in few cases it is associated to the environmental damage.

Therefore, it is worth to highlight that wasting food has a threefold impact: environmental, economic and social.

Several studies have been carried out to estimate the food waste impact even if they usually focus on one of the three perspectives. In Table 1 the main relevant works and the respective topics are indicated.

*Table 1 – Literature review about food waste impacts assessment*

| AUTHORS | ENVIRONMENTAL IMPACT | ECONOMIC IMPACT | SOCIAL IMPACT |
|---|---|---|---|
| *S. Salhofer, 2008 [17]* | | | x |
| *L. Ventour, 2008 [18]* | | x | |
| *M. Kummu et al., 2012 [19]* | x | | |
| *BFCN, 2012 [15]* | x | x | x |
| *FAO, 2013 [9]* | x | | |
| *FAO, 2014 [20]* | | x | |
| *A. Bernstad Saraiva Schott and A. Cánovas, 2015 [21]* | x | | |

According to the results described in a review paper of eight previous publications [21], the climate impact from prevention of end-consumer food waste has been estimated to between −0.8 and −4.4 kg $CO_2$/kg prevented waste. In general, the review shows that benefits related to end-consumer food waste prevention are largely explained by avoided food production and related services, rather than reduced waste management.

M. Kummu et al. said that 23–24% of total use of water, cropland and fertilisers are used to produce losses, half of which could be prevented with a more efficient supply chain and could fed one billion extra people [19].

A FAO study [9] investigated the magnitude of food wastage impacts on the environment and relative sources along the food supply chain. It is based on a life cycle approach and focuses on impacts on climate, water, land, and biodiversity. The results show that the carbon footprint of food wastage – without accounting for GHG emissions from land use change – is 3.3 Gtonnes of CO2 equivalent: as

such, it ranks as the third top emitter after USA and China. In particular, Europe, North America & Oceania and Industrialized Asia have the highest per capita carbon footprint of food wastage (approximately 700 to 900 kg CO2 eq. per capita and per year). Analysing the contribution of each phase of the FSC (Figure 3), it emerges that the consumption phase is the most critical one despite the food wastage volume at this level is lower than that at upstream stages.

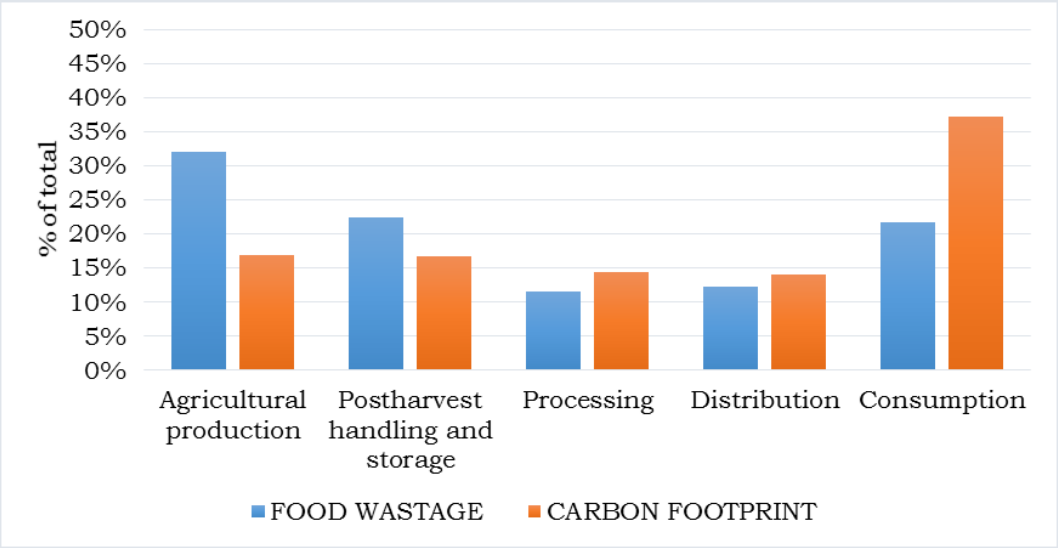



*Figure 3 – Contribution of each phase of the food supply chain to food wastage and carbon footprint [9]*

As far as the global blue water footprint (i.e., the consumption of surface and groundwater resources) of food wastage is concerned, it has been esteemed to about 250 $km^3$ [9]. Furthermore, it is worth to highlight that it is higher than that of any country.

In addition, to produce uneaten food vainly occupies almost 1.4 billion hectares of land, which represents about the 30 percent of the world's agricultural land area [9].

Despite numerous approaches and contributions related to the environmental impacts assessment, a clear guidance on how to evaluate the benefits associated to the implementation of food waste prevention initiatives or systems is still missing.

The social impact of waste can partly be tackled recalling the *food security* concept that describes the state in which "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their

dietary needs and food preferences for a healthy and active life", according to the definition provided by the World Food Summit in 1996 [22]. Therefore, from a social point of view, the food availability should be able to satisfy the energy requirements of the global population and guarantee an equilibrate diet with the proper nutrient content. However, the malnutrition continues to be one of the major public health problems, especially in the poorest areas of the world.

From the other side, in societies where availability is abundant and access to food is guaranteed, food waste from overeating is becoming a serious problem to deal with as well as the obesity phenomenon. For this reason, it is worth to highlight that the quantity of food that ends up in the garbage in industrialized countries (222 million tons) is nearly equal to the available food production in Sub-Saharan Africa (230 million tons) [15].

To estimate the economic impact of food waste is an arduous challenge because of numerous aspects that must be considered and the relative hidden costs. For this reason, the FAO introduced a methodological approach for the full-cost accounting (FCA) of the food wastage footprint. According to the FAO study, the total cost of global food wastage amounts to USD 2.6 trillion annually, roughly equivalent to the GDP of France, or approximately twice total annual food expenditure in the USA [20]. As shown in Table 2, such amount comprehends:

- Economic costs related to the wasted food and subsidies;
- Environmental costs related to the environmental impacts to the atmosphere, water, land and biodiversity that must be paid by society and future generations;
- Social costs affecting people's well-being and livelihood, which are related to the environmental degradation, the increasing scarcity of natural resources and the health damage.

*Table 2 – Estimated costs of food wastage [20]*

| COST CATEGORIES | COSTS (billion USD) |
|---|---|
| Environmental costs | 696 |
| Social costs | 882 |
| Economic costs | 1055 |
| **Total costs** | **2625** |

Quantifying the full costs of food wastage allows increasing the global awareness about the impact of food system inefficiencies, encouraging concrete actions to address the supply chain weaknesses and better evaluating the associated benefit-cost ratio (BCR).

## 1.3 The reasons behind food waste

The reduction of the described impacts is a global challenge that governments, industries and consumers are called to face. The first step to reach such goal is the analysis of the food supply chain and the identification of weaknesses and hot spots to really understand the causes of food waste. For this reason, several studies have been conducted, some of them focusing on single country [23] [24], others facing the problem from a global perspective.

Food is lost or wasted along the whole food supply chain, from initial agricultural production down to final household consumption. However, the first evidence is the strong dependence of causes from FSC phases and regions' characteristics. For this reason, the same distribution of food waste, shown in Figure 2, can confirm this statement.

In low-income countries food is mostly lost during the production-to-processing stages of the FSC and the major causes are [13] [15]:

- Limited technical, financial, and managerial resources;
- Premature harvests due to urgent need for food or to obtain income;
- Inefficient and obsolete practices, harvesting methods, technologies, and infrastructure;
- Storage facilities and logistical management that do not ensure proper conservation conditions and which promote deterioration or insect infestation.

On the other hand, the highest-income countries can take advantage of more efficient techniques, advanced technologies, systems and infrastructures and agronomic expertise that allows them to reduce the food waste. Indeed, in these regions, it occurs because of overproduction, the lack of demand for certain products at certain times of the year, high levels of perfection in appearance and freshness required by consumers and qualitative standards for human consumptions imposed by national and international laws [13] [15].

At the processing phase, technical inefficiencies and malfunctions play a key-role in all regions. However, in low income countries, they are more frequent and have a higher impacts. In the industrialized regions, they lead to defects in terms of weight, shape, appearance or packaging and, consequently, to dispose the final products, although their safety, taste and nutritional value have not been affected [13] [15].

At retail level, the large quantities to get beneficial prices and a wide range of food types and brands, offered to satisfy the consumer expectations, lead to food waste in industrialized countries. Indeed, a lot of products reach their "sell-by" date before being sold or are ignored by consumers because too close to their expiration. Instead, in developing countries wholesales and supermarkets are often small, overcrowded, unsanitary and lacking cooling equipment. Too few facilities satisfy the storage and sales conditions requirements [13].

In the developing countries the food wastage at household level is particularly low. To the contrary, the increase in average income and availability and variety of food has progressively led developed countries to greater tolerance to food waste. Indeed, several studies prove that the main causes of the household food waste are related to the preparation of abundant portions, the incorrect planning of purchases, and the confusion about the product expiration dates. Furthermore, food too often is not consumed in time and it is thrown away because deteriorated [15].

In particular, consumers' tend to buy more food than needed. Such a behaviours is influenced by several factors, for example:

- Incorrect planning of purchase often related to the lacking awareness about the food stocks available at home [25];
- Retailers' pricing strategy for foods (e.g., price promotions, 2x1 special offer, lower price per unit for bigger package sizes, etc.) [15] [25];
- Stock of items bought for a special recipe or occasion that has never occurred or has been partly consumed and never reused. At some point, these items are thrown out [26].

As far as the food preparation and consumption are concerned, several studies stated that portions too much abundant are served and, consequently, too much food remain on the plate [15]. According to the WRAP study, nearly a third

by weight and three tenths by cost of edible food was thrown away in UK (1,2 million tonnes annually) because it was left over on the plate [18].

In relation to the date labels, the results of dedicated studies highlight that the majority of people is not able to correctly distinguish between “best before”, “use by” and “display until” dates. In particular, from a study carried out by WRAP it emerged that only two fifths of the interview participants were able to give a full and correct definition of the labelling system [27].

Consequently, all the dates are often treated in the same manner because consumers do not know the existence of the difference between them. In other cases, they are aware of this distinction and want differentiate their behaviour according to the specific information, but they do not know the exact meaning of it. For example, a Belgium survey demonstrated that 30,4% of respondents not to know the difference of meaning between date labels [28]. Moreover, someone is reluctant about the data reliability and accuracy. All these misunderstandings lead to throw away edible foods.

Another factor that should not be underestimated is the lack of knowledge or carelessness about the proper storage conditions of the products. In general, people do not check the fridge temperature to verify that it is adequate or do not know which is the most appropriate placement of foods in the fridge. This behaviours reduces the shelf-life of products. For example, 76% of participants in one telephone survey stated that they would have clear instructions on how food should be stored to prolong its shelf-life and some participants stated that they would prefer specific instructions about where to store products, rather than just a generic “store in a cool dry place” [27].

It is worth to specify that also packaging and its functions play a significant role for the amount of food waste in households. For this reason, a Swedish study demonstrated that 20-25% of the food waste was related to the packaging design attributes [29].

Underlying all these aspects, there are other causes of household food waste that can be addressed through consumer-targeted policies: lack of awareness about the extent of food waste issue; lack of knowledge about prevention measures; low attention in food purchasing because of the abundant availability and a generally low price level of food; consumers’ preferences and attitudes and socio-economic factors [30]. In order to overcome these difficulties,

new methods and tools able to lead users in the food preparation and consumption are required.

Table 3 summarizes all possible causes of food waste distinguishing them by region and by FSC phase.

*Table 3 – Causes of food waste by phase and by region of the food supply chain*

| FSC PHASE | MEDIUM/HIGH INCOME COUNTRIES | LOW INCOME COUNTRIES |
|---|---|---|
| **UPSTREAM STAGES** *(i.e., agriculture, postharvest handling and storage)* | ▪ Supply greater than demand<br>▪ Qualitative standards<br>▪ Aesthetic requirements | ▪ Premature harvesting<br>▪ Technical, financial, and managerial resources<br>▪ Inefficient and obsolete methods and technologies<br>▪ Lack of adequate infrastructures<br>▪ Low expertise |
| **PROCESSING** | ▪ Overproduction<br>▪ Low demand at certain times of the year<br>▪ Misshapen products<br>▪ Product or packaging damage | ▪ Inadequate technologies<br>▪ Technical malfunctions and inefficiencies |
| **DISTRIBUTION** | ▪ Marketing, qualitative and safety standards<br>▪ Excessive products and brands differentiation<br>▪ Inappropriate ordering because of contractual agreement between suppliers and distributors<br>▪ Incorrect projections of demand | ▪ Inefficient technologies to conserve products<br>▪ Inadequate facilities<br>▪ Lacking of a logistics management system<br>▪ Product or packaging damage during transportation |
| **CONSUMPTION** | ▪ Abundant portion sizes<br>▪ Exceeding the expiration date<br>▪ Insufficient shopping and meal planning<br>▪ Marketing strategies influence<br>▪ Misunderstanding about data labels<br>▪ Inadequate storage conditions<br>▪ Improper use of packaging<br>▪ Lack of awareness and knowledge<br>▪ Personal preferences and attitudes<br>▪ Socio-demographic factors | - |

## 1.4 How to reduce food waste

One of the first initiatives against food waste was the conference "Transforming food waste into a resource" (October 2010), organized by the Last Minute market at the European Parliament in Brussels. In that occasion, the "Joint Declaration Against Food Waste" was presented according to which governments are called to develop strategies and resolutions aimed to halve food waste by 2025. Nowadays, several EU legal instruments address the issue of treatment of bio-waste as, for example, the Waste Framework Directive (WFD) [31] that laid down two important waste management requirements: the environmental and human health protection during waste treatment and the priority for waste recycling. However, the development of strategies to prevent the food waste remains the first step to achieve ambitious goals in terms of sustainability, rather than focusing on waste itself.

It is worth to remember that synergic strategies and differentiated, focused actions according to the specific consumers' target group are some of the most important pillars of a successful intervention. For this reason, the standardization of definitions, metrics and assessment methods and the data sharing could be the first step to better understand the extent of the food waste phenomenon, the relative causes and the possible intervention areas.

First of all, strategies should be finalize to minimize the inefficiencies that lead to losses and waste, rather than focusing only on recovery initiatives. When waste cannot be eliminated, the priority should be to take action to recover and redistribute it to struggling sections of society. When waste cannot be redistributed, it should be designated for reuse for other purposes, such as animal feed or bioenergy production [15].

Cooperation and agreements between several actors of FSC (i.e., farmers, producers, and distributors) could reduce the risk of overproduction by ensuring a more appropriate planning of food supply according to the demand trends and projections. Furthermore, in each stage of the FSC, it is essential to train operators in order to improve their skills and knowledge, to ensure the food production, handling and storage according to food safety standards and to encourage the adoption of good agricultural and hygienic practices [30].

In this context, governments are called to improve the date labelling system, to tax food waste and potential changes that alter the economic feasibility

and to ensure that the adoption of standards does not introduce unjustified losses and waste along the food supply chain.

On the other hand, increasing the efficiency, reducing the reputational damage, and enhancing the brand image and value are the main drivers behind retailers' activities. Therefore, these latter should lead to relax quality standards related to aesthetic factors, also towards suppliers and importers, innovate packaging in order to increase the shelf-life of foods and develop markets for suboptimal products [25].

As far as consumers are concerned, creating awareness about the food waste issue as a whole and the individual daily food related practices is a prerequisite for a successful action. Most experts suggest that the education is the starting point to change people's attitudes towards the current massive food waste. Indeed, it is important to teach consumers how to purchase, preserve, prepare, and ultimately dispose of food in a more sustainable way [15]. For example, to help users to better use the domestic refrigerator (e.g., by setting the most proper temperatures) could be a first simple step to increase the storage lives of food and reduce waste [32]. Also the correct interpretation of the expiry date as well as the assessment of foods by looking, smelling and tasting play a significant role. Information initiatives need to be promoted via various sources and undergoing crucial life moments, which are known to entail changes in perceptions and habits.

Furthermore, other campaigns to promote the use of "doggy bag" at restaurants or to encourage the diffusion of leftover cookbooks in bookstores could be carried out to address the food waste problem [25].

## 1.5 The overeating phenomenon

In addition to the food waste problem, the growing availability and differentiation of foods in developed countries are leading an excessive consumptions that exceed the energy requirements of the organism. The overeating phenomenon is one the most relevant causes of overweight and obesity as well as other health problems. For this reason, the overeating and food waste are often linked and new food care initiatives and solutions are called to deal with both aspects.

In particular, obesity-related health problems has more than doubled since 1980. In 2014, 39% of adults (more than 1,9 billion) were overweight (BMI ≥ 25 kg/m$^2$) and 13% of adults (over 600 million) were obese (BMI ≥ 30 kg/m$^2$), according to Global Health Observatory (GHO) data. The prevalence of overweight in high income countries was more than double that of low and middle income countries. For obesity, the overall prevalence is over four times higher in high income countries compared to low income countries. As shown in the following charts, Americas and Europe have the highest concentration of overweight and obese people that amounts respectively to 61% and 51% for overweight (Figure 4) and to 27% and 23% for obesity (Figure 5) [33].

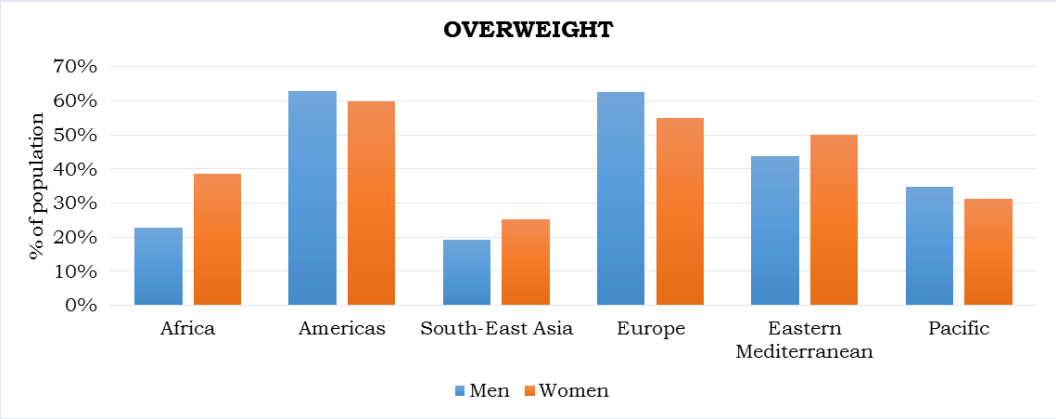



*Figure 4 – Overweight adults worldwide in 2014 (source: GHO)*

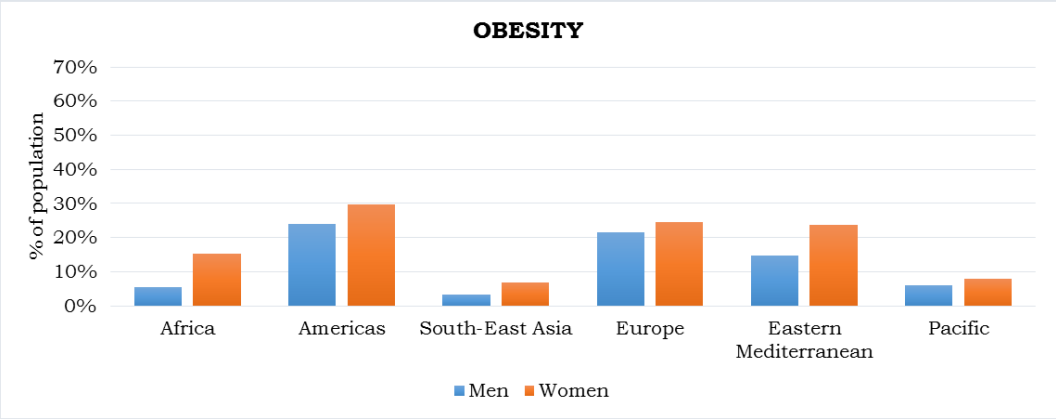



*Figure 5 – Obese adults worldwide in 2014 (source: GHO)*

It is indicative of a worsening trend of poor diets and low physical activity levels that has to be inverted to preserve the population health. The majority of

developed countries are called to face this problem by means of concrete initiatives able to improve consumers' food habits. Indeed, a regular food intake is required for the basic physiological functions of everyday life, such as blood circulation, respiratory activities and cell turnover.

For this reason, universal dietary recommendations has been defined by health authorities and institutes and many governments policies are pushing for their divulgation in order to reach the population nutritional goals. These recommendations are based on prevention of nutritional deficiencies on one hand, but also aim at reducing chronic diseases and obesity on the other hand.

In order to encourage a change in the consumption and production practices, oriented to the adoption of a heathy diet with a lower environmental impact, all actors of the FSC have to be involved. For this aim, several approaches, instruments, measures, and actions could be adopted at different stages of the supply chain, as suggested by the European Commission (EC) and international research institutes [34] [35].

In particular, actions of food producers should be finalized to avoid an unsustainable and unhealthy competition. This is possible by setting minimum standards, promoting certified/labelled food, making the healthy option available and affordable and advertising best practices as well as the development of novel products according to social, environmental and health issues and societal expectations.

Government can influence the food market and consumption patterns by means of:

- Scientific information and education campaigns to raise awareness of the health problems related to poor nutrition, overweight and obesity;
- Structures, programs and projects for direct public feedbacks and physical activities promotion;
- Sustainable food procurement for school, public offices, etc.;
- Concession of incentives or healthcare insurance based on people lifestyle healthiness;
- Direct restrictions on sales and advertising of less healthy food to protect consumers' health;
- Promoting transparency on the environmental, social and health aspects of specific food products (e.g., via voluntary or obligatory labelling rules);

- Limiting possible cartels block that obstacle the healthier foods consumption;
- Fostering innovation policies that support the development of healthy and sustainable food products.

Consumers themselves play a key-role in changing consumption patterns and are the most important driver for a sustainable food production and innovation. In particular, they should be exercising more sustainable and healthier choices, organising local healthy food clubs or associations and putting pressure on industry to respect sustainable and healthy values.

## 1.6 The role of the consumer

A key-role for the success of the proposed strategies is played by consumers. Therefore, it is worth to focus the attention at this stage of the FSC in order to make people aware of the impact of household waste and the importance of their contribution in reducing it. For this aim, the consumers' behaviour has been investigated by many researchers in order to understand everyday practices around food and waste from the household perspective. For this reason, the Theory of Planned Behavior (TPB) [36] is often used as a starting point to predict household decisions to minimize or recycle waste.

The food demand is not only related to the survival and satiety issue but it is influenced by other factors such as enjoyment, preference, culture, prestige, etc. People have different economic, social, and demographic characteristics and, consequently, different behaviours and attitudes to the food consumption and waste. For this reason, Gracia and Albisu [37] analysed the main determinants of differences between European countries in terms of food-related behaviour as well as common patterns. It emerged that the macro-economic factors influenced the expenditure allocated to food; countries' culture and history continue to characterize the diet patterns and the people age is responsible of many differences related to meals patterns (e.g., ready-to-eat meals vs traditional meals, home cooked meal vs eating out, etc.). However, a general and common trend emerged: consumers are becoming more interested, knowledgeable and critical towards food, therefore, they requires a more added value, safety and diversified products that allow them to follow an adequate and varied diet to maintain good health and prevent diet-related disease.

In addition to these evidences, L. Secondi et al. [38] stated that older people, women, individuals with a lower level of education and people living in rural areas are less likely to generate waste respectively compared with youths, men, individuals with a higher level of education and people living in urban areas.

Looking at Italian consumers, Cersosimo et al. [39] discussed in a deepened way about the evolution and trends of food consumptions of Italian families as well as the behaviours that they have adopted in response to the crisis and its social and economic impacts. The authors stated that the crisis has made Italian consumers less compulsive than in the past. Indeed, they pay more attention to reduce waste rather than give up essential goods.

However, several studies shows that few consumers are aware of the amount of food they waste and the related impacts, especially the environmental one [40] [41] [42]. On the other hand, the most important pillar for the success of any strategies is the general people aversion to waste [43]. In order to enhance such aversion, it is important to increase the consumers' perception of economic and environmental implications of food waste. However, awareness campaign alone could be ineffective. Indeed, it is necessary to identify consumers' segments according to the food-related practices in order to adopt tailored policies and actions as well as the definition of drivers and barriers that characterize each target group. Only in this way several approaches and tools can be developed.

For this aim, Verain et al. [44] identified three consumer segments that differ in the relative importance and perceptions associated with healthiness and sustainability as compared to price and taste: proselves, average consumers and sustainable conscious consumers. De Carvalho et al. [45] developed a Consumer Sustainable Consciousness Construct that identifies five main dimensions lied behind the sustainable consumers' behaviours: sense of retribution, access to information, labelling and peer pressure, health, and crisis scenario.

Several researches sated that cost is one of the key triggers that could encourage the waste reduction [40] [41].

K. Parizeau et al. [46] observed that multiple factors (i.e., social, cultural, economic, and institutional) influence household food waste practices, therefore, many policy levers should be adopted. They also confirm the importance of the collaboration between several actors of FSC in encouraging consumers to waste less.

Aschemann-Witzel et al. [25] carried out a literature review and expert interviews to identify cause and potential of actions related to the household waste and observed that socio-demographics factors are less relevant than the psychographics ones. Indeed, the latter predispose consumers' concerns, perception and behaviours in the store, as well as in their households. The same results has been obtained by E. Ganglbauer et al. [47], exploiting the "theory of practice" lens. In particular, they suggest the development of strategies and technologies that support consumers' intentions about the waste reduction by improving their everyday practices. In the same way, the of study Stancu et al. [48] suggests that food-related routines are the main drivers of food waste in addition to perceived behavioural control. Among the routines, the leftovers reuse and shopping ones are the most important.

In conclusion, several actors of the FSC should collaborate to undertake initiatives aimed to increase the consumers' awareness and influence their behaviour. Each strategy should be tailored to the target users' group and exploits different means. In particular, they should highlight the environmental impact of waste, exploit the financial issue as a driver, suggest the best-practices that consumers' have to follow (i.e., reuse leftover, check the stock and their expiration date, reduce the portions size, preserve food correctly, etc.) and help users to understand the benefits for the whole society that could arise from their actions.

# *Chapter 2*

# Literature review and commercial solutions

In literature, a lot of papers focus on the reuse of food waste coming from food industries [49], the systems to engage people in behaviours of recycling [50] and the assessment of waste management systems [51]. However, methods and tools oriented to the prevention of food waste that help consumers in overcoming their careless attitude towards this theme are not sufficiently deepened. For this reason, in the following paragraphs a review of existing initiatives, intelligent household appliances and smart technologies that aim to reduce the food waste at household level is presented.

It is worth to highlight that also the Waste Framework Directive indicates that the highest priority of the waste legislation and policy of the EU Member States has to be paid to the food waste prevention, as shown by hierarchy of Figure 6.


*Figure 6 - Waste management hierarchy (source: WFD)*

## 2.1 Action initiatives

There are many organizations and action initiatives in the world aimed at the food waste reduction. Awareness campaigns, online platforms, websites and applications, training programs, regulatory instruments, call for research projects, and "zero impact" initiatives are the main instruments adopted for this aim [15] [30].

Food waste awareness campaigns

The majority of awareness campaigns are addressed to consumers, but sometimes also schools and restaurants are the target as well as industries.

Some of them (e.g., Think.Eat.Save, Every Crumb Counts, Food Surplus Entrepreneurs Network, etc.) aim to galvanize widespread global actions and catalyse different sectors and actors to share ideas and know-how and undertake projects in order to face the food waste problem. Other movements (e.g., Stop Wasting Food, Stop Food Waste, Slow Food, DoSomething's FoodWise, Réduisons nos déchets, etc.) seek to increase the public awareness by mobilizing the press and media and encouraging discussion, debate and events. Other initiatives focus on training programmes or student education (e.g., Edible Schoolyard Project, Waste No Food, Appetite for Action, etc.). Furthermore, a lot of information tools such as internet websites, guides and handbooks have been created and several documentary films on food waste have been shot (e.g., Dive! in USA, Just Eat It in Canada, Taste the waste in Germany, etc.).

Table 4 summarized the most famous campaigns worldwide aimed to increase people awareness on food waste problem.

*Table 4 – International food waste awareness campaigns*

| | CAMPAIGN | COUNTRY | YEAR | TARGET |
|---|---|---|---|---|
| [52] | Slow Food® | EU countries | 1989 | Consumers, farmers |
| [53] | THE EDIBLE SCHOOLYARD PROJECT | USA | 1996 | Schools |
| [54] | RÉDUISONS VITE NOS DÉCHETS, ÇA DÉBORDE. | France | 2005 | Consumers |
| [55] | STOP WASTING FOOD | Denmark | 2008 | Consumers |

| | CAMPAIGN | COUNTRY | YEAR | TARGET |
|---|---|---|---|---|
| [56] | LOVE FOOD hate waste | United Kingdom | 2008 | Consumers |
| [57] | STOP FOOD WASTE | Ireland | 2009 | Consumers, schools |
| [58] | appetite for action | United Kingdom | 2009 | Schools |
| [59] | StillTasty Your Ultimate Shelf Life Guide | USA | 2009 | Consumers |
| [60] |  Waste No Food | Hong Kong | 2010 | Schools |
| [61] | DO SOMETHING! FOODWISE YOUR SITE FOR SUSTAINABLE FOOD | Australia | 2010 | Consumers |
| [62] | END FOOD WASTE NOW .org | USA | 2012 | Consumers |
| [63] | THINK·EAT·SAVE REDUCE YOUR FOODPRINT | Global | 2013 | Consumers, retailers, hospitality |
| [64] | EVERY CRUMB COUNTS JOINT FOOD WASTAGE DECLARATION | EU countries | 2013 | Institutions and FSC partners |
| [65] | FSE Network Building Solutions to Food Waste | Belgium | 2014 | Social innovators |
| [66] |  | Sweden | 2014 | Consumers |

Food redistribution initiatives

Quantities of edible food waste at the retailers' level are very large. For this reason, several initiatives and projects have been launched in order to collect still edible and unsold food products, which would be destroyed or thrown away, and donate them to charities, homeless poor and other people in need (e.g., City Harvest, Feeding America, Banco Alimentare, Buon fine, etc.). The recovered products are donated from industry, restaurants, and food services as they do not respect the aesthetic standards or are close to their expiration. Sometimes, intact and unused foods are recovered from public events, catering services and concerts (e.g., Rock and Wrap It Up!). In other cases, associations recover and prepare food in community kitchens and then serve it in cafeterias, at charity dinners or during collective events (e.g., Dinner Exchange). Other initiatives are finalized to promote the food sharing between consumers (e.g., foodsharing.de, I food share). Other organizations (for-profit) collect unsellable food from retailers and resell it in secondary markets at discounted prices (e.g., Approved Food).

Table 5 summarized the most famous organizations or initiatives worldwide oriented to divert food from trash to charities.

*Table 5 – International organizations and initiatives aimed to the food redistribution*

| | CAMPAIGN | COUNTRY | YEAR | TARGET |
|---|---|---|---|---|
| [67] | FEEDING AMERICA | USA | 1979 | Food bank |
| [68] | CITY HARVEST – RESCUING FOOD FOR NEW YORK'S HUNGRY | USA | 1982 | Food rescue organization |
| [69] | Banco Alimentare | Italy | 1989 | Food bank |
| [70] | Rock and Wrap It Up! | USA | 1994 | Anti-poverty think tank |
| [71] | last minute market | Italy | 1998 | Food redistribution project |
| [72] | FareShare – fighting hunger, tackling food waste | United Kingdom | 2001 | Food supply organization |

| | CAMPAIGN | COUNTRY | YEAR | TARGET |
|---|---|---|---|---|
| [73] | | Italy | 2003 | Food redistribution project |
| [74] | | United Kingdom | 2009 | Charity |
| [75] | | United Kingdom | 2009 | Online retailer |
| [76] | | United Kingdom (Germany) | 2009 (2011) | Social enterprise |
| [77] | | Germany | 2013 | Food-sharing online platforms |
| [78] | | Italy | 2013 | Food-sharing online platforms |

Regulatory measures and governments' programmes and policies

Regulatory measures and initiatives promoted by local governments should be the starting point to reduce, reuse, and recycle food. However, they are not enough widespread. The most important are:

- Commission Regulation (EC) No 1221/2008 of 5 December 2008 that reduces the aesthetic requirements for many fruits and vegetables;
- "Good samaritan food donation act" and the Italian Good Samaritan Law (No 155/2003) created to encourage food donation to non-profit organizations by minimizing liability;
- The French law that bans supermarkets from destroying unsold food and obliges them to give it to charity;
- The Waste Prevention Programme for England that set out the roles and actions for government and others to reduce the amount of waste produced in England;

- The German law on Life-Cycle Management that includes regulations on the prevention, recycling and disposal of waste as well as other waste management measures.

Furthermore, there are national programmes to promote the Food Waste Regulations such as the initiative FoodWaste.ie in Ireland and other EU legislation and policies with implications on food waste, which are summarized in the review document of Vittuari et al. [79].

Research programme and projects

Research programmes frequently support stakeholders to collaborate in developing new methodologies and technologies to prevent food waste. Some of the most interesting topics are sensors and indicators to track and monitor the food conditions and quality along the FSC; new packaging (e.g., Modified Atmosphere, Oxygen scavengers, etc.) able to extend the shelf life of products and platforms to increase public awareness.

On the other hand, calls for project proposal on this theme are encouraging the collaborations between several actors of the food system as demonstrated by the kick-off of ongoing projects such as FUSIONS [80], FoRWaRd (Food Recovery and Waste Reduction) [81] and REFRESH (Resource Efficient Food and dRink for the Entire Supply cHain) [82].

Other initiatives are related to the logistical improvements in the retail environment (e.g., stock management tools, selling plan for product near expiry, etc.) and service venues (e.g., reservation policies, satisfaction surveys to understand and meet customer preferences, etc.) and waste measurement activities involving consumers and employees in order to stimulate food waste reductions in a more effective way.

## 2.2 HCI and IoT in the FSC

Analysing the literature, it emerged that the implementation of Human Computer Interaction (HCI) in the food system has been investigated at each stage of the supply chain. For example, Odom [83] discussed resistances and leverages about the use of interactive technologies in agricultural practices, Kuswandi et al. [84] presented a new method to develop smart packaging able to give feedback

about the product freshness and Wang et al. [85] developed a sensor-based system to monitor the storage conditions of perishable products during the transportation. However, the focus of the present research work is related to the use of smart technologies in the household environment. For this aim, new concepts of household appliances and the growing interest of the IoT world towards the food care issue have been investigated.

As shown from the following references, several efforts have been dedicated to the design and development of smart fridges able to track, monitor and proper manage data related to food products, eating habits and user patterns in order to support consumers in daily practices and to reduce waste.

Some researchers suggest the use of stickers, sliders and/or LCD screen for the domestic refrigerator able to provide useful feedbacks and encourage people to prevent the waste [86].

Gu and Wang [87] presented a Content-aware Fridge based on RFID (Radio-Frequency IDentification) able to monitor the stock of the fridge and suggest an intelligent shopping list depending on user's eating habits and health and the requirements related to food item nutrient components. A virtual prototype of another smart fridge using RFID technology that supports users' in checking goods, creating a grocery shopping list and managing messages has been developed by Bucci et al. [88].

Luo et al. [89] proposed an application for a smart fridge able to provide warnings about food which is going to expire, generate the shopping list and help user to control their diet. In particular, the fridge is equipped with a bar code reader which can scan every item while it passes the door sensor and read the relative information.

T. Sandholm et al. [90] proposed a smart fridge implementing three type of sensors (visual, proximity, and force) able to detect users' actions (e.g., opening/closing of the fridge door) and items presence. The system also integrates two web applications that support the user in managing stocks and consuming the recommended amount of calories and nutrients.

Rouillard [91] presented an application-oriented system that can be used with different technologies (i.e., camera barcode, scanner, voice, and image recognition) and aims to provide reminders to the consumers about deadlines and validity of food stored in the fridge and cupboards.

Li et al. [92] described a smart oven that suggests recipes according to the users' patterns, nutrients intake and cooking history and proposes exercise plan according to the recipe selected or the energy amount user entered.

Chi et al. [93] presented a kitchen augmented with sensors that track the calories and composition of food ingredient and guide user in the meal preparation by means of just-in-time digital feedback.

Schäfer et al. [94] proposed a cooking assistant application that reads out loud the cooking instructions and integrates a speech recognition system to answer questions during cooking.

On the other hand, E. Heiskanen et al. [95] demonstrated the importance to take into account the consumers' resistance towards product innovation and smart technologies. It means that each new feature should be developed according to consumers' needs and requirements in order to be understood and accepted by them.

Furthermore, Grimes and Harper [96] discussed the importance to adopt approaches, during the development of new technologies able to support the human-food interactions, that emphasize the users' skills and help them to exploit their expertise as well as the corrective techniques. Also Kirman et al. [97] stated that persuasive technologies should exploit all existing techniques, in terms of positive and negative reinforcements, in order to motivate real changes and engagement and maximise their effectiveness.

From a commercial point of view, the first smart household appliances start to appear on the market. In particular, LG launched a refrigerator (LFX31995ST) and an oven (LRE3027ST) with the *Smart ThinQ*™ technology [98], which allows managing food items by memorizing their expiration date, accessing to a recipes' database and creating the shopping list as well as the consumption monitoring, the remote control and the smart diagnosis. Franke proposed ovens connected to the app *Franke myMenu* [99] that supports user in the recipes preparation. Also other manufactures presented or are developing connected household appliances, but their functions are mainly related to the remote control, warnings and notifications, maintenance service or web browsing rather than to the food management and preparation. Examples are the range of products of Candy, *Simply|Fi* [100] and GE [101], the smart fridge (RF28HMELBSR/AA) of Samsung [102], *Miele@home* appliances [103] and the *Home Connect* application that should control Bosh and Siemens appliances [104].

As far as the IoT world is concerned several devices have been developed to improve consumers' eating habits, increase food safety and support users' in food preparation:

- *HAPIfork* [105] that helps people to monitor and track their eating habits and eat more slowly in order to avoid digestion problem and control weight;
- *Tellspec* [106] that identifies calories, macronutrients, and allergens in foods, as well as specific nutritional information such as glycemic index and fiber;
- Kitchen smart scales (e.g., Smart Diet Scale [107], Situ [108], Drop [109], etc.) that tell calories and nutrients of food and lead users' in the meal preparation;
- *SmartPlate*™ [110] that is equipped with advanced object recognition and weight sensors which enable it to automatically identify, weigh and analyse your food intake.

Despite the numerous solutions cited, it emerges that a concrete, complete and efficacious tool that allows tracking the food stocks and, consequently, guiding the user in the food management, purchase and preparation has not been presented yet on the market. In particular, none of them provides a food placement training to increase the users' awareness about the storage conditions. The shopping list feature do not suggest the special offers of the supermarkets, which could allow users to save money and encourage them to use the tool with perseverance. The recipes suggestion generally only focuses on the products availability and the users' preferences, neglecting other essential aspects such as the waste prevention and the variegated diet. However, the integration of several smart devices could help to reach more ambitious goals.

The main challenge is to encourage users in reducing waste and changing their eating habits in the most natural way possible. For this reason, the present work would try to fill this gap.

## 2.3 Driving forces and barriers

Analysing the presented context, it emerges the presence of several driving forces that are pushing all stakeholders of the FSC towards the food waste reduction, especially at consumption level. However, at the same time, there are

numerous barriers that obstacle the full success of ongoing initiatives and the launch of new ones.

The global attention to the enormous quantity of edible food wasted at households in industrialized countries are highlighting the contrast with the hunger reality that developing countries deal with. In addition, the growing phenomenon of obesity and overweight are calling urgent and concrete interventions to reduce the onset of health problems. However, the sedentary lifestyle of developed countries makes this task more complicated.

Furthermore, consumers' are more demanding about quality, products variety and safety, on one side, but are little aware about the extent of the food-related problems, on the other side. In particular, the environmental impact of food waste is often unknown for consumers and, consequently, it cannot represent a driver for a more sustainable behaviour.

On the contrary, the reduction of household expenses could play a key-role in changing users' behaviour even if it has to face the effectiveness of marketing strategies in influencing the shopping practices.

The high cost related to the adoption of smart technologies at different level of the FSC limit the advantages coming from their potentialities. At the same time, the world of IoT and HCI is called to lunch on the market user-friendly devices that satisfy the users' needs in order to overcome consumers' resistance towards the technology. In addition, all these aspects should be pushed by governments by means of laws and policies that encourage the food traceability, improve the labelling system, etc., in order to reach the goal of EU to halve the food waste by 2025.

The described drivers and barriers are summarized in Table 6.

*Table 6 – Drivers and barriers toward the household food waste reduction*

| FIELD | DRIVERS | BARRIERS |
|---|---|---|
| **SOCIAL** | ▪ Reduction of paradox between waste and hunger<br>▪ Reduction of the obesity and overweight phenomenon as well as health problems<br>▪ Improvement of consumers' satisfactory and safety | ▪ Limited consumers' awareness about the extent of the food waste problem<br>▪ Wealthier and more sedentary lifestyle in developed countries |

| FIELD | DRIVERS | BARRIERS |
|---|---|---|
| **ECONOMIC** | ▪ Reduction of households expenses | ▪ Market strategies that encourage consumers' to buy more food than necessary<br>▪ Higher investments to ensure the food traceability<br>▪ Smart technologies are more expensive than traditional ones |
| **ENVIRONMENTAL** | ▪ Reduction of environmental damages | ▪ Lack of people awareness about the environmental impact of food waste |
| **REGULATORY** | ▪ Call to halve food waste by 2025 | ▪ Lack of rules that encourage the implementation of food traceability systems and the insertion of the expiration date in the barcode<br>▪ Labelling system unclear |
| **TECHNOLOGICAL** | ▪ Growing market of IoT | ▪ Resistance towards smart technologies or lack of understanding of their real potentialities by consumers' |

# *Chapter 3*

# The methodology

As described in the previous chapters, the role of consumer is essential to efficaciously deal with the food waste issue. For this reason, the present methodology is based on the User Centred Design (UCD) model that puts the user in the centre of the development process. During the years, this process has reached a large diffusion and dedicated international standards has been defined (ISO 9241-210:2010 [111]) in order to provide the best user experience. Although, the literature presents different versions of the same approach, it is founded of three main and common pillars: observe the end-user behaviour, design products/services able to satisfy his/her needs and validate them directly with the end-user. Thus, a high-level system design requires a holistic and knowledge-based approach and must focus on the user's needs satisfaction to support the design of an intelligence-based information management tools.

According to this philosophy, the adopted approach consists of five main steps (Figure 7), which are described in more detail in the following paragraphs:

1. Identification of the users' habits and needs;
2. Definition of the requirements that the new services should respect in order to satisfy the users' needs identified in Step 1;
3. Identification of a general information management model and design of proper algorithms;
4. Design of the smart system through the definition of the general architecture able to realize the desired functionalities as well as to ensure an efficient algorithms implementation;
5. Evaluation of the services offered by the smart system in terms of user appreciation and environmental and economic benefits.

The described approach should be iterate to ensure the continuous improvement and to satisfy new needs and expectations of consumers that arise from the society and market evolution and the technological progress.

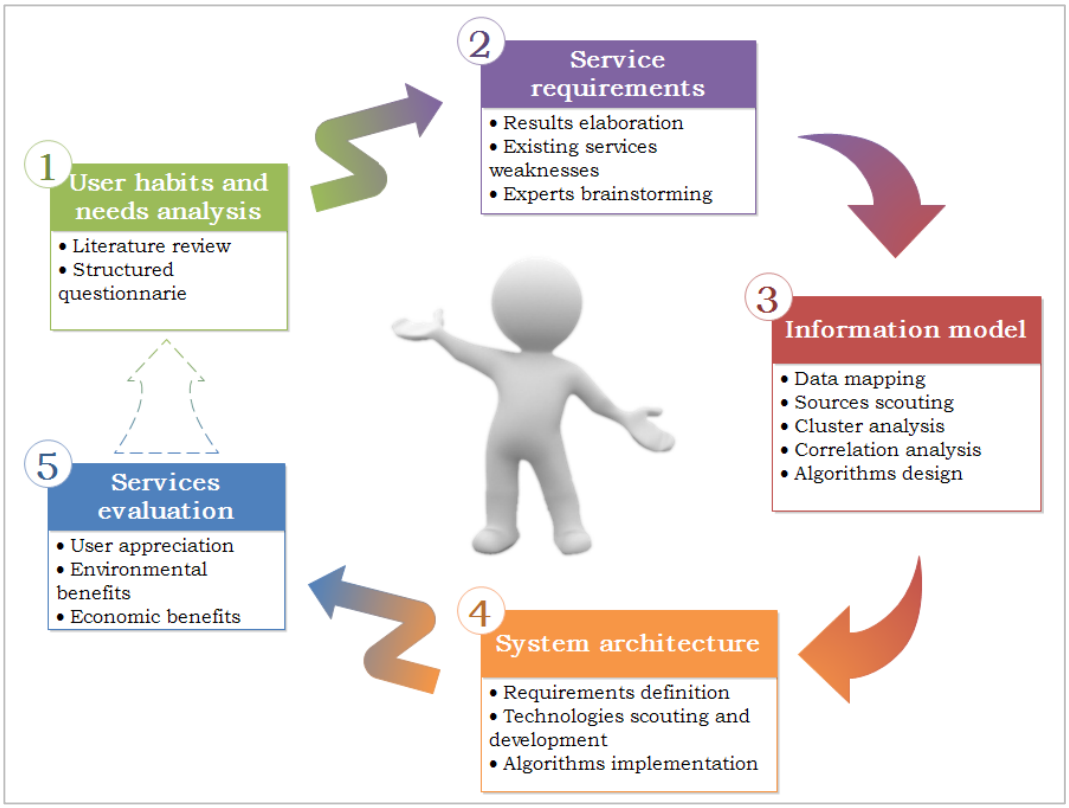



*Figure 7 - User-centred design approach for smart services design*

## 3.1 Analysis of user's needs and habits

This first step is essential to study the users' behaviour, understand users' needs and expectations and translate them into a set of services requirements. For this reason, the literature review, presented in the previous chapters, provided useful ideas and advices about the proper execution of this step and allowed understanding which aspects deserve a particular attention. According to this, the analysis have been carried out by submitting a structured questionnaire to consumers to investigate their eating habits and daily practices about food management as well as driving forces, benefits and barriers of the smart technologies and services related to food care in the household environment. To create the questionnaire and easily distribute it the Google Forms tool has been exploited. Also online platforms such as Facebook, LinkedIn, university network, etc., have been used to ensure a widespread and efficient distribution as well as asking to the potential respondents to forward the link. The survey focuses on Italian family/housing unit so it has been developed in Italian. Questions were

referred to the whole family/housing unit because the characterization of the individual user would be less significant. A total of 234 respondents coming from 20 different Italian provinces participated in the survey. The answers to the questionnaire have been elaborated to define the users' profiles according to the frequency of similar answers and to design new services able to satisfy the users' needs. The variety and size of the user sample allowed obtaining an overall vision of the context and validating the analysis.

In particular, the survey consisted in about 27 questions and was organized in four main sections:

1. Family/housing unit characterization;
2. Eating habits investigation;
3. Food management routines;
4. New services suggestion.

Thanks to questions of the first section it was possible to collect socio-demographics information, define the household profile and correlate the daily practices to specific household's patterns. Table 7 summarize the main characteristics of the sample. In this section, also other qualitative data have been collected in order to better contextualize and interpret the household food-related routines. For example, it emerged that about 42% of people have dinner or lunch out of home and in the majority of cases (40%) respondents declared a high level of cooking skills (level 4 in a 5-point scale).

*Table 7 - Family/housing unit characteristics*

| CHARACTERISTIC | SAMPLE |
|---|---|
| *Household size* | 2,99 (mean) |
| *Presence of children (under 10 years)* | 4,5% |
| *Number of children* | 1,1 (mean) |
| *Income between 20000 € and 50000 € (most common)* | 35,47% |
| *Number of workers* | 1,84 (mean) |
| *Number of meals consumed at home* | 2,52 (mean) |
| *Presence of people with food intolerance/allergies* | 24,89% |

The second section focused on eating habits in terms of food products purchased and consumed more frequently and/or specific diet that users choose to follow. In particular, it emerged that approximately in the 8% of household units there is almost one member that does not eat meat (left graph of Figure 8) and in the 3% of the sample someone does not consume all animal products including eggs and dairy (right graph of Figure 8).

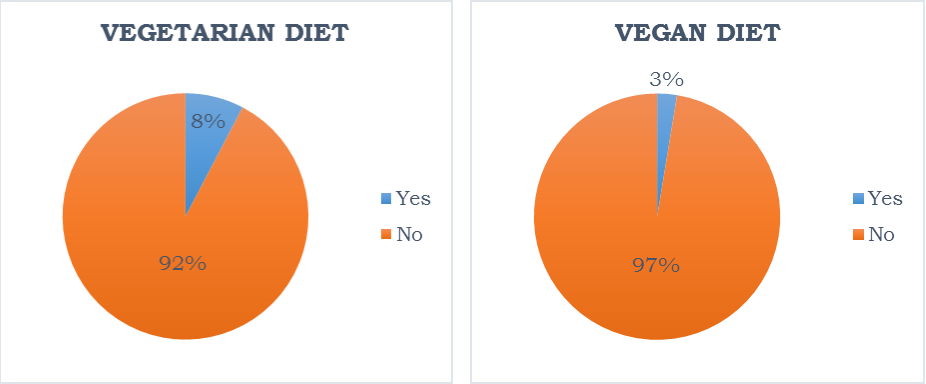



*Figure 8 - Family/housing unit in which almost one member follows a vegetarian (left) or vegan diet (right)*

Questions related to the food stored in the fridge and the refrigerator have been asked to understand which products are more present at home and, consequently, which ones require more attention in terms of dedicated solutions to increase their shelf-life, reduce waste, etc. As shown in the left graph of Figure 9, vegetables are most always present in the fridge (92% of cases) as well as fruits (86%), eggs (82%), cold cuts (78%), milk (76%), and dairy (74%). Most of the time we can find also meat in the fridge (59%) even if it is the most common product into the refrigerator (71%) as well as the ice-cream (69%). Fish (52%), vegetables (41%), and legumes (33%) are the other foods often frozen (right graph of Figure 9). Less frequent is the presence of pasta into the fridge (18%) and ready meal in the refrigerator (11%).

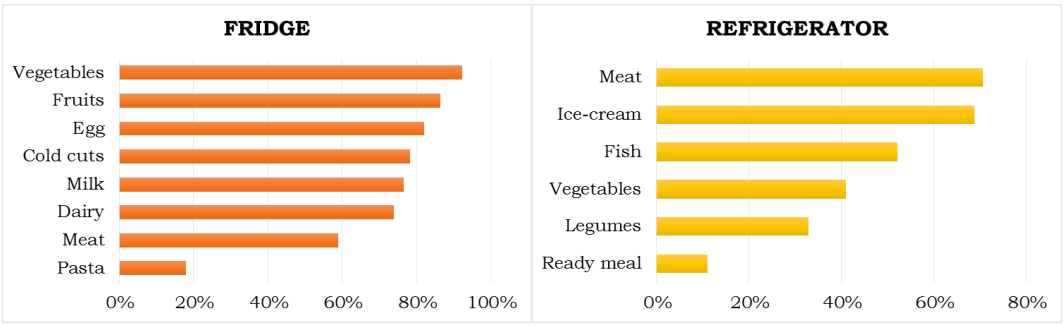



*Figure 9 – Most common foods stored in the fridge (left) and refrigerator (right)*

A great part of this section has been dedicated to the daily meal habits in order to identity typical breakfast, lunch and dinner that can be used as an input for other analysis such as LCA, LCC, etc. In particular, it has been asked to respondents to indicate the food consumed day-to-day for each meal. The answers related to these questions have been elaborated and they are summarized in the following graphs. Assuming that people tend to eat the same things for breakfast every day, only the consumed food has been asked neglecting the frequency. Figure 10 shows that coffee (87%), milk (86%), and cookies (84%) are the most typical breakfast foods for the respondents.

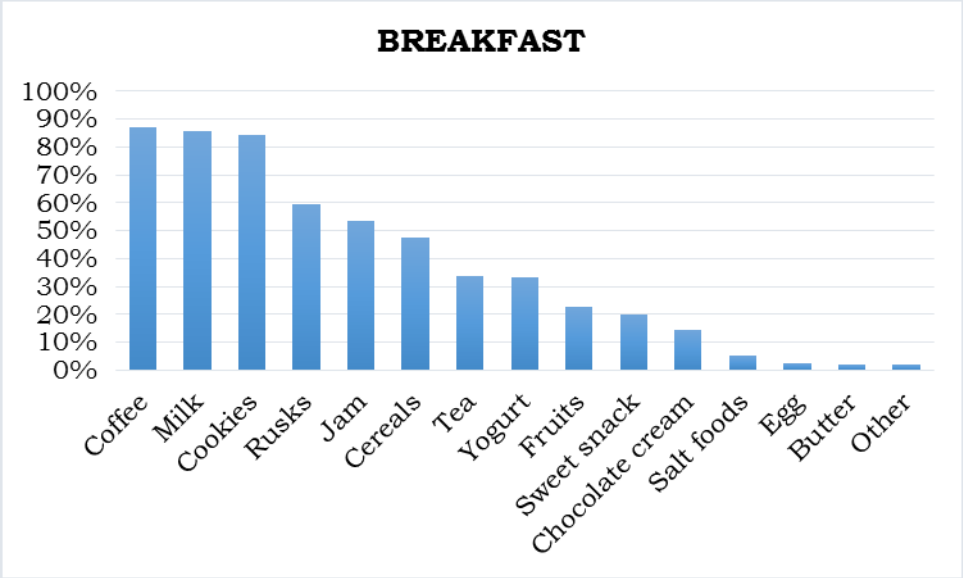



*Figure 10 – Typical food consumed for breakfast*

As far as lunch and dinner are concerned, respondents had to indicate which food they usually consume during the week and how many time. In

particular, observing Figure 11 it emerges that fruits, vegetables and dry pasta are consumed for lunch almost every day, whereas other products like meat, fish, rice, etc., just a couple of time.

LUNCH

| FOOD | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Cold cuts | 28% | 16% | 14% | 7% | 6% | 3% | 6% |
| Fish | 38% | 25% | 11% | 2% | 1% | 1% | 0% |
| Canned fish | 33% | 12% | 4% | 0% | 0% | 0% | 0% |
| Meat | 26% | 18% | 15% | 7% | 7% | 3% | 3% |
| Canned meat | 5% | 0% | 1% | 0% | 0% | 0% | 0% |
| Dry pasta | 3% | 9% | 16% | 12% | 24% | 17% | 10% |
| Fresh pasta | 63% | 9% | 3% | 1% | 0% | 0% | 1% |
| Rice & Cereals | 53% | 24% | 6% | 2% | 1% | 0% | 0% |
| Legumes | 42% | 21% | 14% | 6% | 1% | 1% | 0% |
| Cheese | 25% | 22% | 18% | 10% | 3% | 3% | 2% |
| Egg | 38% | 18% | 5% | 2% | 1% | 0% | 0% |
| Fresh vegetables | 8% | 17% | 22% | 9% | 9% | 9% | 21% |
| Frozen vegetables | 23% | 9% | 5% | 2% | 1% | 0% | 0% |
| Fruits | 5% | 15% | 15% | 7% | 5% | 10% | 39% |
| Ready meal | 12% | 3% | 2% | 0% | 0% | 0% | 0% |

*Figure 11 - Food consumed for lunch*

Observing Figure 12 it emerges the same trend for fruits and vegetables, a higher frequency for meat and cheese and a lower frequency for pasta.

| DINNER | | | | | | | |
|---|---|---|---|---|---|---|---|
| FOOD | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Cold cuts | 15% | 29% | 21% | 12% | 6% | 4% | 5% |
| Fish | 39% | 33% | 11% | 5% | 2% | 2% | 0% |
| Canned fish | 24% | 13% | 2% | 1% | 0% | 0% | 0% |
| Meat | 9% | 26% | 23% | 17% | 13% | 6% | 4% |
| Canned meat | 9% | 3% | 1% | 0% | 0% | 0% | 0% |
| Dry pasta | 13% | 6% | 1% | 0% | 0% | 0% | 1% |
| Fresh pasta | 7% | 1% | 0% | 0% | 0% | 0% | 0% |
| Rice & Cereals | 21% | 9% | 4% | 1% | 0% | 0% | 0% |
| Legumes | 32% | 20% | 10% | 5% | 5% | 1% | 0% |
| Cheese | 21% | 26% | 21% | 9% | 7% | 3% | 2% |
| Egg | 48% | 28% | 9% | 3% | 0% | 0% | 0% |
| Fresh vegetables | 6% | 15% | 20% | 10% | 11% | 15% | 21% |
| Frozen vegetables | 26% | 11% | 7% | 1% | 1% | 0% | 0% |
| Fruits | 6% | 18% | 17% | 6% | 8% | 9% | 32% |
| Ready meal | 14% | 4% | 1% | 0% | 0% | 0% | 0% |

*Figure 12 - Food consumed for dinner*

In the third section of the questionnaire daily routines related to the shopping, food storage and meal preparation have been investigated. For example, it emerged that the presence of special offers (44%) and the location (39%) are the two most important criteria according to which consumers select the supermarket (Figure 13). In addition, more of 40% of respondents declared to have two favourite supermarkets and only the 21% indicated to have not one.

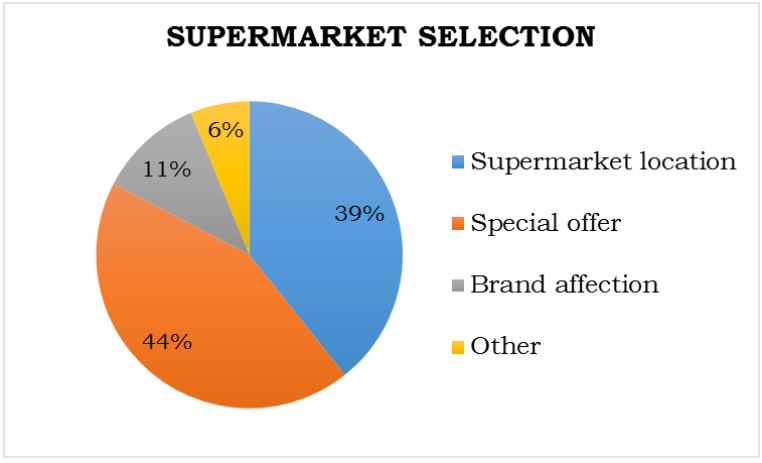



*Figure 13 – Supermarket selection criteria*

In order to verify if the user pay attention to the proper placement of foods inside the refrigerator a specific question has been dedicated to this issue. As shown in Figure 14, the most important drivers for the product placement are the free space in the fridge (55%), the product typology (41%), without criteria (31%), and the food use frequency (18%). It is worth to highlight that only 6% of respondents declared to follow the fridge instructions to guarantee the better storage conditions to the products according to the requirements of each commodity group.

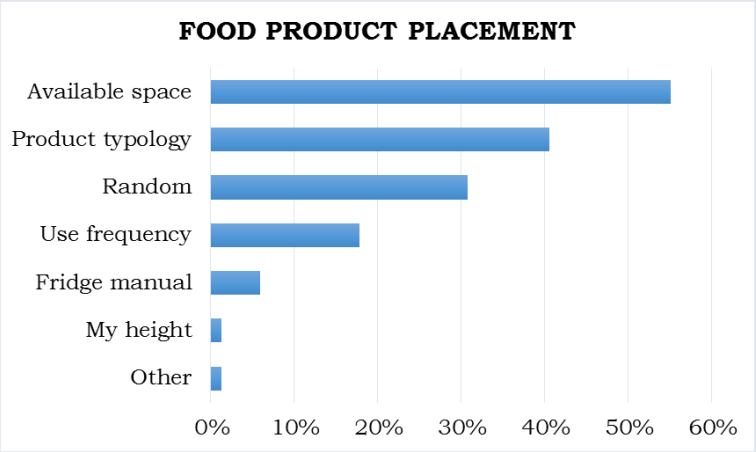



*Figure 14 – Criteria for food placement inside the refrigerator*

As far as recipes are concerned, the results shows that about 7 in 10 respondents choose what to eat according to the ingredients available at home; more than 1 in 2 is influenced by the time required for the meal preparation and almost 1 in 2 aim to follow an healthy diet (Figure 15). Other selection criteria are dishes preferences (38%), the presence at home of ingredients close to their expiration date (30%) and the intention to lose weight following a specific diet plan (24%).

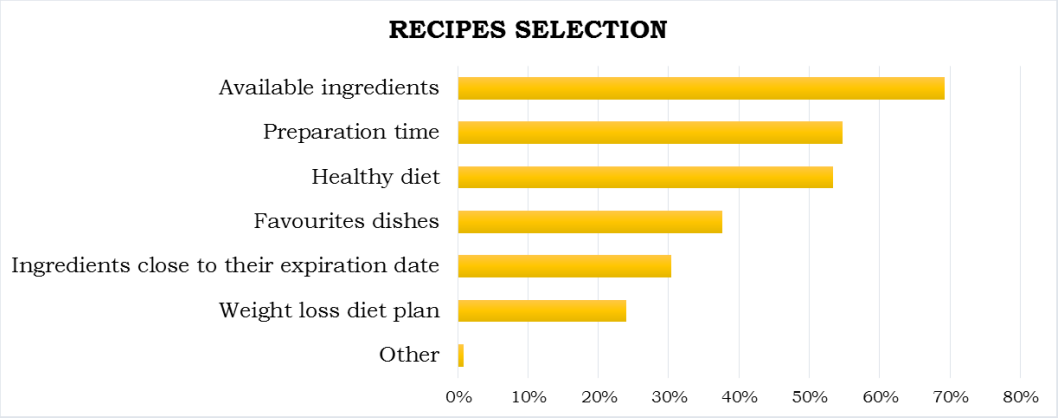
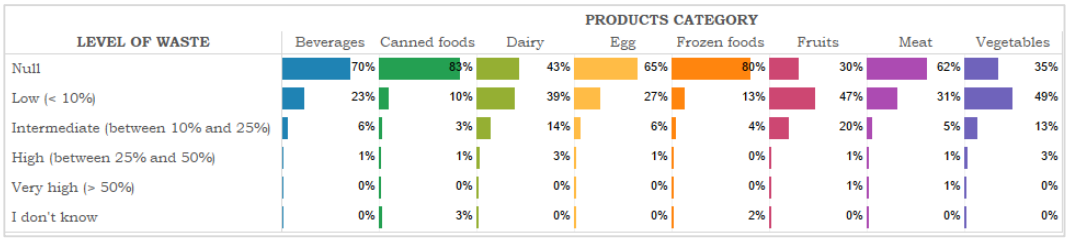



*Figure 15 - Recipes selection criteria*

The last section aimed to know the users' awareness about the household waste, their opinion about the relative causes and their moral attitudes as well as the most efficient solutions that can support them in reducing food waste. For this reason, the graph of Figure 16 shows the most common products wasted according to the users' declaration. It is worth to notice that almost none of respondents selected the "I don't know" option. It could mean that people think to be aware about the level of food waste at home. Furthermore, they indicated a null or low level of waste for the majority of products categories and only in few cases (e.g., fruits, vegetables, and dairy) an intermediate level. These results are a bit in contradiction with the reality presented in the previous chapter related to the context description, highlighting the necessity to increase the consumers' awareness about this issue.



| LEVEL OF WASTE | PRODUCTS CATEGORY | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Beverages | Canned foods | Dairy | Egg | Frozen foods | Fruits | Meat | Vegetables |
| Null | 70% | 83% | 43% | 65% | 80% | 30% | 62% | 35% |
| Low (< 10%) | 23% | 10% | 39% | 27% | 13% | 47% | 31% | 49% |
| Intermediate (between 10% and 25%) | 6% | 3% | 14% | 6% | 4% | 20% | 5% | 13% |
| High (between 25% and 50%) | 1% | 1% | 3% | 1% | 0% | 1% | 1% | 3% |
| Very high (> 50%) | 0% | 0% | 0% | 0% | 0% | 1% | 1% | 0% |
| I don't know | 0% | 3% | 0% | 0% | 2% | 0% | 0% | 0% |

*Figure 16 – Level of waste for each products category according to users' answers*

Analysing the causes of household food waste – summarized in the chart of Figure 17 – it emerges that users concern about food waste. However, they tend to purchase or cook too much food and leave products to pass their expiration date. These results confirm some of the causes identified at international level.

The user's behaviour has been investigated in more detail to identify their attitude to the waste. For example, in case a product passes its expiration date 1 in 3 said to taste it, 1 in 6 to throw it away and 1 in 2 to behave differently according to the product typology.

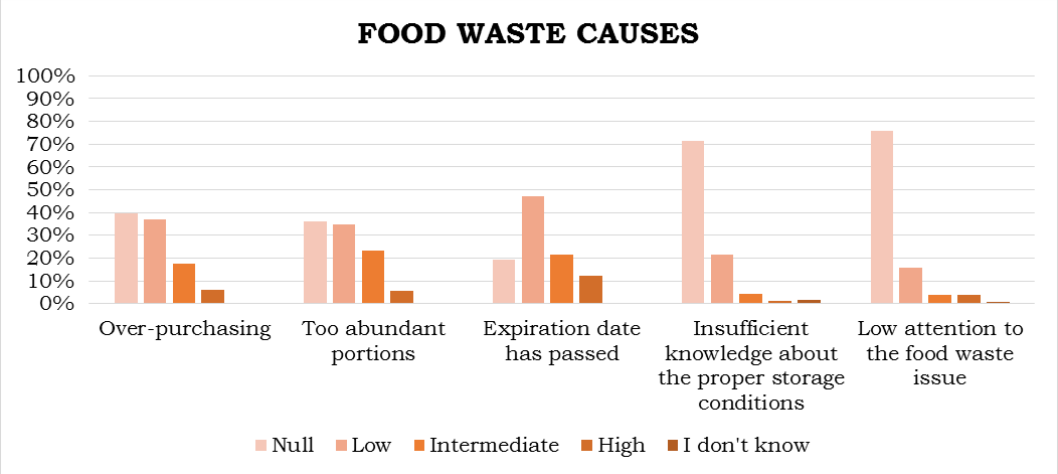



*Figure 17 – Causes of household food waste according to users' answers*

After the investigation of the users' confidence level with the technology, the appreciation of new services offered by smart technologies (e.g., smart fridge, web application, etc.) has been evaluated. As shown in Figure 18, all proposed services received a good appreciation. However, processing and analysing the results in more detail, it is possible to notice a higher preference to the functionalities related to the recipes and special offers suggestion compared to the remote control or energy consumption monitoring functionalities.

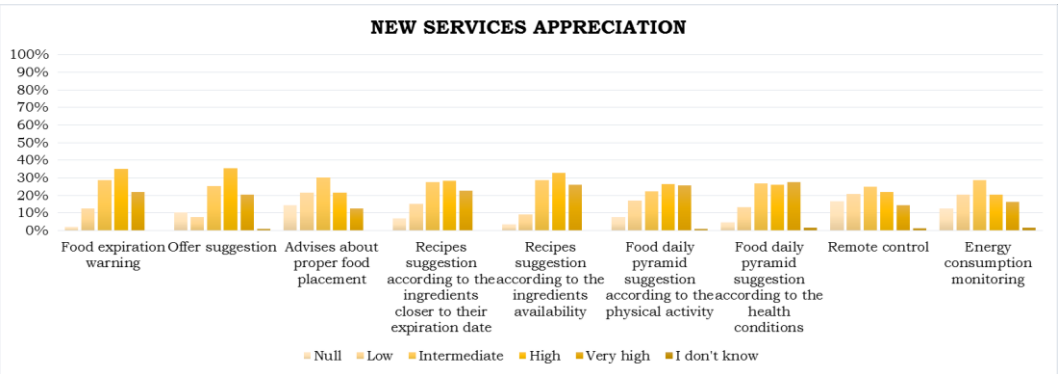



*Figure 18 – Users' appreciation of new services that aim to reduce the household food waste*

## 3.2 Services requirements

Thanks to the analysis of the survey results it was possible to define the requirements of new services, which aim to satisfy the identified users' needs. This step has been carried out by organizing a couple of brainstorming sessions with experts of several company departments (i.e., R&D, marketing, etc.) to review the results and the services proposals. In these occasions, the technical and economic feasibility has been evaluated as well as the features appreciation.

The development of any functionality requires the implementation of a traceability system that allows knowing the stocks and the relative expiration dates. The benefits of this system are indirect because they derive from correlated services. Therefore, it has to be less invasive possible for the user. For this reason, automatic solutions have to be preferred. In particular, the system should be able to answer the following questions:

- *Which product is at home? In which quantity?*
- *Where is it stored?*
- *When did the user buy it?*
- *When does it expire?*
- *Has the user consumed it? Partially or entirely?*

Thanks to this information and appropriate warnings and reminders, it is possible to prevent that products pass their expiration date and the purchase of items that users leave to expire frequently, to create a grocery shopping list according to foods present at home and to monitor the consumption of periodic

products. However, it is important not overload users with warning messages, therefore, the notifications should be provided moderately and at the right time.

Another advantage of the adoption of the traceability system is the possibility to suggest recipes that require ingredients close to their expiration in order to support user to reduce food waste. At the same time, to suggest recipes that allow minimizing purchases by exploiting ingredients already available at home is very appreciate by the user because more practical. Furthermore, this service can be extended by considering the physical activity of the user as well as body characteristics in order to create a food daily pyramid that help users' to control their weight. In addition, by tracking possible users' food disorders it is also possible to prevent health problems. These services to be effective should take into account:

- Users' preferences to satisfy their expectations;
- Historical data to suggest a variegated diet;
- Nutrient content to follow a balanced diet;
- Calories to respect the recommended daily calorie intake.

The main goal is to reach the right balance between sustainability and healthiness.

Another service that could be provided is the suggestion of special offers, which resulted one of the most important drivers of the shopping practices. The integration of offers information with the shopping list and the data provided by the traceability system allow supporting users in the purchase planning by suggesting alternative products according to the cheaper prices, advising to anticipate or postpone some purchases in relation to the discounts validity period and reminding the imminent expiration of offers related to items inserted in the shopping list.

From the survey, it emerged that the training about the proper food placement in the fridge is not one the most appreciate functions. However, people stated to not follow the manufactures' instructions in putting foods in the refrigerator. These evidences suggest that consumers need to be guided in managing their stocks in a very discrete and natural way. For example, highlighting the proper fridge compartment according to the food category when the fridge door is open could encourage users to follow the advises and increase the shelf-life of products.

Additional services related to the suggestion of practical information about opening time of supermarkets and pharmacies, their locations, etc., could complete and enhance the system appreciation.

It is worth to specify that all the described features should be user-friendly considering the average user as target.

A strong point of the proposed services should be the integration and the synergy between them in order to overcome the limits of the existing systems. Indeed, the world of IoT is often technology-oriented, focuses on a specific feature and neglects the users' needs and expectations. In addition, the importance of a high-level information management is still underestimated.

## 3.3 Information model

The creation of new services according to the defined requirements entails managing a large amount of information, identifying the sources that provide reliable data, understanding their explicit and tacit relationships and identifying logical rules able to ensure an efficient system operation. To do that, information must be properly selected, interpreted and processed. For this aim, a mapping and a classification of all relevant data generated along the FSC has been carried out in order to properly design and populate the database. In particular, food products and the relative characteristics (e.g., calories, total fats, carbohydrates, etc.) have been mapped, grouped in homogeneous categories and correlated with information related to the following entities of the food supply-chain: Shopping lists & Supermarkets (purchase), Stocks' inventory (traceability/consumption), Fridge (storage) and Recipes & Oven (preparation).

In particular, for the purchase phase, data related to the supermarkets (i.e., name, location, opening time, relative large-scale retail trade, etc.), offers (i.e., start and end date, brand, price, discount, etc.) and shopping list (i.e., product, quantity, etc.) have been collected in order to map and suggest offers to the user according to him/her real needs and purchase habits (e.g., favourite place, most frequent products, etc.). As a source of the supermarkets' information the relative websites have been chosen. Furthermore, data have been grouped according to the large scale retail trade and the geographic position of the supermarket in order to make the algorithm computational activity more efficient.

In order to ensure an updated inventory of stocks the characteristics of food items available at home have to be stored such as the ID, the name of the product, the quantity, etc. They are useful to implement the traceability function and prevent that foods reach and pass their expiration date. In this case, foods have been organized into homogeneous categories (e.g., fruits, meat, fish, etc.) in order to simplify their management and suggest tailored best-practices, especially in relation to the optimal storage conditions. According to the literature, several classification criteria are possible (i.e., type, nutrients, processing, etc.), therefore, the most common and user-friendly classification has been selected.

Information that concerns the fridge layout and features (i.e., compartments, temperatures, etc.) are exploited to ensure the best storage conditions and increase the product shelf-life. These data have been collected thanks to the R&D activities and expertise of the *Cooling Business Unit* of the Indesit Company that allow it to continuously innovate its products according to the foods requirements.

The meal preparation is supported by the storage of the data related to the recipes (i.e., ingredients, servings, instructions, etc.) and the oven features (i.e., cooking programs, temperatures, etc.). These data have been collected by investigating the structure of the most famous websites of recipes and by integrating international open databases with the expertise of the *Cooking Business Unit* of the Indesit. The latter also suggested the most proper cooking programs according to the meal and the oven characteristics.

In addition to the food products, the developed system also considers medicines and pharmacies with the relative characteristic data (i.e., prescriptions, expiration dates, opening times) in order to provide useful reminders to the user, track the left quantities and make the possible repurchasing easier. In this case, the open database provided by the Ministry of Health has been used.

Finally, users information has to be considered in order to tailor the algorithm according to their eating habits and shopping preferences. For example, the suggestion of recipes must take into account possible users' allergies or intolerances, the notifications about special offers should prefer those of the favourite supermarket, etc.

In Figure 19 the main relationships between data of each entity have been represented. In particular, the shopping list should be created according to the stocks and, consequently, to the product finished, expired or close to expire. Also

the special offers of the supermarket should be taken into account during the selection of products to insert in the list. The opening time of pharmacies and supermarkets is an additional information that could be very useful for the user that is planning to go shopping. In order to ensure the optimal storage conditions of products, a link between the food category and the fridge compartment has to be created. On the other hand, the suggestion of the best recipes requires to know the ingredients available at home and which ones have to be bought. In addition, preferring the product close to their expiration and correlating the recipes to the user information it is possible to reduce the waste, prevent health problems and face the obesity phenomenon. Finally, to each recipe the best cooking program could be associated.

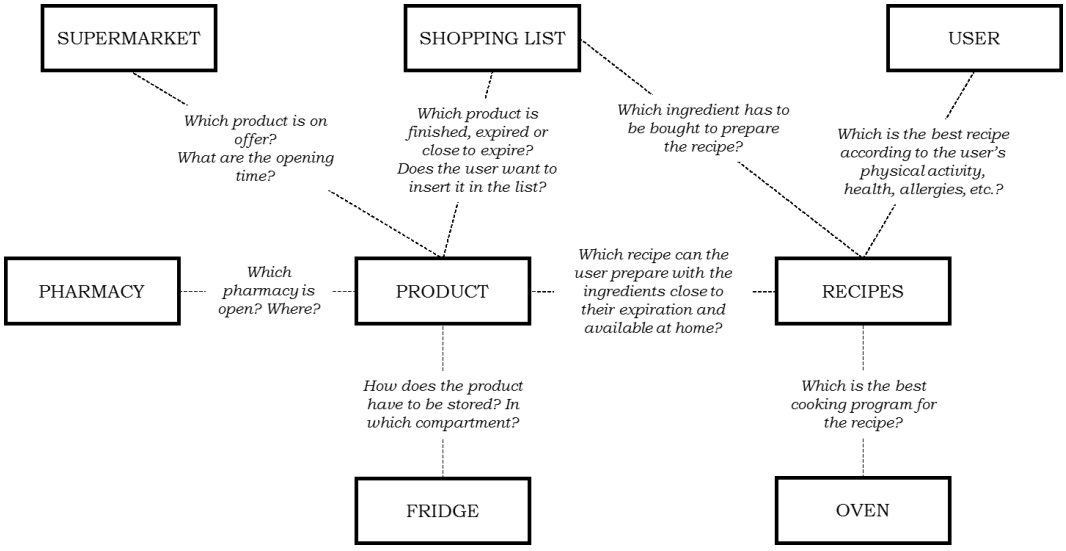



*Figure 19 – The information model*

The rationale, which allows a high-level management of the information and the relative relationships, should consist of several algorithms able to implement the services identified and to respect their requirements. In particular, they should:

- Track the products check-in and check-out;
- Periodically verify the expiration dates of products to manage warnings and reminders;
- Monitor the left quantity and the expiration of products in order to suggest the repurchase if necessary;

- Periodically verify the special offers, especially if related to the products that have to be repurchased or have been inserted in the shopping list;
- Identified the best recipes according to several factors such as users' information, preferences and habits, ingredients available and close to expire, etc.;
- Suggest the proper cooking programs for the selected recipe;
- Suggest the fridge compartments according to the food category;
- Provide supermarkets and pharmacies information when required;
- Interpreter statistical information to improve the offered services.

## 3.4 System architecture

The most common system used to automatically identify and manage the flow of food products from receipt at a retailer's depots and stores is the barcode. Its adoption improved retailers' efficiencies by enabling product descriptions and prices to be captured accurately at the checkout and allowing the update of the stock management and financial system. However, barcode does not contain essential data such as the batch information, the product source and the expiration date of items. Furthermore, the presence of different standards for the data recording does not facilitate the barcode decoding. These difficulties obstacle the food traceability, especially at consumption level.

The impossibility to read the expiration date of products from the barcode entailed the investigation of alternative solutions that could enable the development and implementation of the proposed system and services. In particular, RFID and NFC (Near Field Communication) technologies have been considered. Indeed, by equipping the fridge and/or the pantry with a RFID or NFC reader it is possible to support user in managing their stocks in a semi-automatic way. On the other hand, these devices should be connected to the Internet to allow the interaction with a web application that properly exploit and manage the collected data. The latter should be stored in a well-structured database that allows their elaboration in an efficient way. The application should be multi-platform (i.e., Android, iOS, etc.) to cover a wider range of users and run on multiple devices to ensure more flexibility (i.e., smartphone, pc, fridge display, etc.). In addition, the architecture should be more modular as possible to be easily adapted to market changes and evolution.

It is worth to specify that this solution is effective for the packaged products, but it has some limitations with fresh products (e.g., vegetables, fruits, etc.) because their expiration date is not indicated. Indeed, in this case, only the purchase date can be tracked. For this reason, a literature review and a scouting of commercial technologies about sensors able to detect the shelf-life of products have been conducted. The low cost and the high accuracy of data are the two main requirements for a feasible and safety implementation in a household appliance. In particular, several methodological approaches, passive sensors, e-nose and e-tongue have been investigated and implemented by researchers in the food industry [112] [113] [114], but they mainly focus on quality control during the processing stage. Furthermore, about 20 commercial sensors (e.g., AIRSENSE Analytics, Biomemristic Technologies, Electronic Sensor Technology, etc.) have been identified, but none of them could be used in the described architecture because too expensive or limited to a laboratory use. For this reason, some collaborations with sensors' producers has been established in order to develop tailored solutions. The main difficulties are related to the presence of many products in the fridge that emit different substances during their degradation process. Therefore, the fridge layout should be redesigned in order to create closed boxes equipped with a dedicated sensor for a specific product typology. Obviously, this is a utopian solution. Thus, further studies are required to develop new technologies that allow reaching the ambitious goal. Also the responsibility related to the suggestion to the user to consume foods without expiration date, but still edible, is a critical issue that should not underestimated. Considering these evidences, this work will not treat the implementation of such sensors in the proposed system. However, it is considered as a future work.

## 3.5 Services evaluation

In order to evaluate the effectiveness of the developed services several perspectives have to be considered: social, environmental, and economic. Furthermore, these three aspects are strongly interrelated. Indeed, to satisfy the users expectations encourages the services appreciation and diffusion and, consequently, allows achieving important goals from an environmental and economic point of view. On the other hand, the reduction of the environmental impact and the economic benefits are the key-divers to push consumers' to exploit

the proposed smart system. Therefore, only positive results in all three aspects can ensure the success of innovative solutions. Conversely, any inefficiencies should be the stimulus for the continuous improvement.

In particular, the consumers' satisfaction has to be evaluated by involving the end-users' in the evaluation process. Therefore, the proposed services have to be tested by them in order to identify positive and negative aspects in terms of features, interface, usability, usefulness, etc.

The environmental benefits can be evaluated by means of the Life Cycle Assessment analysis. In this case, a comparison between the reference situation and the proposed system has to be carried out. It is important to consider more phases of the life cycle. Indeed, the increase of the impact in the manufacturing phase should be compensated by the benefits in the consumption or end-of-life phase.

Thanks to the Life Cycle Costing analysis the economic benefits deriving from the system adoption can be evaluated. Also in this case, a comparative analysis has to be executed and different phases of the life cycle should be considered.

# *Chapter 4*

# The system architecture

According to the requirements defined in the previous chapter, the system architecture has been created. It consists in a cloud database, a smart fridge and a web application (Figure 20). The interaction between these three modules allows implementing a smart system able to enrich the data collected from the FSC and offer useful services to the users during the purchase, storage, preparation, and consumption phase.

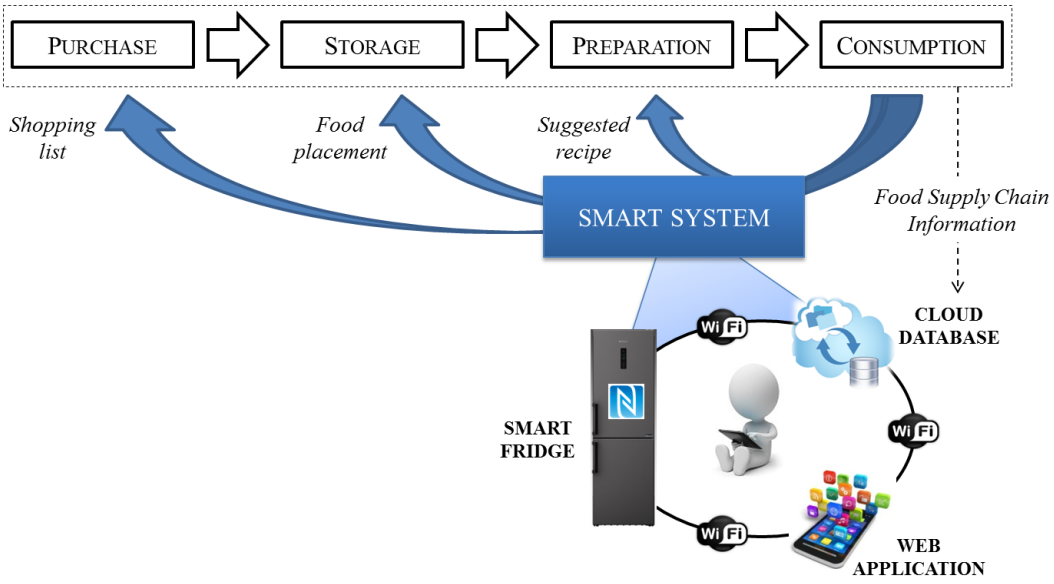



*Figure 20 – System architecture*

## 4.1 The cloud database

The cloud database collects data provided by the food supply-chain and generated from the interaction between the user and the proposed system. To ensure the optimal storage and elaboration of data, the standard design process of databases has been followed. Once understood the information that has to be stored in it – third step of the methodology – the data dependency has been analysed. In particular, the Entity-Relationship model (ER model) has been created and it has been analysed and reviewed with stakeholders more and more

times. The ER model allowed better understanding the domain, clarifying the terminology and creating logical connection between several concepts. The first step consisted in the definition of the main entities and the relative attributes, the second one in the definition of the relationships between entities and the relative cardinalities, and the last one in the identification of all primary keys, foreign key constraints and other constraints (i.e., not null, unique and check). The resulting schema has been refined according to the quality requirements such as completeness, correctness, readability, and flexibility.

After, the ER model has been translated to a rational schema, which consists of 16 main entities: *Product*, *Category*, *Fridge compartment*, *Product list*, *Shopping list*, *Item*, *Brand*, *Supermarket*, *Supermarket brand*, *Pharmacy*, *Recipe*, *Cooking program*, *Dish*, *Dish Typology*, *User* and *Physical activity*. On the other hand, the relationships between these entities have been translated in a different way according to their cardinality. Indeed, the many-to-many relationships such as *Ingredient*, *Preparation*, *Recipe Characterization*, *Meal Consumed*, *Special offer*, *Favourite supermarket*, and *Favourite pharmacy* have been represented as a new tables, whose columns are the primary key attributes of the participating entities and any descriptive attributes of the relationship. The one-to-many relationships have been translated by adding the primary keys of the 1 cardinality entity as a foreign keys of the N cardinality entity (e.g., "Food category_name" in *Product*, "Brand_name" in *Item*, etc.). The final database model is represented in Figure 21. The coloured layers has been created to increase the readability of the model. Indeed, they group entities belonging to the same food-related activity (storage, preparation, and purchase). It is worth to specify that the links not represented in the schema are managed by software (e.g., suggestion of recipes according to the user information and activity, suggestion of the pharmacies opening time when a medicine is finished and has to be repurchased, etc.).

According to the described model, the database structure has been created by using mySQL, which is a famous open source RDBMS (relational database management system).

The database has been populated in Italian since the target users are Italian people. However, its translation in English will be the first step after the system validation.

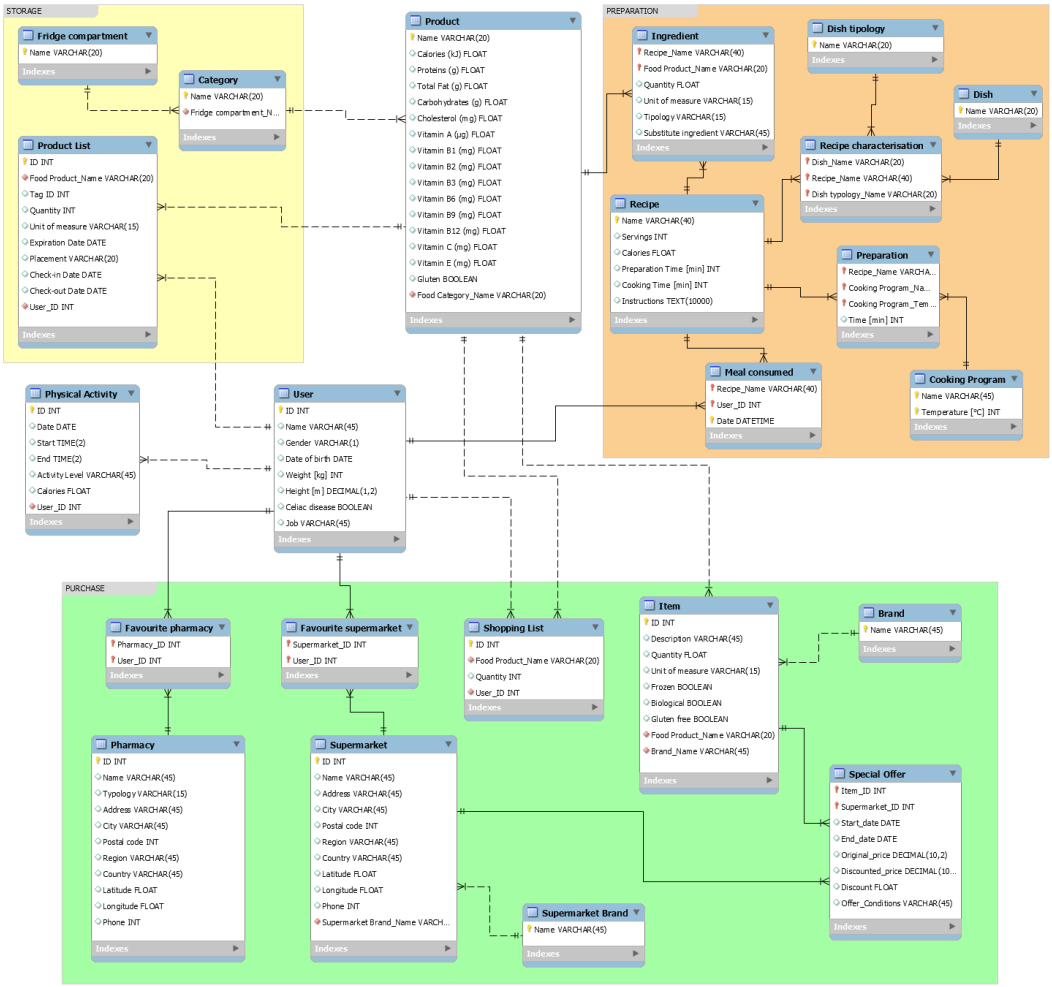



*Figure 21 - Database model*

As far as its population is concerned, several sources have been exploited. In particular, the table *Category* consists of 16 records such as fruits, meat, fish, dairy, beverages, etc. For this aim, the most common food classifications presented by the international organizations has been reviewed. The entity *Product* contains 392 records that represent the most common Italian foods. Data have been gathered by consulting several databases available in literature. The list has been validated by verifying that each product of ten leaflets of different supermarket brands could be associated to a record of the table. Furthermore, a category has been assigned to each product of the table by respecting the referential constraint. However, to ensure greater flexibility, the value “other” for

each food category has been inserted (e.g., other vegetables, other meat, etc.). In Figure 22 an extract of the entity "Product" is shown.

| Food Name | Food Category | Calories (kJ) | Protein (g) | Total fat (g) | Carbohydrates (g) | ... | Gluten |
|---|---|---|---|---|---|---|---|
| Almond | Fruits | 24.970.000 | 205.000 | 558.000 | 51.000 | ... | Y |
| Anchovy canned | Fish | 7.620.000 | 254.000 | 89.000 | 0.0000 | ... | N |
| Apple | Fruits | 2.210.000 | 0.3000 | 0.2000 | 127.000 | ... | N |
| Apple juice | Drinks | 1.200.000 | 0.2000 | 0.0000 | 70.000 | ... | N |
| Apricot | Fruits | 1.510.000 | 0.8000 | 0.1000 | 70.000 | ... | N |
| Artichoke | Vegetables | 940.000 | 33.000 | 0.2000 | 15.000 | ... | N |
| Asparagus | Vegetables | 860.000 | 30.000 | 0.1000 | 17.000 | ... | N |
| Avocado | Fruits | 8.430.000 | 18.000 | 216.000 | 0.4000 | ... | N |
| Bacon rasher | Cold cuts | 6.370.000 | 219.000 | 58.000 | 31.000 | ... | N |
| Baked beans | Legumes | 3.220.000 | 49.000 | 0.5000 | 102.000 | ... | N |
| Banana | Fruits | 3.660.000 | 14.000 | 0.3000 | 196.000 | ... | N |
| Bar, muesli or snack | Dessert | 16.450.000 | 66.000 | 124.000 | 651.000 | ... | Y |
| ... | ... | ... | ... | ... | ... | ... | ... |

*Figure 22 – Entity "Product"*

The table *Fridge compartment* has been populated in collaboration with some engineers of the Cooling Business Unit of the company. It contains 8 records, however, they could change in relation to the different fridge models. In this case, the structure of the developed smart fridge has been considered. Also the table *Cooking programs* has been populated in collaboration with some engineers of the company (Cooking Business Unit). The most common five programs have been considered (i.e., conventional, fun, grill, fun grill, and pastry) and associated to different temperatures. To classify the recipes, 5 records (i.e., starters, first course, second course, side dish, and dessert) have been inserted in the table *Dish* according to the most common structure of the Italian restaurants' menu and 5 records (i.e., meat, fish, hot, cold, and vegetarian) in the table *Dish typology* that reference to the filters used by the most famous Italian recipes websites. However, other recipes' tags could be managed in the future (e.g., cost, difficulties, etc.). The table *Recipe*, linked to the latter ones by means of the table *Preparation* and *Recipe characterization*, consists of 53 records. In Figure 23 an extract of this table is shown (English version). Furthermore, this table has been linked to the table *User* to track the meal consumed.

| Name | Servings | Calories | Preparation time [min] | Cooking time [min] | Instructions |
|---|---|---|---|---|---|
| Grilled Chicken | 4 | 1020 | 15 | 15 | Preheat grill for high heat.<br>In a bowl, mix the peanut butter, lime juice, soy sauce, garlic, curry powder, and cayenne pepper.<br>Lightly oil the grill grate. Place chicken on grate, and brush with 1/2 the sauce. Grill 6 to 8 minutes. Turn chicken, and brush with remaining sauce. Continue grilling 6 to 8 minutes, until chicken juices run clear. |
| Mushroom risotto | 4 | 2040 | 5 | 15 | Put the dried mushrooms into a large bowl and pour over 1 litre boiling water. Soak for 20 mins, then drain into a bowl. Chop the mushrooms.<br>Heat the oil in a pan over a medium flame. Sauté onions with butter. Add mushrooms, season with salt and pepper and continue to cook for 8 mins until the fresh mushrooms have softened.<br>Tip the rice into the pan and cook for 1 min. Keep the pan over a medium heat and pour gradually in a quarter of the mushroom stock. Simmer the rice, stirring often, until the rice has absorbed all the liquid and it starts to become creamy, plump and tender.<br>Continue stirring until the rice is cooked. If the rice is still undercooked, add a splash of water. Take the pan off the heat, add the butter and scatter over half the cheese and the parsley. |
| Chocolate cookies | 24 | 6960 | 20 | 10 | Mix butter, white sugar, eggs and vanilla in large bowl. Stir in flour, baking soda and salt (dough will be stiff). Stir in chocolate chips and nuts.<br>Drop by large spoonfuls onto ungreased pans.<br>Bake for about 10 minutes in the preheated oven, or until edges are nicely browned. Cool slightly; remove from cookie sheet. |
| ... | ... | ... | ... | ... | ... |

*Figure 23 – Entity "Recipe"*

The most famous brands of large retailers have been considered and 124 records have been inserted in the table *Supermarket brand*. At the moment, the table *Item* consists of 281 records and the table *Brand* of 95 records. Considering the enormous variability of the products available on the market, it should be evaluated the possibility to create a shared platform that encourages users to populate these two tables.

The other tables related to the food purchase focus on the supermarkets of Ancona. This is due to the impossibility to receive, in an electronic way, the special offers of the supermarkets few days before their start date. Therefore, in order to validate the system, a manual population has been carried out and the target has been limited. In particular, the table *Supermarket* consists of 38 records and the table *Special offer* counts on average 2500 records since they are temporary because of their validity period. An extract of the latter table is shown in Figure 24.

| Item ID | Supermarket ID | Start date | End date | Discounted price | Original price | Discount | Offer conditions |
|---|---|---|---|---|---|---|---|
| 88 | 1 | 26/03/2015 | 04/04/2015 | € 2,69 | € 3,59 | 25% | |
| 89 | 1 | 26/03/2015 | 04/04/2015 | € 1,34 | € 1,79 | 25% | |
| 90 | 1 | 26/03/2015 | 04/04/2015 | € 1,79 | | | |
| 91 | 1 | 26/03/2015 | 04/04/2015 | € 2,39 | | | |
| 92 | 1 | 26/03/2015 | 04/04/2015 | € 1,59 | | | |
| 93 | 1 | 26/03/2015 | 04/04/2015 | € 3,99 | | | |
| 94 | 1 | 26/03/2015 | 04/04/2015 | € 0,69 | | | |
| 95 | 1 | 26/03/2015 | 04/04/2015 | € 3,89 | | | |
| 96 | 1 | 26/03/2015 | 04/04/2015 | € 2,99 | | | |
| 97 | 1 | 26/03/2015 | 04/04/2015 | € 7,98 | | | |
| 98 | 1 | 26/03/2015 | 04/04/2015 | € 3,49 | | | |
| 99 | 1 | 26/03/2015 | 04/04/2015 | € 5,40 | | | |
| 100 | 1 | 26/03/2015 | 04/04/2015 | € 7,77 | | | |
| 101 | 1 | 26/03/2015 | 04/04/2015 | € 3,99 | | | |
| 102 | 9 | 04/06/2015 | 17/06/2015 | € 0,89 | | | 100% Refunded: vouchers of 5€, 10€ |
| 103 | 9 | 04/06/2015 | 17/06/2015 | € 0,79 | | | 100% Refunded: vouchers of 5€, 10€ |
| ... | ... | ... | ... | ... | ... | ... | ... |

*Figure 24 – Entity "Special offer"*

To populate the table *Pharmacy* the open database of Ministry of Health has been used. In particular, it includes all the Italian pharmacies and consists of 18422 records. An extract of the table is shown in Figure 25.

| ID | Name | Address | City | Postal code | Region | ... |
|---|---|---|---|---|---|---|
| 10052 | COMUNALE 2 VELLETRI | Via Filippo Turati, 9 | VELLETRI | 00049 | LAZIO | ... |
| 10053 | RIPOLI ROBERTO | Via Fratelli Wright, 39 C/D | CIAMPINO | 00043 | LAZIO | ... |
| 10054 | SENESI ALFREDO | Via Col di Lana, 152 | CIAMPINO | 00043 | LAZIO | ... |
| 10054 | SENESI ALFREDO | Via Col di Lana, 152 | CIAMPINO | 00043 | LAZIO | ... |
| 10054 | SENESI DR. ALFREDO | Via Col di Lana, 148/166 | CIAMPINO | 00043 | LAZIO | ... |
| 10055 | LE VELE DI CARRADORI PAOLA | Via Scipione Borghese, 31 | NETTUNO | 00048 | LAZIO | ... |
| 10055 | EUROPA DI TIMPANO UGO & C. SNC | Via Aldo Moro, 19 | NETTUNO | 00048 | LAZIO | ... |
| 10055 | EUROPA DI TIMPANO UGO & C. SNC | Via Scipione Borghese, 31 | NETTUNO | 00048 | LAZIO | ... |
| 10056 | ARRIGO ROSSELLA | Via Vittorio Emanuele, 45 | MONTE ROMANO | 01010 | LAZIO | ... |
| 10056 | MINELLI DAVID | Via Vittorio Emanuele, 45 | MONTE ROMANO | 01010 | LAZIO | ... |
| 10056 | MINELLI DAVID | Via Vittorio Emanuele, 45 | MONTE ROMANO | 01010 | LAZIO | ... |
| 10057 | BARBAGLI CARLO FELICE | Via Giuseppe Garibaldi, 52 | ORTE | 01029 | LAZIO | ... |
| 10057 | BARBAGLI CARLO FELICE | Via Giuseppe Garibaldi, 52 | ORTE | 01028 | LAZIO | ... |
| 10058 | S.BARTOLOMEO DELLA DR.SSA STEFANIA | Corso Umberto I, 33 | RONCIGLIONE | 01037 | LAZIO | ... |
| 10058 | S.BARTOLOMEO DELLA DR.SSA STEFANIA | Corso Umberto I, 33 | RONCIGLIONE | 01037 | LAZIO | ... |
| ... | ... | ... | ... | ... | ... | ... |

*Figure 25 – Entity "Pharmacy"*

Finally, the population of the tables *Product list*, *Shopping list*, *User* and *Physical activity* occurs automatically when the user interacts with the smart system, therefore, they have not been described in this paragraph. In the same way, the preferences of the users about supermarkets and pharmacies populate the relative tables *Favourite supermarket* and *Favourite pharmacy*.

## 4.2 The smart fridge

In collaboration with the Indesit Company, a smart fridge has been developed to ensure the food traceability at household level. It is equipped with a NFC reader and a communication node. The first allows reading specific NFC tags that the user has to put on the product packaging and configure according to the food information (e.g., name, quantity, expiration date, etc.). The second allows the fridge to communicate via Wi-Fi with the router and, consequently, interact with the application. The picture in Figure 26 shows the first prototype that has been developed to test and optimize the proposed system: it consists of all electronic devices that have to be used to simulate the system operation such as electronics boards, sensors, and tags.


*Figure 26 – The first "smart fridge" prototype*

The picture in Figure 27 shows the last prototype of the smart fridge, ready to be tested with end-users. In particular, the right picture shows the tag reader in detail, which is placed on the left side of the cabinet. The tags are of different colours, which could be associated to different product categories, in order to increase the usability of the system.

*Figure 27 – Smart fridge*

In particular, when the user purchases a new product he/she can use and set a tag and execute the check-in. In this way, the application recognizes the presence of the product and manages proper reminders/warnings for the user if necessary. Furthermore, if the user gets out a food, the fridge executes the check-out automatically. In the case where the food are partly consumed, but not entirely, a new check-in has to be performed that automatically cancels the previous check-out and the left quantity can be updated. Tags can be reused and reset by the user. The Figure 28 shows how the check-in and the check-out work.

*CHECK-IN*


*CHECK-OUT*


*Figure 28 – Check-in and check-out steps*

The use of tags is very useful especially for the products that are periodically purchased because the user has not to reset the tag every time, but only to update the expiration date. Indeed, the system recognizes that the tag has been already associated to a product and asks to the user if he/she wants to reuse the tag for the same item typology and, consequently, only update some data such as quantity and expiration date.

However, a manual check-in/check-out can also be performed in order to manage a greater quantity of food products and not only that ones are stored in the fridge.

## 4.3 The web application

Once defined the information model and the smart fridge architecture, the web application has been developed in order to elaborate all the data and offer

several high-level services. According to the services requirements, the following functionalities have been developed and implemented in the web application:

- Shopping list management that supports users in the purchase phase by remembering him/her the products available at home, with the relative quantities and expiration dates, in order to prevent the purchase of excessive and/or useless items and suggesting special offers to guarantee the money saving;
- Proper foods placement training, which leads the user in putting the products in the right fridge compartment according to the specific commodities group to guarantee the better storage conditions and increase the shelf-life;
- Ingredients management that traces foods conserved in fridge, freezer and pantry and sends reminders to the users about the products near to their expiration date;
- Smart recipes suggestion, which proposes recipes, and the relative cooking programs, that use ingredients nearest their expiration date and do not require the purchase of extra products in order to reduce wastes and costs. Furthermore, the suggestion of recommended portions can help users to improve their eating habits;

In addition, by exploiting the same architecture, it is possible to track the data related to the medicines storage and consumption - a fridge dedicated compartment is also provided - and give useful advices/warnings to the users. Indeed, it allows monitoring the expiration date of drugs and suggesting the opening time of the closest and/or favourite pharmacies.

In order to develop a user-friendly application, the tenets and specifics of material design have been followed. These principles allows also creating a unified experience across platforms and device sizes. Going into more detail, the application has been created by using the native Android tools (i.e., platform Android Studio 1.4, SDK version 1.2 and Android version 5.0 Lollipop) and the Java programming language.

The Figure 29 shows the screen related to the user registration (left picture) and the main menu of the web application (right picture), which includes all the described features.

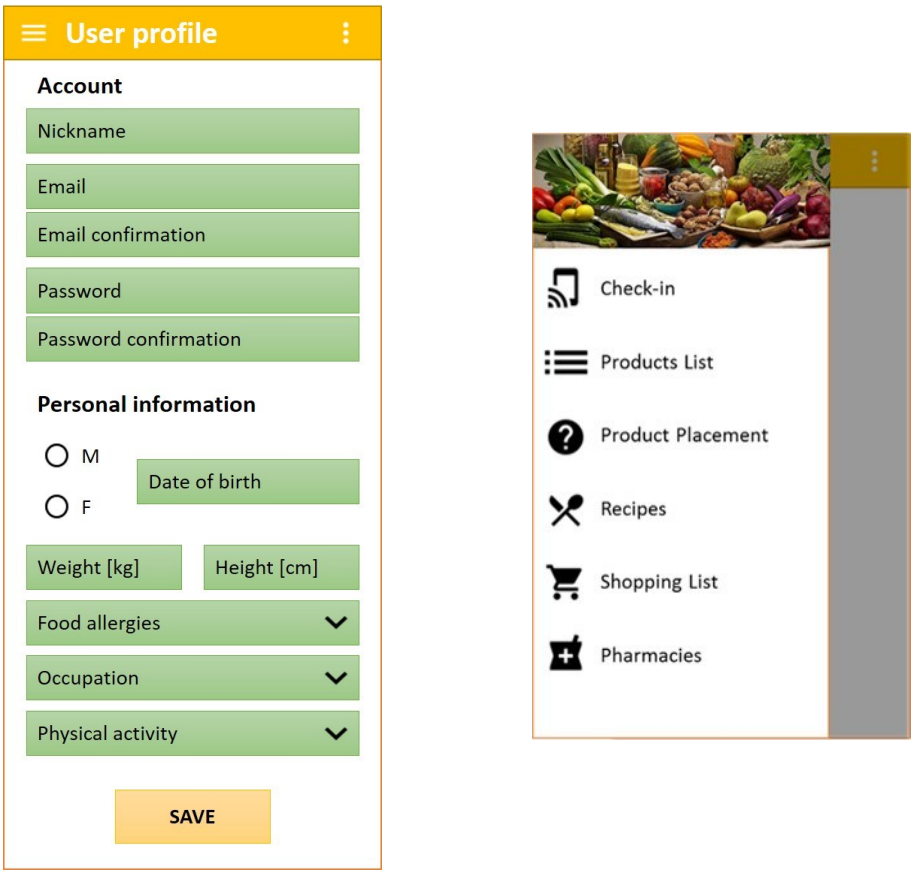



*Figure 29 – User registration and web application menu*

### 4.3.1 Check-in

Selecting the *Check-in* feature from the main menu it appears the left screen shown in Figure 30 where the user can select the check-in modality. The *TAG* item allows the user to program an NFC tag when he/she has to register a new product or update the left quantity of an existing one. In particular, the application suggests to the user to put the tag on the product packaging and approach it to the smartphone (right screen of Figure 30).

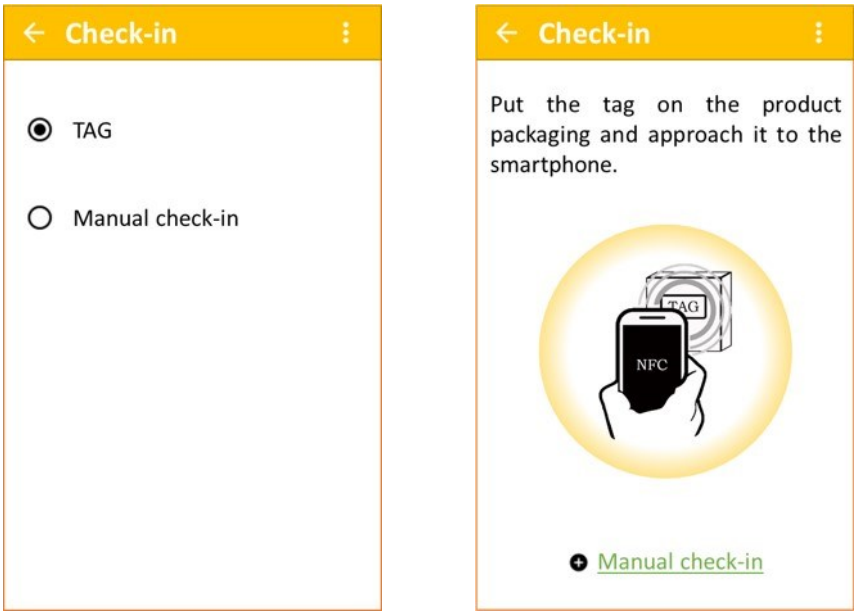



*Figure 30 – NFC TAG programming*

When the tag is read an acoustic feedback is given and it automatically appears the next screen (first picture of Figure 31), which is the same that appears when the manual modality is selected. It allows completing the product check-in. The user has to choose a category and a product (exploiting the list filtered according to the previous selection), to set the quantity, to select the placement and to specify the characteristic dates (i.e., expiration, purchasing, and opening) by manually increasing the days or using the calendar. Once confirmed the screen, the check-in is completed and the proper fridge compartment is shown if the fridge has been selected as a placement. At this point, the user can decide to execute a new check-in or go back to the home screen. In Figure 31 an example of the product check-in is shown.

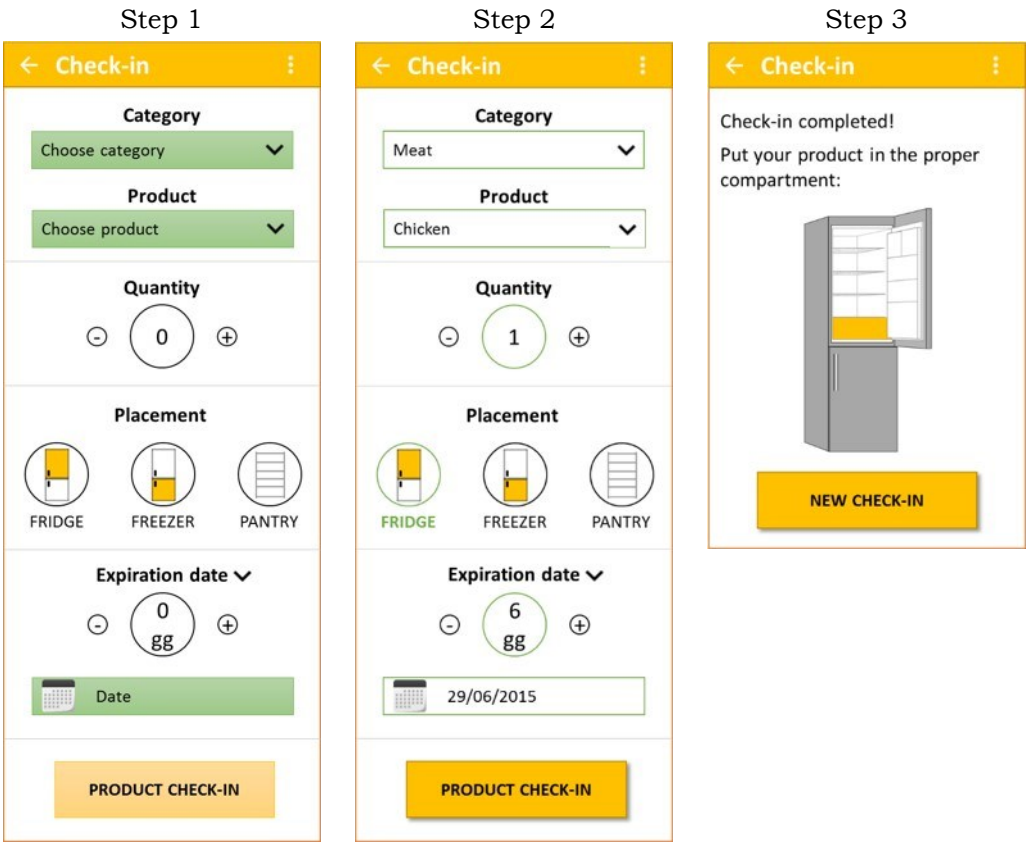



*Figure 31 – Product check-in by means of the web application*

### 4.3.2 Product placement

As described in the previous paragraph, the suggestion of the proper product placement has been inserted at the end of the check-in process. Thus, additional screens or warning messages are not necessary and the user is encouraged to respect the manufactures indications in a natural and non-intrusive way. The Figure 32 shows the part of the algorithm that starts once confirmed the product check-in. In particular, the fridge compartments have been associated to one or more categories that require a refrigerated storage in order to highlight the correct area according to the user choices.

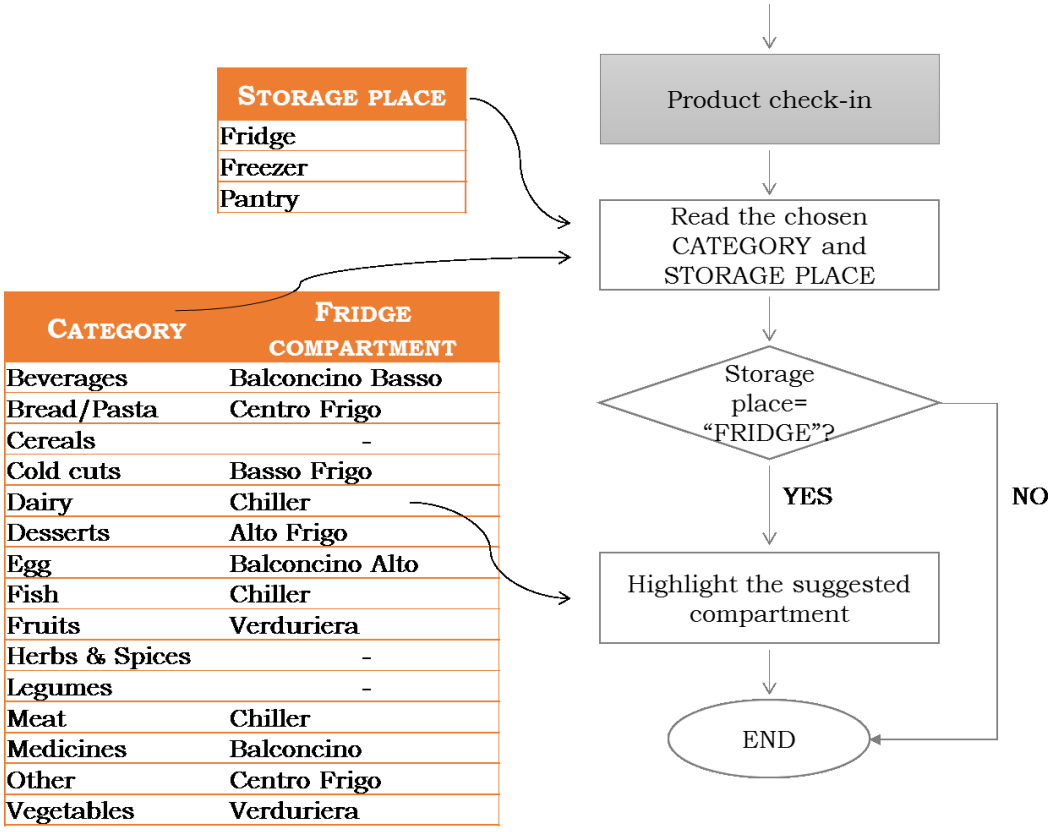



*Figure 32 – Algorithm for the fridge compartment suggestion during the product check-in*

Furthermore, the user has the opportunity to select the product placement feature directly from the main menu. In this case, he/she has only to choose the category and, consequently, the related compartment is highlighted in the fridge 3D model. An example of the screenshot of the web application is shown in Figure 33.

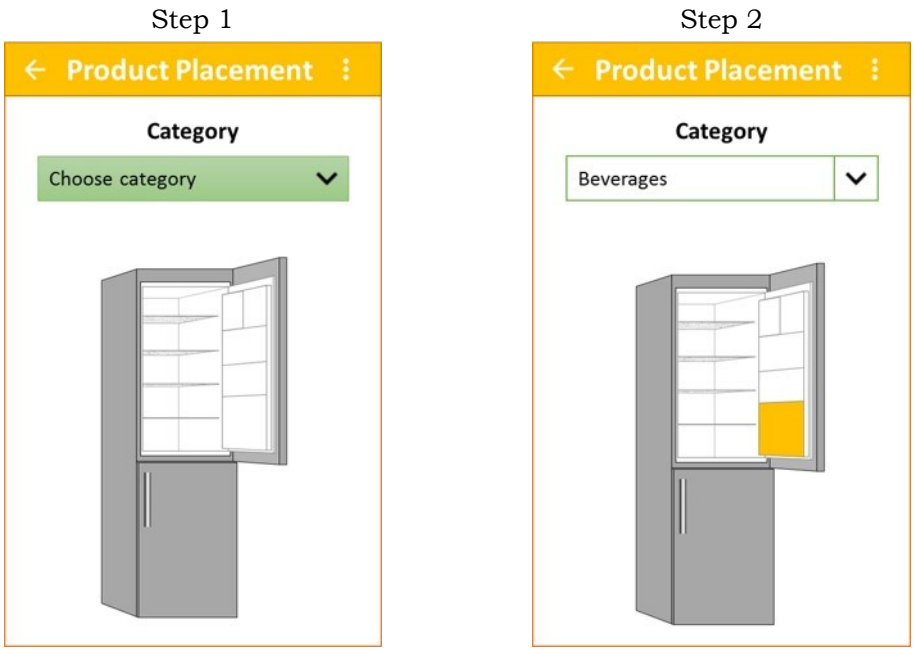



*Figure 33 – "Product placement" feature*

The rationale behind this feature is very similar to the previous one, as demonstrated by the algorithm of Figure 34.

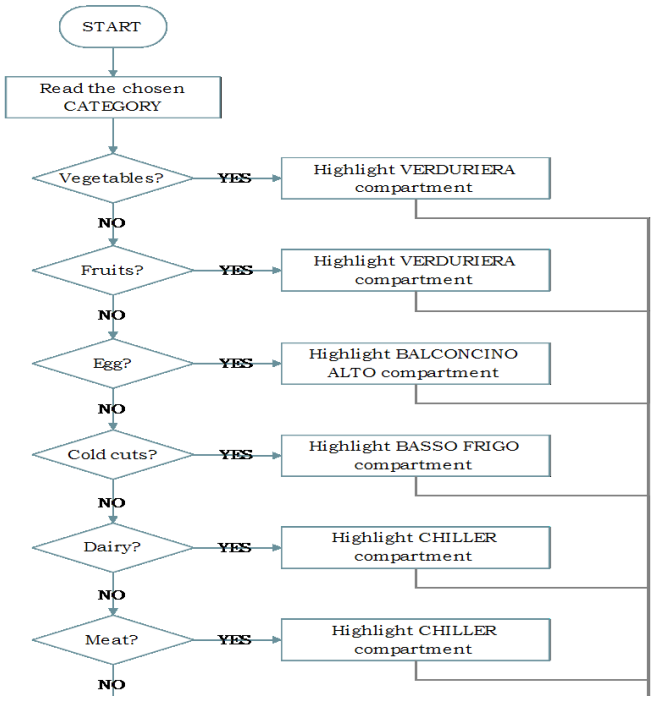



*Figure 34 – Extract of the algorithm related to the food placement feature*

### 4.3.3 Products list

The user can access to this feature directly from the main menu by clicking the relative item and selecting the sorting criteria between placement, category, product, and date. In Figure 35 the screenshot related to the list organized according to the placement is shown. In this case, the products are sorted by date: opening, purchase, and expiration. However, the order of each sub-list can be changed by the user thanks to the specific button *Sort by*. By clicking on the placement item the user can view the related product list closing the previous one automatically. The entire list can be consulted by using the scroll bar on the right. In Figure 36 the products are grouped by category and sorted according to the alphabetic order. Also in this case, the organization can be modified by means of dedicated buttons and the same options cited before can be selected.

Both screens inform the user about the food products available at home, the left quantity and the date of opening, purchase, and/or expiration. The red date remembers to the user that the product will expire in 2 days or less. The symbol next to the product name indicates that a tag has been associated to it. The full shopping cart means that the product has been inserted in the shopping list, whereas the shopping cart with the plus sign allows to the user to add the product to the list. The system also provides a warning when the consumer inserts a food in the list that has often been thrown away. The link at the bottom of the screen allows to register a new product and add it to the list.

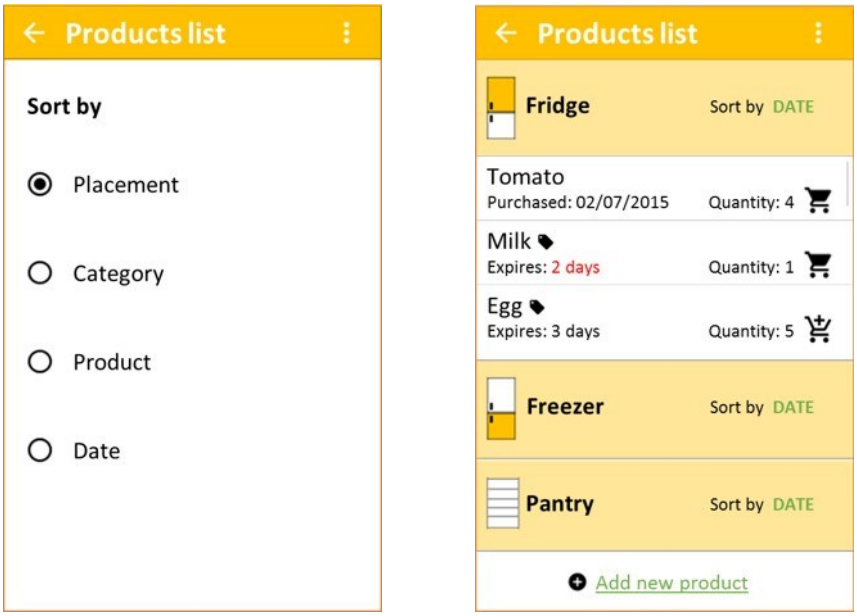



*Figure 35 – "Products list" feature, order by placement*

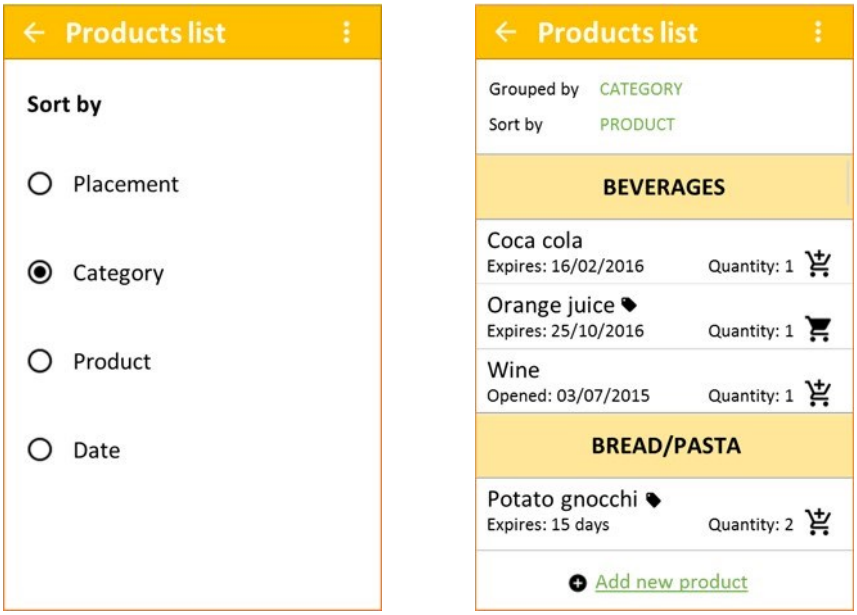



*Figure 36 – "Products list" feature, order by category*

By clicking on the product row the user can access to the product detail and update information such as the left quantity or the dates (Figure 37). By means of the red button the product check-out can be executed.

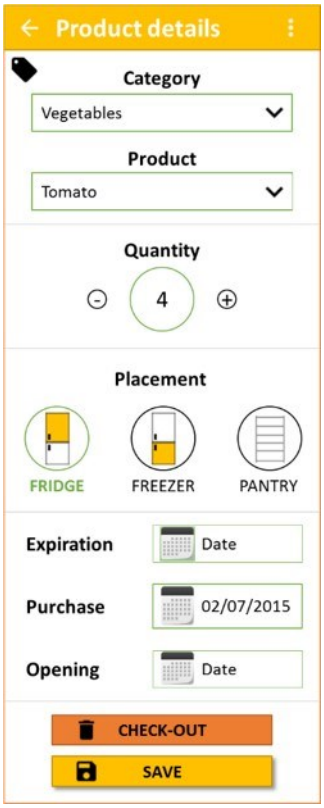



*Figure 37 – Product detail screen*

To be efficient the application has to manage some equivocal cases. For example, if a product packaging contains more units it is recommended to use only one tag and set the quantity instead of to put a tag on each item. When a product is consumed without executing the check-out and the same tag is reused for a new product, the check-out of the old item is carried out automatically. On the other hand, if the user executes the check-out and after reinserts the product in the fridge without reprogramming the tag, the previous check-out is cancelled because it is not considered finished, but partly consumed.

To properly manage the product traceability, several algorithms have been developed, which start after specific events or conditions. In particular, every day the system verifies if there are products expired or close to their expiration. In the first case, a warning message suggests to the user to thrown away the item, especially if it is a medicine. However, in case of food and “best before” date, the system suggests to smell or taste the product before waste it. In case of products close to expire, the application gives a feedback to advise the consumer (e.g., the expiration date becomes red, priority in the recipe suggestion, etc.) and if a new

product of the same typology is purchased, it remembers to consume the oldest one before.

Another algorithm (Figure 38) starts when a check-out is executed. It controls if the left quantity is zero and, in the affirmative case, verifies if the product is a periodic one, which means that it is purchased at least once a week. If the product is not periodic it has to be added to the list of products recently finished. Otherwise, the distinction between food and medicines have to be taken into account. In the first case, the product can be directly added to the list of suggested products, which is available in the *shopping list* feature. In the second case, a warning is shown to the user to remember him/her that the medicine he/she usually takes is finished and has to be repurchased. However, before inserting the item in the shopping list a confirmation is asked to the user. Furthermore, the application offers the possibility to set a specific reminder that will be shown until a new check-in is executed.

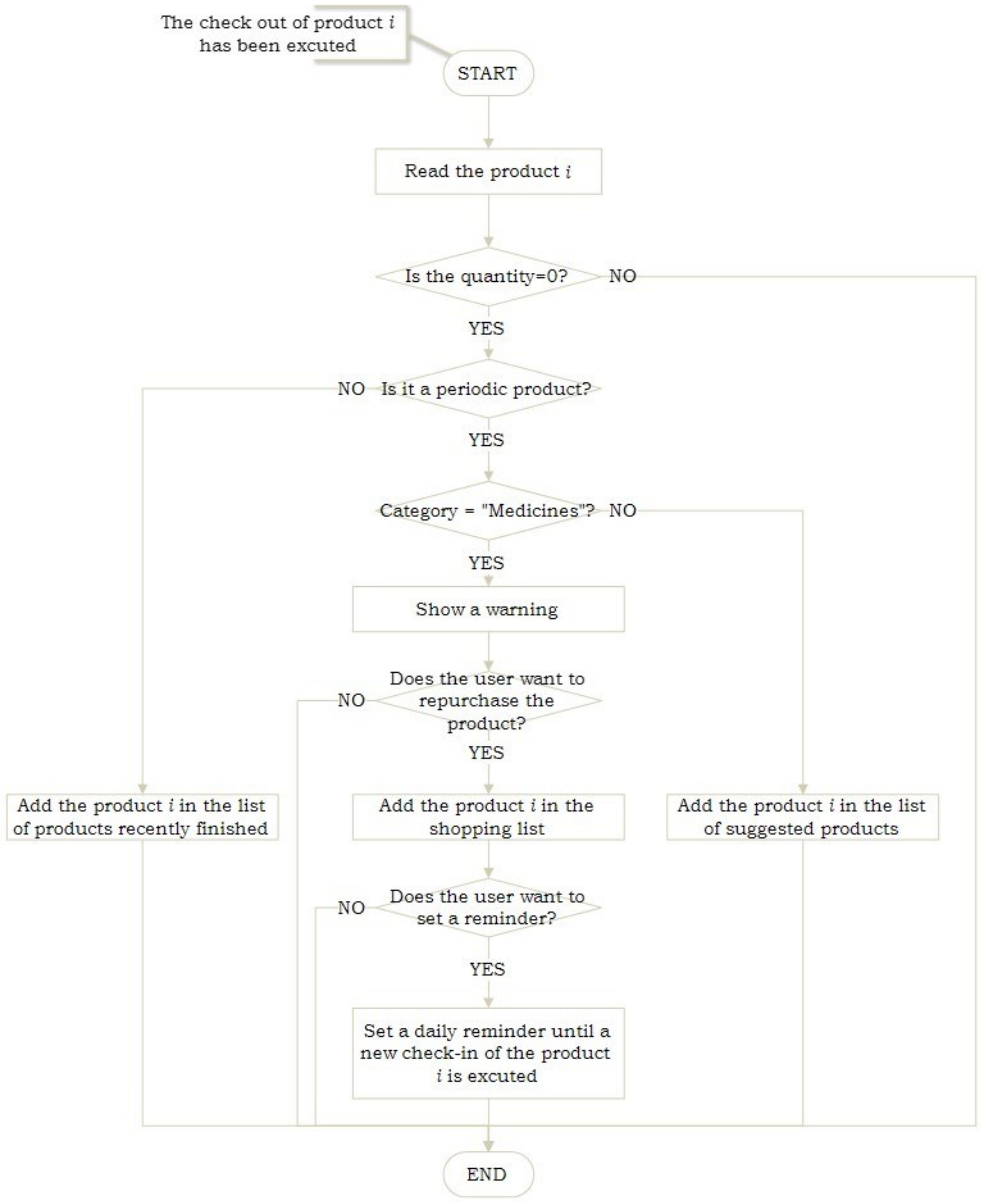



*Figure 38 – Algorithm related to the product check-out*

### 4.3.4 Recipes

As far as the recipes are concerned, the system suggests the most suitable ones by checking, filtering and ordering them according to the maximum number of ingredients available at home and closest to their expiration date. Also other parameters such as allergies, calories and meals recently consumed are taken into account in order to ensure the right balance between health and waste reduction. Furthermore, also the users' preferences cannot be neglected, therefore, useful

information related to the preparation time, dish, ingredients, etc., are considered. For this reason, the left screenshot of Figure 39 shows the filters that can be selected by the user. They consist in dish and ingredient and the relative sub-filters. In the example, the fish first course has been selected. However, more than one filter can be set at the same time. The two buttons up allow confirming or cancelling the settings. Once confirmed, the screen shown in the right picture compares, where the ordering criteria can be selected. The options are the availability, the expiration and the name of the ingredients and the total time required to prepare a recipe. Both screens offer a link to access to the list of the suggested recipes.

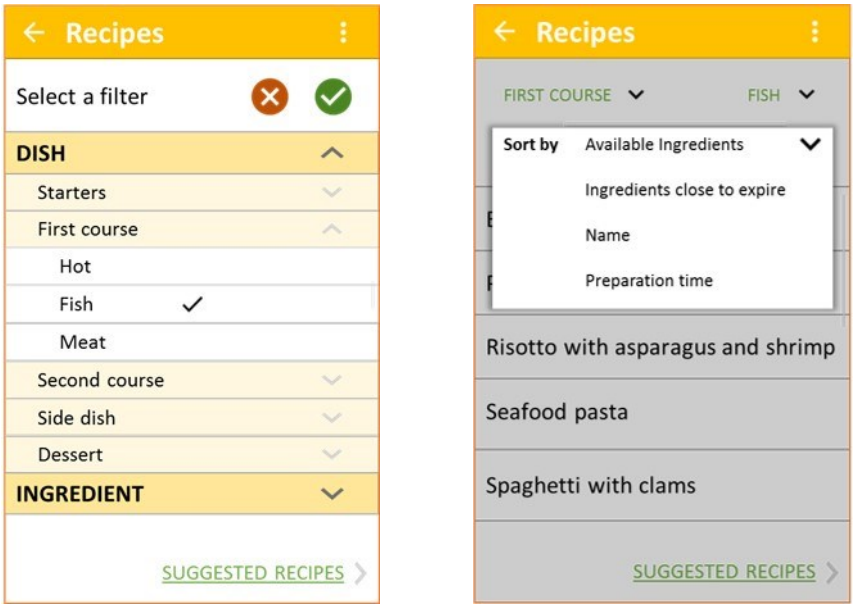



*Figure 39 – Recipes filters and list*

By clicking in the recipe row the relative screen appears, as shown in the left picture of Figure 40. In the upper part, there are the generic information of the selected recipe such as name, servings, calories, preparation time, and cooking time. Furthermore, a specific button allows setting the recipe as a favourite. Below, the list of ingredients with the relative required quantities is shown. Next to each product name, a feedback abut its availability is given. In particular, the green check indicates that the food is present at home, the full cart that it has been added in the shopping list and the cart with the plus sign allows inserting the ingredient in the shopping list because not available at home. By

selecting the *instructions* row the user can read which is the correct procedure to prepare the meal. In the same way, the link to the preparation guide allows accessing to a sequence of screens that supports the user step by step. A future update of the application will include pictures of the most critical tasks in order to make this feature more efficient.

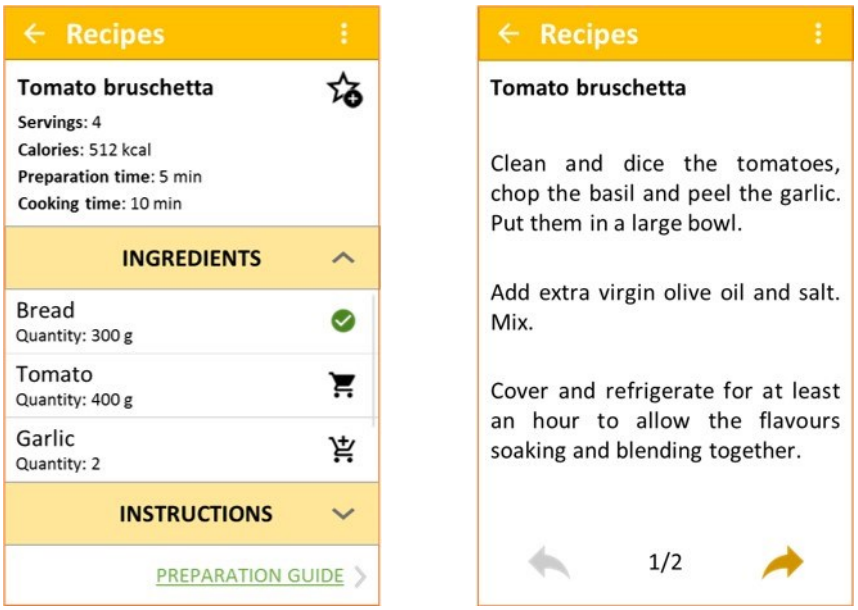



*Figure 40 – Recipe details and preparation guide*

In order to take into account the majority of the critical issues that the society has to face, a method that allows determining the best recipe to suggest to the user has been developed. The main flow is shown in Figure 41 and mainly consists in five steps and four modules.

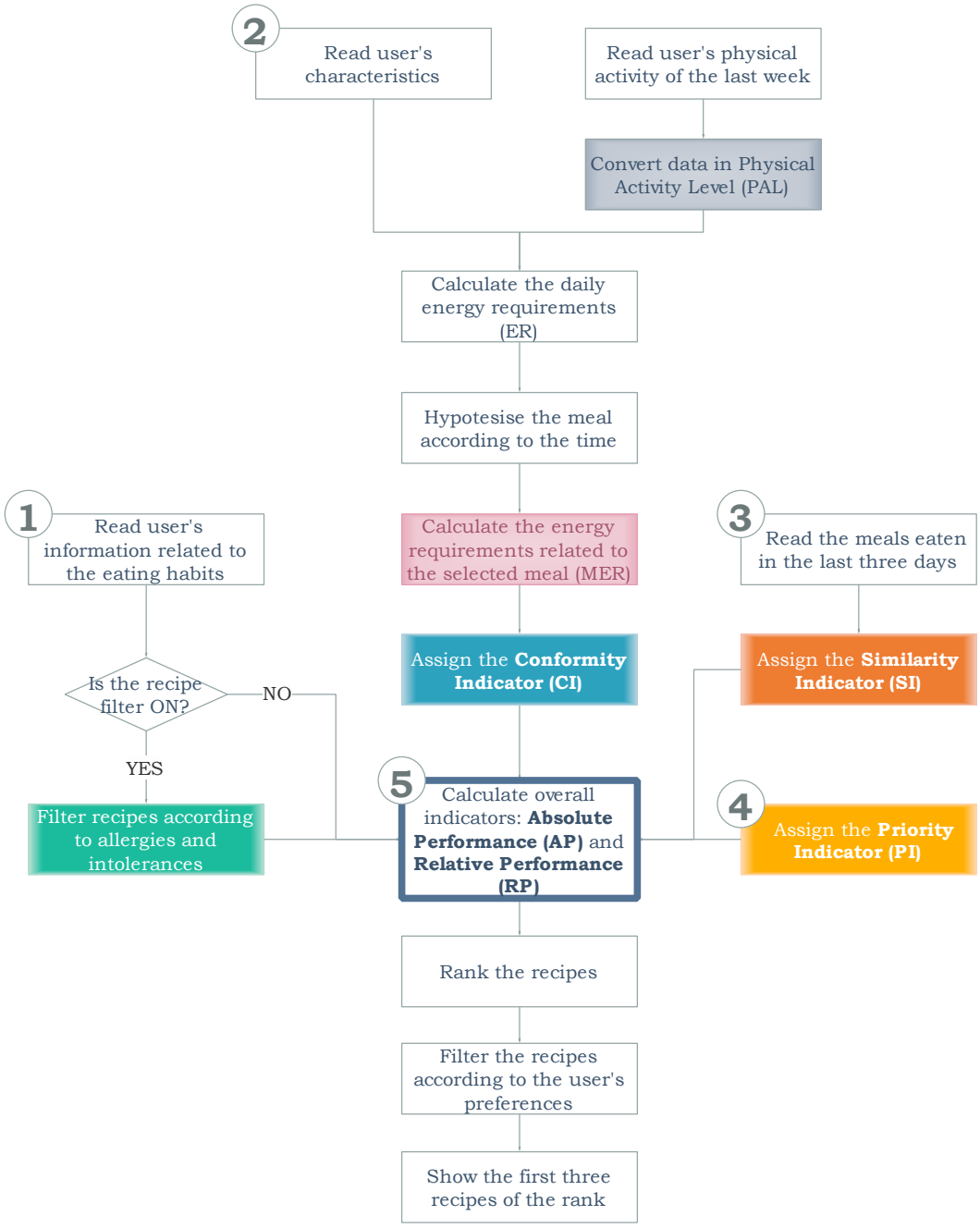



*Figure 41 – Recipe suggestion algorithm*

The goal of the Step 1 is to filter the recipes according to possible allergies of people. For this reason, it is necessary to start by reading the user's information related to the eating habits. If there are not nutrition problems or the specific recipes filter is disabled (e.g., a user that has an intolerance is preparing a meal for another user without food problems), the filter module is not executed.

Otherwise, the system follows the rationale described in Figure 42. In particular, the critical ingredients for the selected allergy have to be identified. In this way, the system can verify if a recipe needs a critical food and could be dangerous or if it can be inserted in list of suggested recipes. In the first case, further steps are necessary. Indeed, the methods aims to review the recipe, if possible, to ensure a wider range of choices to the user. In particular, it verifies for each critical ingredients if there is the possibility to substitute it with another one. For example, in case of a celiac user the normal pasta can be substituted with the pasta gluten free. If it is not possible the ingredient typology has to be investigated:

- *Primary*, which means that the ingredient is typical and, consequently, essential for the recipe;
- *Secondary*, which means that the ingredient is essential for the meal preparation, but not typical;
- *Optional*, which means that the ingredient is not essential because mainly related to the user's preferences and if substituted or not used the recipe is still tasty.

If the critical ingredient is optional the recipe is added to the list, but a warning is shown to the user to advise him/her to not use that food. If the ingredient is primary or secondary, the recipe cannot inserted in the list.

To filter the recipes at the beginning of the algorithm allows reducing the computational complexity. Indeed, a limited number of recipes have to be analysed by the other modules.

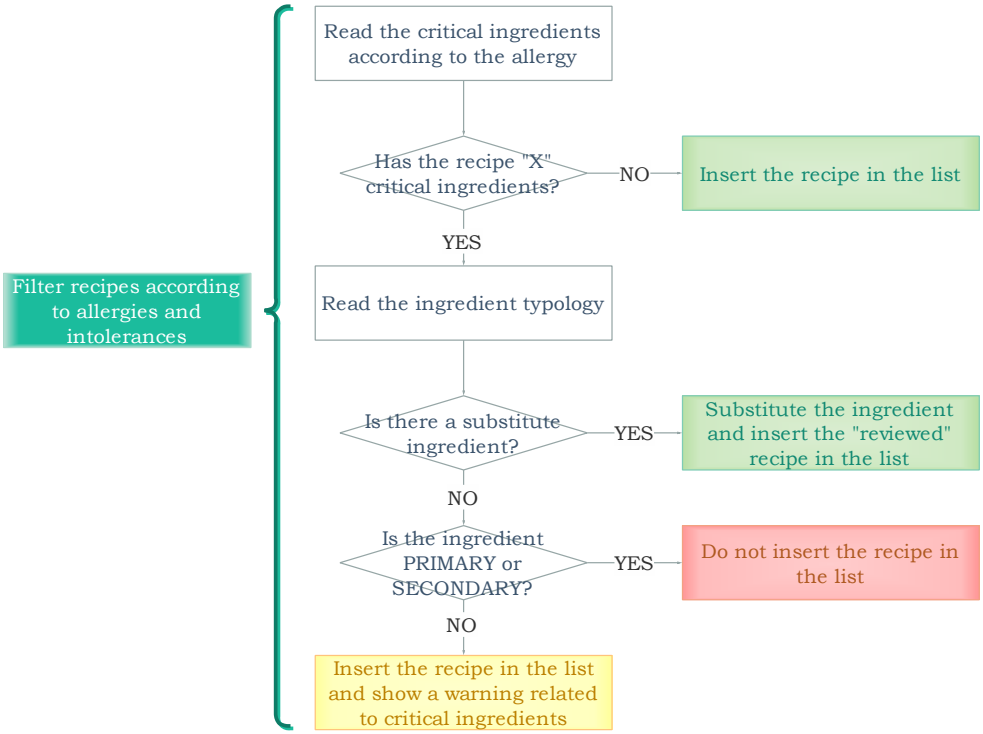



*Figure 42 – Recipes filter according to allergies and intolerances*

The Step 2 aims to support users in following a healthy diet able to satisfy the nutrients and energy needs of people. For this reason, it is important to introduce the concept of *Energy Requirements* (ER) that is defined by FAO as "the amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity consistent with long-term good health" [115]. According to this definition, it is useful to refer to daily requirements or recommended daily intakes in order to suggest meals that satisfy the energy needs and take into account the user habits and physical activities. In order to calculate this value, the *Basal Metabolic Rate* (BMR) and the *Physical Activity Level* (PAL) have to be determined. The former is the minimal rate of energy expenditure compatible with life and the latter is the number used to express the daily physical activity of a person.

Based on these definitions, the ER can be calculated as described by the (1) [115]:

$$ER = BMR * PAL \quad (1)$$

And the BMR can be esteemed by using the equation of Mifflin St. Jeor [116]:

$$BMR = 10 * weight\,[kg] + 6.25 * height\,[cm] - 5 * age\,[years] + s \qquad (2)$$

where $s$ is +5 for men and -161 for women.

On the other hand, the PAL represent different levels of activity associated with population's lifestyle, as shown in Table 8 [115]. In general, the inactive level refers to the cerebral palsy patient and the extremely active level refers to professional athlete and is difficult to maintain over a long period of time. Therefore, they are often neglected. As far as the other levels are concerned, they describe the following lifestyles:

- *Sedentary*, which refers to people whose occupation does not demand much physical effort (e.g., office worker) and spend most of the time in activities such as talking, reading, watching television, using computers, etc.;
- *Moderately active* that involves people whose occupation is not strenuous, but more energy-consuming than the sedentary ones (e.g., shop assistant, labourers, domestic service, etc.). Alternatively, it refers to persons that spend about one hour per day in physical activities such as running, swimming, cycling, dance, etc.;
- *Vigorously active*, which refers to people regularly engage in a strenuous work (e.g., military, agricultural workers, construction workers, etc.) or a highly active leisure (e.g., running, swimming, cycling, dance, etc., for about two hours per day).

*Table 8 – Physical Activity Level*

| **PHYSICAL ACTIVITY LEVEL** | |
|---|---|
| Inactive | PAL < 1.4 |
| Sedentary | 1.4 ≤ PAL < 1.7 |
| Moderately active | 1.7 ≤ PAL < 2.0 |
| Vigorously active | 2.0 ≤ PAL < 2.4 |
| Extremely active | PAL > 2.4 |

In this context, the developed algorithm has to read the user characteristics such as age, gender, weight and height in order to calculate the BMR and his/her occupation and physical activity to identify the relative PAL. In particular, the conversion of activity data in PAL could be carried out by following two different methods according to the information source (dark grey block of the algorithm of Figure 41). In case of qualitative data stated by the user during the first registration, the records related to the occupation or the general activity leisure has already been associated to a PAL according to the cited definitions and the following criteria:

- No moderate and intensity activity represents a sedentary level;
- Moderate activity for at least two hours per day or intensity activity from 30 minutes to one hour per day is associated to the moderately active level;
- Intensity activity for at least one hour per day represents a vigorously active level.

In case of quantitative data collected by means of specific devices such as the activity trackers, the duration and the intensity of the activity has to be analysed and associated to a PAL according to devices characteristics and the global recommendations on physical activity provided by the World Health Organization (WHO) [117].

At this point, the system can calculate the ER according to the formula presented. Furthermore, it is possible to hypothesize the meal according to the time and the following rules: breakfast from 6 am to 10 am, lunch from 12 pm to 2:30 pm and dinner from 7 pm to 9:30 pm. However, the user can changes the meal if necessary. In this way, the system can calculate the energy requirements for the specific meal by taking into account possible other meals consumed during the day. According to the literature it is possible to assume the distribution by meal of the daily ER shown in Figure 43 [118]. Based on it, the meal energy requirements (MER) can be calculated (pink block of the algorithm of Figure 41, which includes several steps). In particular, for breakfast the default percentage is assumed, instead for lunch and dinner the algorithm verifies the calories intake until that moment by consulting historical data, if available. In this case, the calories intake are subtracted from the total ER and the results is redistributed according to the default percentages.

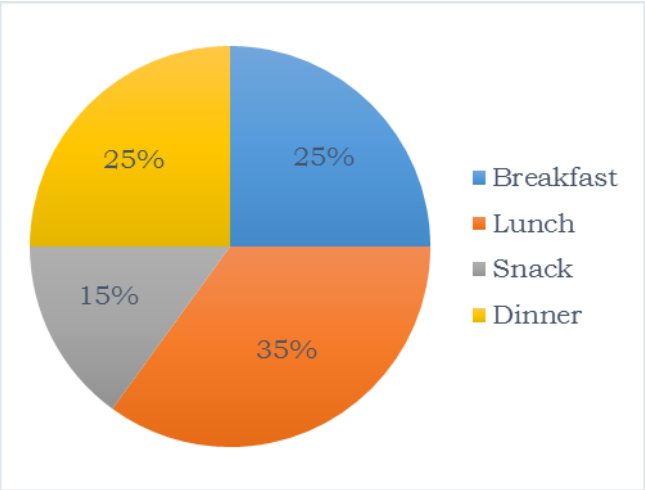



*Figure 43 – Daily energy requirements by meal*

The next step is the assignment of the Conformity Indicator (CI) to each recipe remained after the filter action. It represents the correspondence between the recipe calories (RC) and the MER. In particular, the assignment is executed according to the rationale of Figure 44, where the detail of the blue block of the algorithm of Figure 41 is shown. If the RC deviates from the MER of less than ±10%, the CI is set to 0. If the RC deviates from the MER of less than ±25%, the CI is set to 1. If the RC deviates from the MER of less than ±50%, the CI is set to 3. Otherwise, the CI is set to 9. In this way, the recipes closer to the target value will have a priority by assuming a better place in the rank.

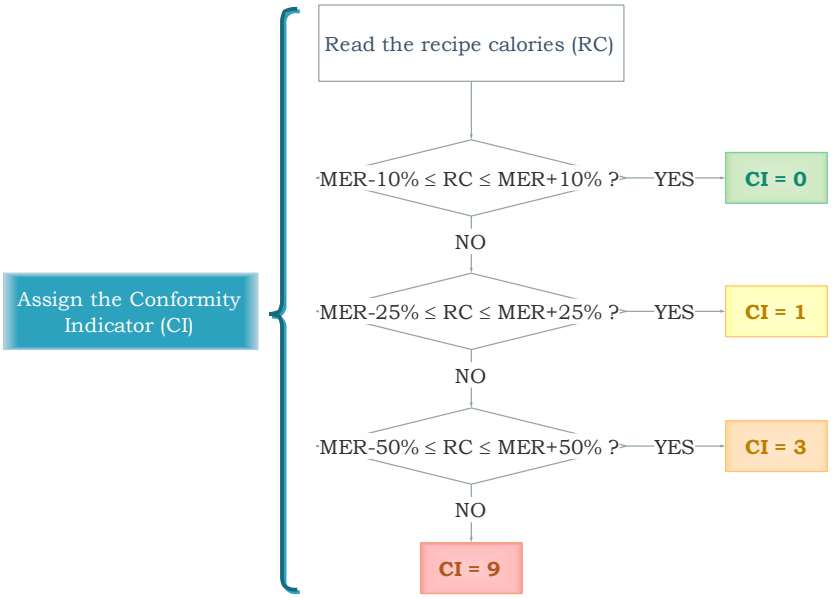



*Figure 44 – Conformity Indicator assignment*

The goal of the Step 3 is to ensure a variegated diet to the user by consulting the meals consumed in the last three days and suggesting different recipes. For this reason, a correlation matrix between recipes has to be created and the $R_{ij}$ indicator, which represents the percentage of common primary ingredients between the recipe *i* and the recipe *j*, has to be determined (Figure 45). In particular, it is the ratio between the number of common ingredients and the number of primary ingredients of the recipe *i*.

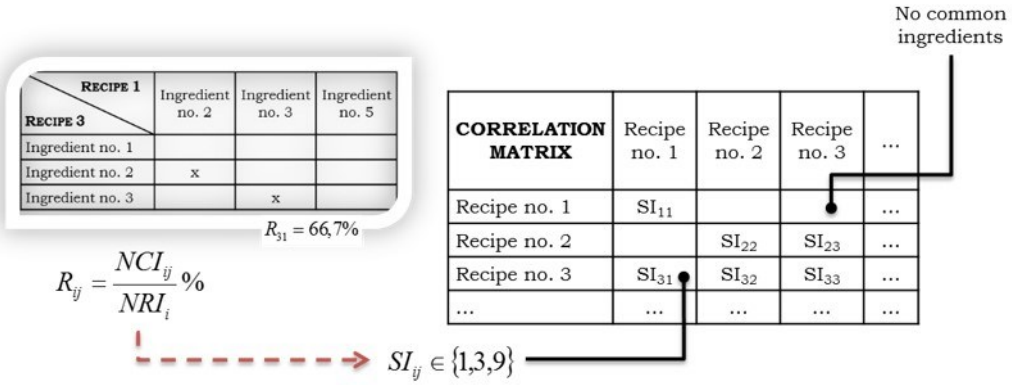



*Figure 45 – Correlation matrix between recipes*

According to $R_{ij}$ value, the Similarity Indicator (SI) can be assigned (Figure 46). If $R_{ij}$ is equal to 0, the $SI_{ij}$ is set to 0 because the two recipes do not have

primary ingredients in common. If $R_{ij}$ is less than 50%, the $SI_{ij}$ is set to 1 and if $R_{ij}$ is less than 100%, the $SI_{ij}$ is set to 3. Otherwise, the $SI_{ij}$ is set to 9 because the two recipes match.

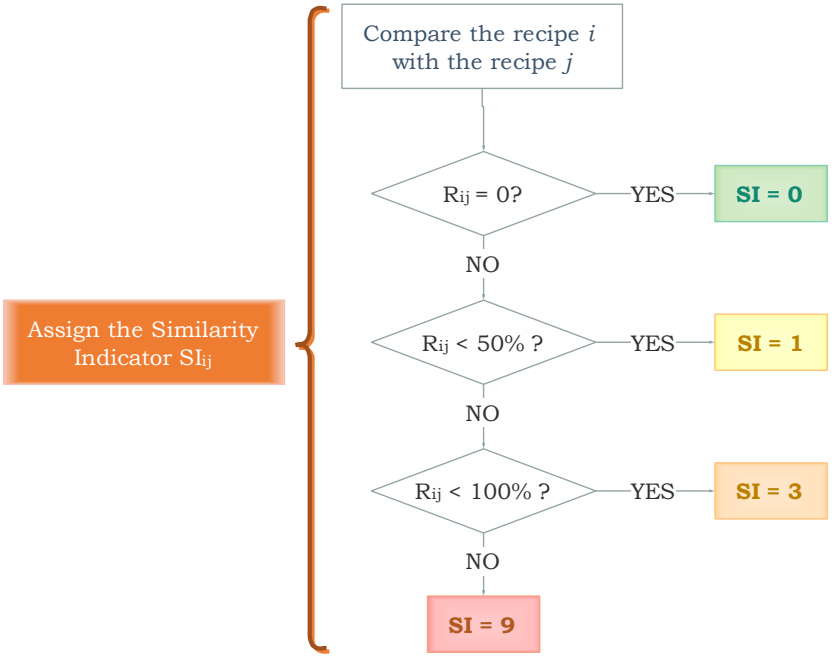



*Figure 46 – Similarity Indicator assignment*

Once known which is the last time that a meal has been consumed, the correlation matrix can be filtered by selecting the only ones with *Days ago* less than or equal to 3 (Figure 47). In this way, the $SI_i$ can be calculated as a weighted sum of $S_{ij}$ where the weights are assigned according to a 3-classes value (9 – recipe consumed 3 days ago, 3 – recipe consumed 2 days ago, 1 - recipe consumed 1 day ago).

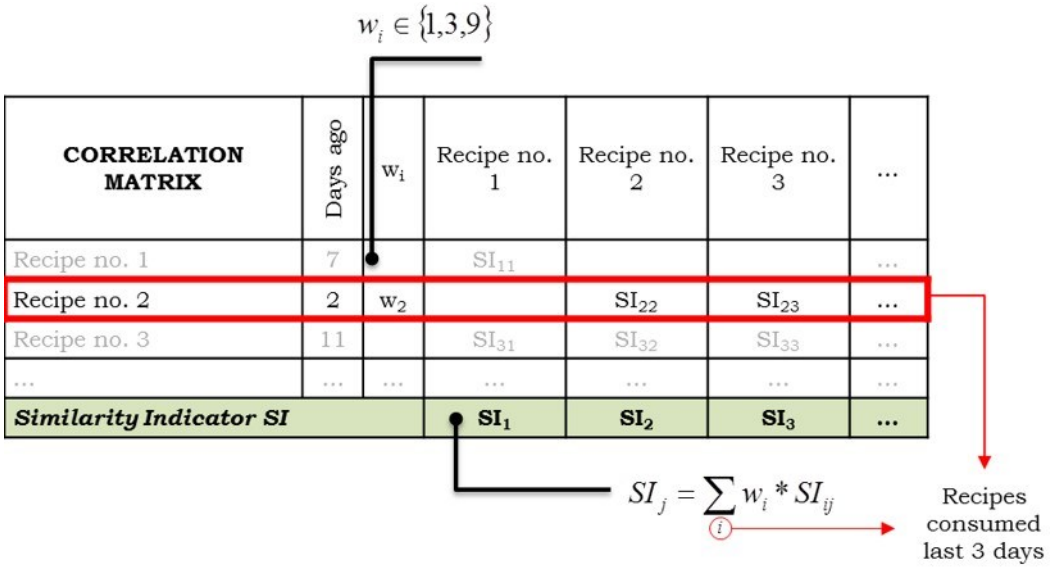



*Figure 47 – Similarity Indicator calculation*

Step 4 aims to give a higher priority to the recipes that need of ingredients available at home and close to their expiration date. For this reason, the algorithm of Figure 48 shows how different weights ($w_z$) are assigned according to the availability and expiration of ingredients. In particular, if the ingredient *z* expires by 1 day, the $w_z$ is set to 1. If it expires by 3 days, the $w_z$ is set to 3. If it expires after 3 days, $w_z$ is set to 9. If the ingredient *z* is not available, $w_z$ is also set to 9.

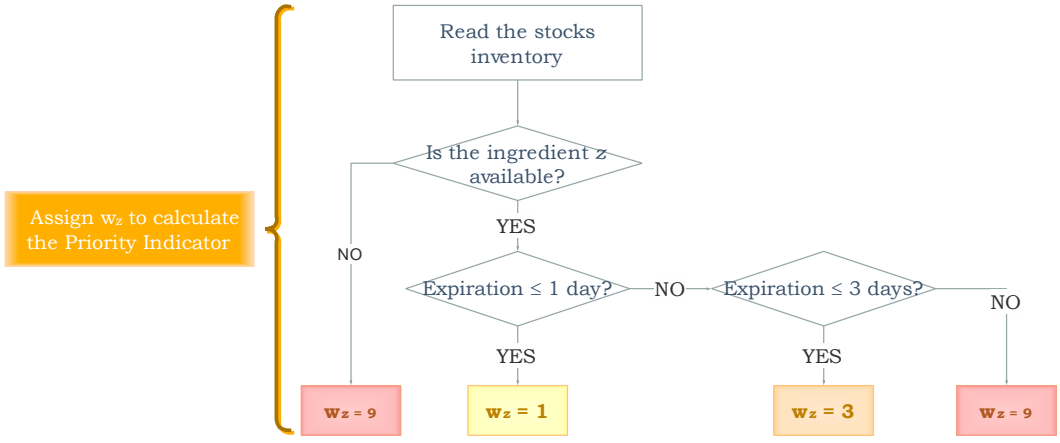



*Figure 48 – Assignment of weights for the Priority Indicator*

These weights populate a column of the matrix that correlates recipes and ingredients (Figure 49). It allows calculating the $PI_i$ as weighted sum of $RI_{zj}$. The

latter expresses the importance of the ingredient *z* for the recipe *j* by also taking into account its typology and availability.

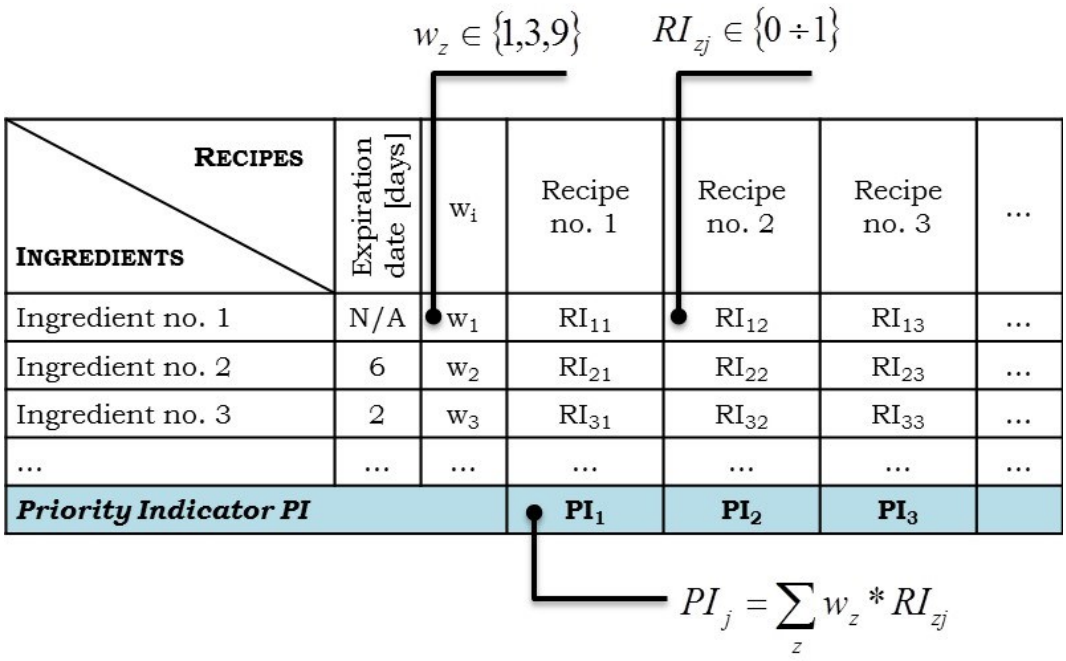



*Figure 49 – Priority Indicator calculation*

In particular, $RI_{zj}$ assumes a value between 0 and 1 according to the rules expressed in Table 9. They aims to increase the priority when a primary or secondary ingredients are close to expire or are not available compared to the optional ones.

*Table 9 – Assignment rules of the $RI_{zj}$ indicator*

| INGREDIENT Z | AVAILABLE | NOT AVAILABLE |
|---|---|---|
| PRIMARY | $RI_{zj}$ =0,1 | $RI_{zj}$ =1 |
| SECONDARY | $RI_{zj}$ =0,8 | $RI_{zj}$ =0,7 |
| OPTIONAL | $RI_{zj}$ =1 | $RI_{zj}$ =0,1 |

The Step 5 allows calculating the overall indicators in terms of Absolute Performance (AP) and Relative Performance (RP). For this reason, a matrix that correlate recipes and indicators has to be created, as shown in Figure 50. However,

to be inserted in the matrix, each indicator has to be normalized. In particular, the CI has been adjusted to a 10-scale, as suggested by (3):

$$\frac{CI_j}{9} * 10 \quad (3)$$

The SI has been normalized to a 10-scale according to the maximum value that it can assume, as suggested by (4):

$$\frac{SI_j}{2*maxw_i*maxS_{ij}} * 10 \quad (4)$$

The PI has adjusted to a 10-scale according to the maximum value that it can assume, as suggested by (5):

$$\frac{PI_j}{9*NRI_j} * 10 \quad (5)$$

When the matrix is completed, the absolute importance of each recipe ($AI_j$) can be defined as the sum of all contributions obtained from all considered indicators as suggested by (6):

$$AP_j = CI_j + SI_j + PI_j \quad (6)$$

Furthermore, by assigning specific weights to three indicators it is possible to pay more attention to an aspects compared to another one. In this way, the relative importance ($RI_j$) can be calculated by multiplying each score $CI_j$, $SI_j$ and $PI_j$ for its corresponding weight $w_k$ and by summing all contributions for each recipe *j* as suggested by (7):

$$AP_j = w_1 * CI_j + w_2 * SI_j + w_3 * PI_j \quad (7)$$

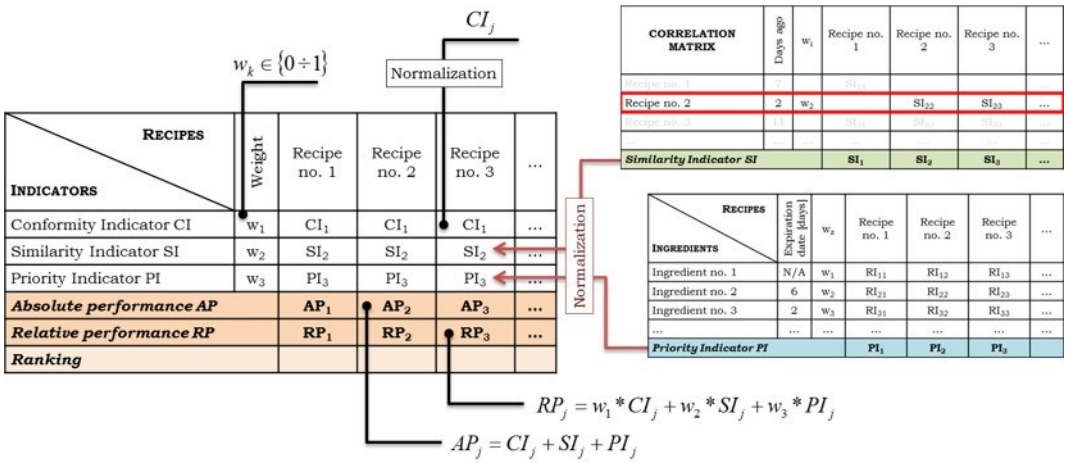



*Figure 50 – Calculation of Absolute Performance and Relative Performance*

At this point, the recipes are ranked according to their relative importance in order to highlight which ones better satisfy the requirements. In case of joint winners, the recipe with a lower PI is preferred. The rank can be filtered according to the user preferences, if necessary. The first three recipes are suggested to the user, but he/she has the possibility to consult the entire classification.

### 4.3.5 Shopping list

It is possible to access to the shopping list from the main menu or the cart icons. This feature allows to better plan the purchases according to the stocks inventory and the offers. The left picture of Figure 51 represents the main screen where all products inserted in the list are shown. They are grouped by category and sorted according to the alphabetic order. The scroll bar allows consulting the entire list. It is possible to change the quantity of each item by means of two specific buttons (minus and plus) or directly setting the number. The smile icons mean that there is at least one offer for the product. The red one gives a feedback to the user by remembering him/her that the offer expires in less of 2 days. By clicking on the link *Add product* the screen of the right picture of Figure 51 appears. It allows choosing the category and the product from the relative lists, set the desired quantity and confirm the screen.

On the other hand, the links *offers* and *suggested* allow consulting respectively the list of products that are on offer or are suggested by the application.

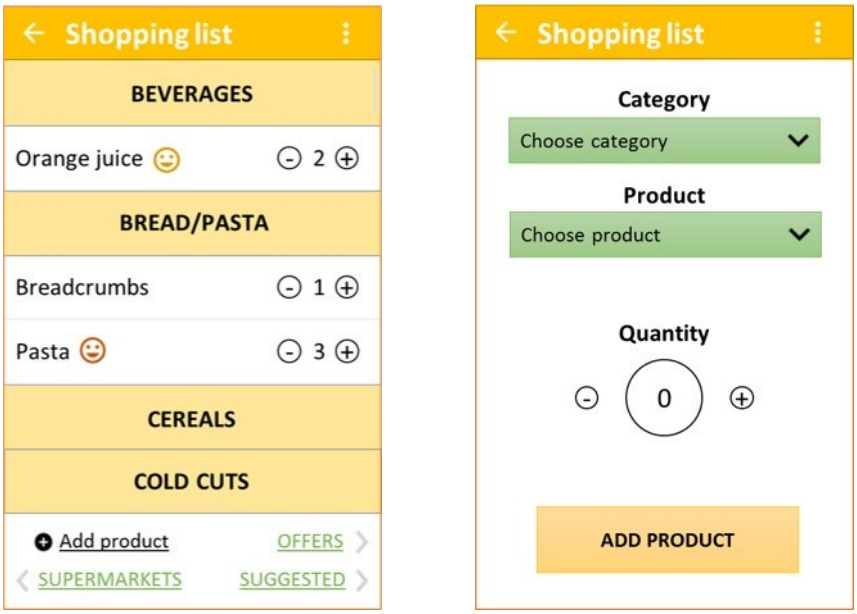



*Figure 51 – "Shopping list" feature*

Going into more detail, the algorithms of Figure 52 describe the rationale of the system respectively when a new offer is added to the database or an older one ends. In the first case, a comparison between the products in the shopping list and the products on offer has to be carried out. When they coincide the application informs the users by adding the smile. In the second case, the system verifies which products are not on offer anymore, deletes the notifications, shows a warning to the user and asks to him/her the confirmation about leaving however the product in the list.

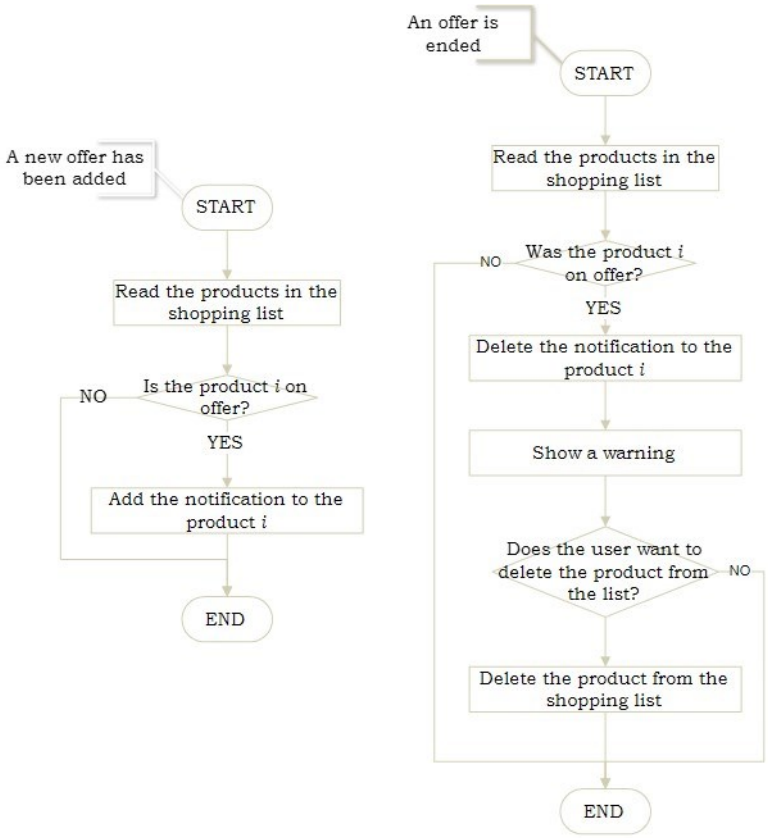



*Figure 52 – Algorithm to notify when a product of the shopping list in on offer*

When a new offer is added to the database also the algorithm shown in the left part of Figure 53 is executed. It compares the periodic products, which are purchased at least once a week, with items on offer and executes different actions according to the left quantity. Indeed, if the latter is less than or equal to 2 the product can be inserted in the list of suggested products. Otherwise, it is added to the list of products that have to be monitored in order to not encourage the user to purchase more products than he/she needs and, consequently, increase the waste. The items of this list are checked every time a check-out is executed, as shown in the right algorithm of Figure 53. Only when the quantity falls below 3 the product is added to the suggested ones.

It is also possible to manage the shopping list in an automatic way when the relative function is enabled. In this case, when a periodic item is finished and a similar product is not tagged, it is directly inserted in the shopping list. Instead, if the product is expired, the application asks the confirmation to the user before

to add it. The same actions could be executed if a new offer related to the same product is added.

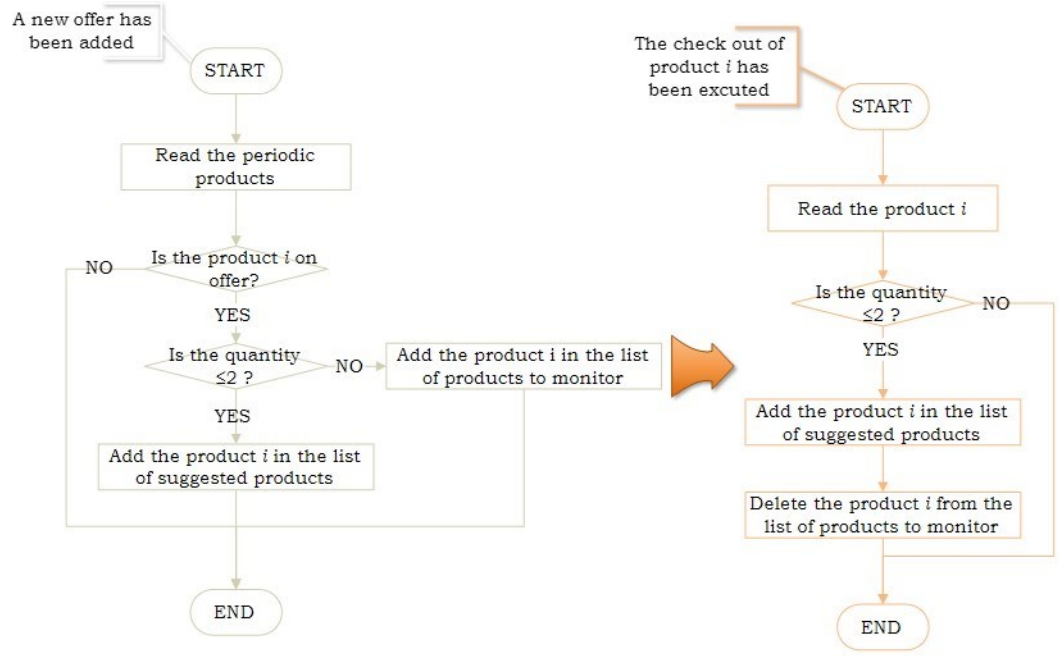



*Figure 53 – Algorithm to notify an offer of a periodic product*

The left screen of Figure 54 appears when the user clicks on the *supermarkets* link. It allows to search for opening hours of them. The search can be executed according to the location – which can be manually inserted or by means of the GPS – and date or thanks to the links to the favourite supermarkets. In particular, the system carries out a redirect to an Italian web site that provides this information in an accurate way. If the user exploits the GPS function, he/she can access to the list of the five closest supermarkets.

To add a new favourite supermarket the user has to specify the name and the location and confirms the data, as shown in the right picture of Figure 54.

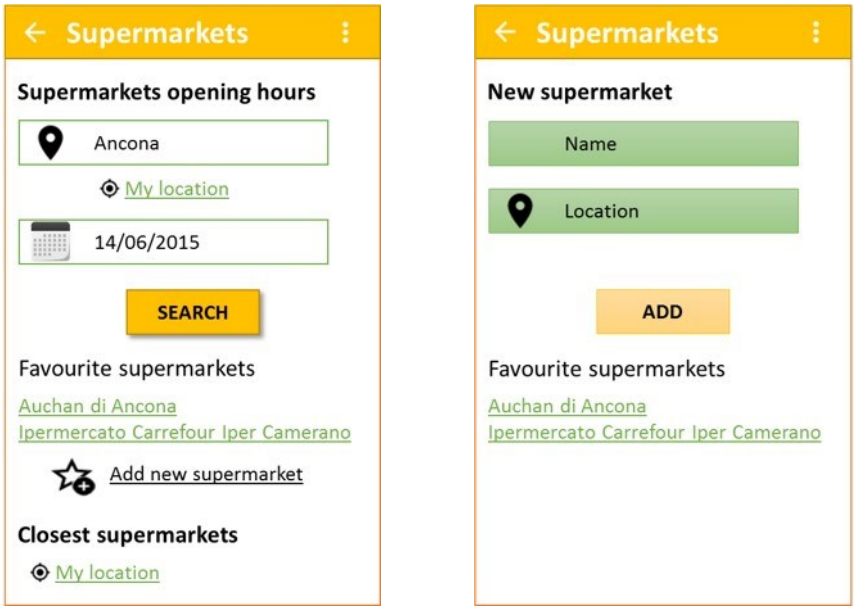



*Figure 54 – "Supermarkets" feature*

### 4.3.6 Pharmacies

As for the supermarkets, the user has the opportunity to search for opening hours of the pharmacies according to the favourite ones, closest ones, his/her location and date. He/she can access to this feature by selecting *Pharmacies* item from the main menu. As shown in the left screenshot of Figure 55, the user has to indicate his/her location – or use the GPS function to insert it automatically – and specify the date to enable the search button. In this way, a redirect to an Italian web site that shows the opening hours of pharmacies according to the search criteria can be carried out. By using the *My location* feature also the five closest pharmacies can be identified and the relative distance calculated, as shown in the right screenshot of Figure 55. Furthermore, both screens allow managing the favourite pharmacies. Thanks to this feature the search can be more rapid and circumscribed. Indeed, the redirect to the web site is executed directly by clicking on the link with the name of the pharmacy (e.g., Del passetto, Del piano). New favourite pharmacies can be added by means of the apposite function.

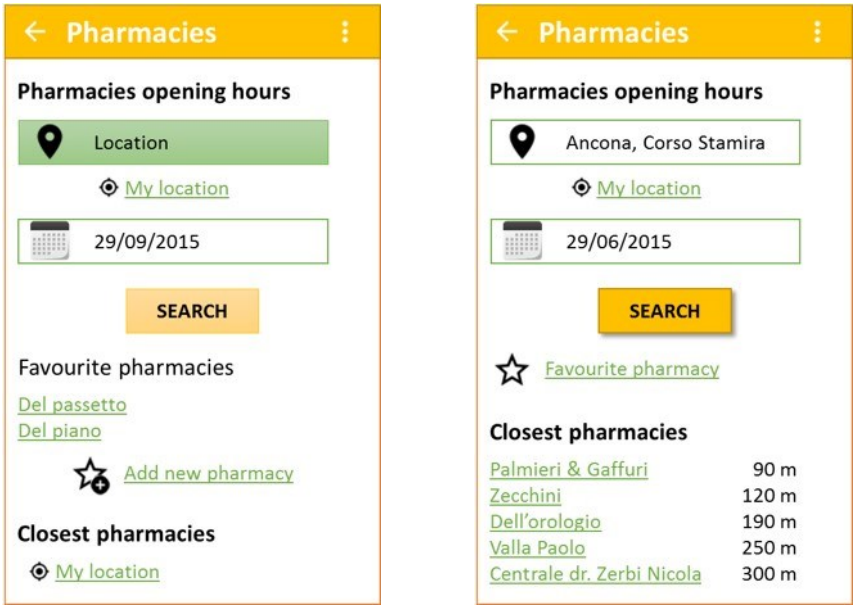



*Figure 55 – "Pharmacies" feature*

# *Chapter 5*
# System performances and sustainability

The potentialities of the proposed system have been evaluated in different moments of the design process and from several perspectives. During the system development phases, several brainstorming sessions have been organized to receive preliminary feedbacks and verify if the designed features satisfied the requirements. Once prototyped, the system has been validated and underwent to several analysis such as performance, usability, LCA and LCC, whose results are presented in the next paragraphs.

## 5.1 Performances evaluation

A preliminary evaluation of the prototype has been carried out in order to detect potential usability problems at an early stage, before the development is complete, and understand more thoroughly the users' expectations and impressions of the system. The feedbacks received in this phase allowed improving the application features and simplifying its usability. For example, the following main changes and improvements have been made:

- Reduction of warning messages pop-ups in favour of other feedback typologies such as different colours, use of smile, etc. Indeed, an excessive number of communications to the user made them less incisive by obtaining the opposite effect that is the carelessness about suggestions;
- Reduction of the number of data in a screen. A minimal structure has been preferred to limit the user's confusion and difficulty in understanding the information;
- The swipe on the product row to execute specific actions such as, for example, the check-out has been substituted with common buttons because it was not intuitive;
- The automatic insertion in the shopping list, when the related feature is enabled, has been limited to the periodic items rather than all products

finished and expired. Indeed, the list created according to the first solution hardly coincided with the user's expectations;

- Use of tags of different colours for a better management.

Once completed the development of the application, the proper functioning of each features has been verified and the algorithm related to the recipes suggestion has been validated. Finally, the usability of the system has been evaluated.

### 5.1.1 Recipes algorithm validation

The algorithm to suggest the most proper recipes according to the health and sustainability aspects has been validated by involving two different users, whose characteristics are summarized in Table 10. Additional qualitative information such as the marital status and the number of housemates has been added to better contextualize the users.

*Table 10 – Users' characteristics*

| CHARACTERISTIC | USER 1 | USER 2 |
|---|---|---|
| Gender | Male | Female |
| Year of birth | 1988 | 1984 |
| Height | 1,75 m | 1,58 m |
| Weight | 72 kg | 55 kg |
| Food allergies | None | Celiac disease |
| Job | PhD student | Wedding planner |
| Marital status | Unmarried | Married |
| Housemates | 2 (colleagues) | 1 (husband) |

In this case study, only the system feature related to the recipes has been taken into account. In particular, data related to the stocks inventory have been manually managed and the information concerned the physical activity has been collected by means of activity trackers. The data collection refer to a time period of two weeks and the algorithm has been tested during the second week.

The first step consisted in the recipe filter according to the food allergies. As described in the previous chapter, each ingredient has a dedicated flag that indicates if it is critical for the user according to his/her health conditions and, when possible, a substitute ingredient has been specified. Furthermore, each ingredient could have a different importance according to the recipe considered. Based on these considerations, the filter can be enabled. In the specific case, it has been only enabled for the celiac user (i.e., User 2). In Figure 56 three examples of recipes and relative ingredients are shown. In particular, it is possible to observe that all ingredients of the first recipe are gluten free so it has been directly inserted in the list of possible recipes to suggest. Instead, the second one and the third one need a critical ingredient each such as *breadcrumbs* and *pasta*. However, in both cases a substitutive ingredient has been provided. Therefore, the two recipes have been added to the list by substituting *breadcrumbs* with *corn flour* and *pasta* with *pasta gluten free*. No recipe has been deleted from the list because for each critical ingredient a substitute one were present, according to the celiac disease requirements.

| RECIPE | INGREDIENT | QUANTITY | UNIT OF MEASURE | TYPOLOGY | GLUTEN | SUBSTITUTIVE INGREDIENT |
|---|---|---|---|---|---|---|
| Frittata con asparagi | Asparagus | 8 | | Primary | N | |
| Frittata con asparagi | Egg | 5 | | Primary | N | |
| Frittata con asparagi | Salt | | | Secondary | N | |
| Frittata con asparagi | Oil | | | Secondary | N | |
| Frittata con asparagi | Onion | 2 | | Optional | N | |

| RECIPE | INGREDIENT | QUANTITY | UNIT OF MEASURE | TYPOLOGY | GLUTEN | SUBSTITUTIVE INGREDIENT |
|---|---|---|---|---|---|---|
| Orata | Orata | 4 | | Primary | N | |
| Orata | Oil | | | Secondary | N | |
| Orata | Salt | | | Secondary | N | |
| Orata | Parsley | | | Optional | N | |
| Orata | Lemon | 1 | | Optional | N | |
| Orata | Breadcrumbs | 4 | Teaspoon | Optional | Y | Corn flour |
| Orata | Pepper | | | Optional | N | |

| RECIPE | INGREDIENT | QUANTITY | UNIT OF MEASURE | TYPOLOGY | GLUTEN | SUBSTITUTIVE INGREDIENT |
|---|---|---|---|---|---|---|
| Pasta al ragù | Pasta | 350 | g | Primary | Y | Pasta gluten free |
| Pasta al ragù | Minced meat | 200 | g | Primary | N | |
| Pasta al ragù | Tomatoes sauce | 400 | g | Primary | N | |
| Pasta al ragù | Wine | 5 | cl | Secondary | N | |
| Pasta al ragù | Onion | | | Secondary | N | |
| Pasta al ragù | Oil | 6 | cl | Secondary | N | |
| Pasta al ragù | Salt | | | Secondary | N | |
| Pasta al ragù | Pecorino | 60 | g | Optional | N | |
| Pasta al ragù | Chili pepper | 1 | | Optional | N | |

*Figure 56 – Recipe filter according to the food allergies*

The second step consisted in the calculation of the BMR, the identification of the most appropriate PAL and the determination of the ER for both users. According to the characteristics of Table 10 and the equation (2), the BMR values inserted in Table 11 have been obtained. In order to define the PAL, the job typology has been analysed. Both occupations are sedentary, so additional information related to the weekly activity of the users had to be considered. For this aim, the data measured by the activity trackers have been elaborated. They classify the activity according to a 3-Level scale (i.e., low, medium, and high). For this reason, the general criteria of PAL assignment, discussed in previous chapter, has been defined in more detail according to the activity tracker characteristics,

as shown in Table 12. In this way, it was possible to calculate the ER according to (1). The results are shown in Table 11.

*Table 11 – Users' Energy Requirement (ER)*

| | USER 1 | USER 2 |
|---|---|---|
| **BMR** | **1684** | **1222** |
| Job | Sedentary | Sedentary |
| Medium-Level activity | 10 hours/week | 11 hours/week |
| High-Level activity | 8 hours/week | 3 hours/week |
| **PAL** | **2** | **1,7** |
| **ER** | **3368** | **2077** |

*Table 12 – PAL assignment according to the activity tracker data*

| ACTIVITY LEVEL | HOURS/WEEK | PAL |
|---|---|---|
| Medium-Level activity<br>High-Level activity | >10<br>2-3 | 1.7 |
| Medium-Level activity<br>High-Level activity | >14<br>4-5 | 1.8 |
| High-Level activity | 6-7 | 1.9 |
| High-Level activity | 8-9 | 2.0 |
| High-Level activity | 10-11 | 2.1 |
| High-Level activity | 11-12 | 2.2 |
| High-Level activity | 13-14 | 2.3 |

Henceforward, the results related to the lunch of Day 10 are presented. However, the same procedure has been carried out for all meals of the test period.

Since no information about the breakfast were available, the lunch energy requirement has been calculated according to the literature percentage (35%). In particular, MER resulted equal to 1179 kcal for the User 1 and 727 kcal for the User 2. However, to determine the contribution only related to the main course a further percentage of 50% has been calculated. Therefore, the two indicators become 589 kcal for the User 1 and 364 kcal for the User 2. According to the

rationale presented in Figure 44, the Conformity Indicator has been assigned to each recipe. The results are shown in Figure 57 and Figure 58 respectively for the User 1 and the User 2. The recipes highlighted in red mean that they have been modified according to the celiac disease requirements.

| RECIPE | Calories | Δkcal % | *Conformity Indicator (CI)* |
|---|---|---|---|
| Arista Di Maiale Al Forno | 375 | 57% | ***9*** |
| Arrosto di maiale | 361 | 63% | ***9*** |
| Cannelloni | 574 | 3% | ***0*** |
| Carciofi ripieni | 218 | 170% | ***9*** |
| Cotoletta panata | 327 | 80% | ***9*** |
| Farfalle con salmone, rucola e pomodorini | 451 | 31% | ***3*** |
| Fettine di pollo arrosto | 110 | 436% | ***9*** |
| Filetto di merluzzo | 318 | 86% | ***9*** |
| Frittata con asparagi | 233 | 153% | ***9*** |
| Frittata con cipolle | 200 | 195% | ***9*** |
| Frittata con patate | 220 | 168% | ***9*** |
| Frittura di calamari | 89 | 564% | ***9*** |
| Lasagna | 688 | -14% | ***1*** |
| Minestra di lenticchie | 704 | -16% | ***1*** |
| Orata | 322 | 83% | ***9*** |
| Pappardelle asparagi e gamberetti | 370 | 59% | ***9*** |
| Pasta aglio, olio e peperoncino | 382 | 54% | ***9*** |
| Pasta al ragù | 430 | 37% | ***3*** |
| Pasta e broccoli | 320 | 84% | ***9*** |
| Pasta e fagioli | 629 | -6% | ***0*** |
| Petti di pollo al prosciutto | 125 | 372% | ***9*** |
| Pollo arrosto | 930 | -37% | ***3*** |
| Pollo fritto | 246 | 140% | ***9*** |
| Risotto agli spinaci | 415 | 42% | ***3*** |
| Risotto ai calamaretti | 500 | 18% | ***1*** |
| Risotto ai funghi | 510 | 16% | ***1*** |
| Spaghetti alla carbonara | 452 | 30% | ***3*** |
| Tortellini alla boscaiola | 674 | -13% | ***1*** |
| Tortellini in brodo | 478 | 23% | ***1*** |
| Zuppa di ceci | 250 | 136% | ***9*** |

*Figure 57 – Conformity Indicator assignment for the User 1*

| RECIPE | Calories | Δkcal % | *Conformity Indicator (CI)* |
|---|---|---|---|
| Arista Di Maiale Al Forno | 375 | -3% | ***0*** |
| Arrosto di maiale | 361 | 1% | ***0*** |
| Cannelloni | 574 | -37% | ***3*** |
| Carciofi ripieni | 218 | 67% | ***9*** |
| Cotoletta panata | 327 | 11% | ***1*** |
| Farfalle con salmone, rucola e pomodorini | 451 | -19% | ***1*** |
| Fettine di pollo arrosto | 110 | 230% | ***9*** |
| Filetto di merluzzo | 318 | 14% | ***1*** |
| Frittata con asparagi | 233 | 56% | ***9*** |
| Frittata con cipolle | 200 | 82% | ***9*** |
| Frittata con patate | 220 | 65% | ***9*** |
| Frittura di calamari | 89 | 310% | ***9*** |
| Lasagna | 688 | -47% | ***3*** |
| Minestra di lenticchie | 704 | -48% | ***3*** |
| Orata | 322 | 13% | ***1*** |
| Pappardelle asparagi e gamberetti | 370 | -2% | ***0*** |
| Pasta aglio, olio e peperoncino | 382 | -5% | ***0*** |
| Pasta al ragù | 430 | -15% | ***1*** |
| Pasta e broccoli | 320 | 14% | ***1*** |
| Pasta e fagioli | 629 | -42% | ***3*** |
| Petti di pollo al prosciutto | 125 | 191% | ***9*** |
| Pollo arrosto | 930 | -61% | ***9*** |
| Pollo fritto | 246 | 48% | ***3*** |
| Risotto agli spinaci | 415 | -12% | ***1*** |
| Risotto ai calamaretti | 500 | -27% | ***3*** |
| Risotto ai funghi | 510 | -29% | ***3*** |
| Spaghetti alla carbonara | 452 | -20% | ***1*** |
| Tortellini alla boscaiola | 674 | -46% | ***3*** |
| Tortellini in brodo | 478 | -24% | ***1*** |
| Zuppa di ceci | 250 | 45% | ***3*** |

*Figure 58 - Conformity Indicator assignment for the User 2*

The third step is finalized to the Similarity Indicator determination. For this aim, the correlation matrix between recipes has been filled in according to the rules shown in Figure 45. An example is described in Figure 59.

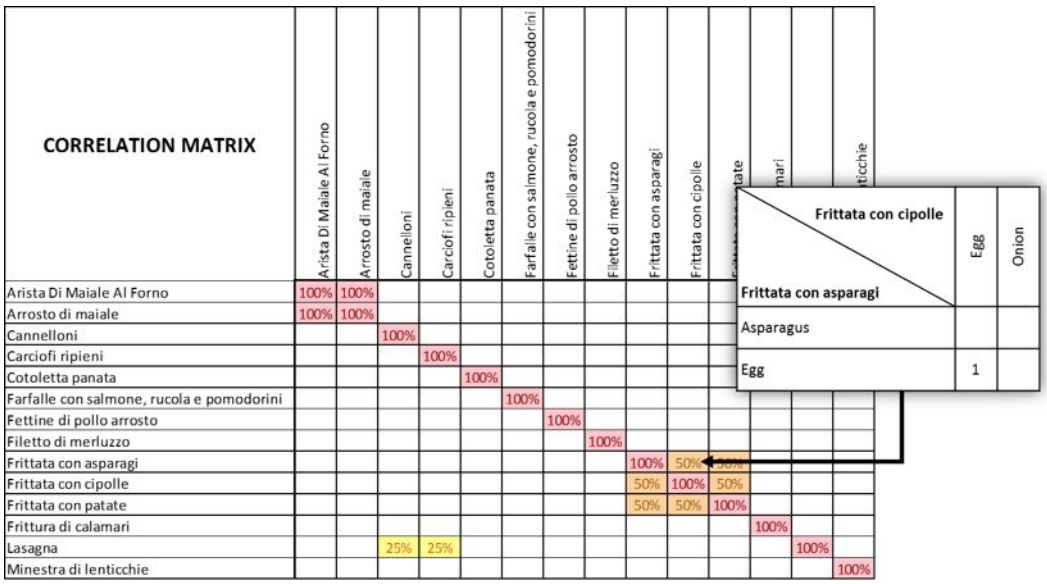



*Figure 59 – Compilation of the correlation matrix*

In order to filter the matrix, the meals consumed in the three days before Day 10 have been analysed as shown in Table 13.

*Table 13 – Meals consumed in the three days before Day 10*

| MEAL | USER 1 | USER 2 |
|---|---|---|
| Day 7 - Lunch | Pasta e fagioli | N/A |
| Day 7 - Dinner | Filetto di merluzzo | Petto di pollo al prosciutto |
| Day 8 - Lunch | N/A | N/A |
| Day 8 - Dinner | Pollo arrosto | Frittata con asparagi |
| Day 9 - Lunch | Spaghetti alla carbonara | Tortellini in brodo |
| Day 9 - Dinner | N/A | Orata |

In this way, it was possible to filter the rows of the matrix and calculate the Similarity Indicator as described in Figure 46 and Figure 47. In particular, Figure 60 shows the results related to the User 1 and Figure 61 the results related to the User 2.

| CORRELATION MATRIX<br><br>USER 1 | Days ago | Weight | Arista Di Maiale Al Forno | Arrosto di maiale | Cannelloni | Carciofi ripieni | Cotoletta panata | Farfalle con salmone, rucola e pomodorini | Fettine di pollo arrosto | Filetto di merluzzo | Frittata con asparagi | Frittata con cipolle | Frittata con patate | Frittura di calamari | Lasagna | Minestra di lenticchie | Orata | Pappardelle asparagi e gamberetti | Pasta aglio, olio e peperoncino | Pasta al ragù | Pasta e broccoli | Pasta e fagioli | Petti di pollo al prosciutto | Pollo arrosto | Pollo fritto | Risotto agli spinaci | Risotto ai calamaretti | Risotto ai funghi | Spaghetti alla carbonara | Tortellini alla boscaiola | Tortellini in brodo | Zuppa di ceci |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Filetto di merluzzo | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasta e fagioli | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 3 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Pollo arrosto | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Spaghetti alla carbonara | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 |
| Similarity Indicator SI | | | 0 | 0 | 0 | 0 | 0 | 12 | 27 | 9 | 9 | 9 | 9 | 0 | 0 | 0 | 0 | 12 | 12 | 12 | 12 | 18 | 0 | 27 | 0 | 0 | 0 | 0 | 84 | 0 | 0 | 0 |

*Figure 60 - Similarity Indicator assignment for the User 1*

| CORRELATION MATRIX<br><br>USER 2 | Days ago | Weight | Arista Di Maiale Al Fomo | Arrosto di maiale | Cannelloni | Carciofi ripieni | Cotoletta panata | Farfalle con salmone, rucola e pomodorini | Fettine di pollo arrosto | Filetto di merluzzo | Frittata con asparagi | Frittata con cipolle | Frittata con patate | Frittura di calamari | Lasagna | Minestra di lenticchie | Orata | Pappardelle asparagi e gamberetti | Pasta aglio, olio e peperoncino | Pasta al ragù | Pasta e broccoli | Pasta e fagioli | Petti di pollo al prosciutto | Pollo arrosto | Pollo fritto | Risotto agli spinaci | Risotto ai calamaretti | Risotto ai funghi | Spaghetti alla carbonara | Tortellini alla boscaiola | Tortellini in brodo | Zuppa di ceci |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frittata con asparagi | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 3 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Orata | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Petti di pollo al prosciutto | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tortellini in brodo | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 9 | 0 |
| ***Similarity Indicator SI*** | | | **0** | **0** | **0** | **0** | **0** | **0** | **3** | **0** | **27** | **9** | **9** | **0** | **0** | **0** | **81** | **9** | **0** | **0** | **0** | **0** | **9** | **0** | **0** | **0** | **0** | **0** | **9** | **0** | **0** | **0** |

*Figure 61 - Similarity Indicator assignment for the User 2*

The next step refers to the Priority Indicator assignment, therefore, all the information related to the stocks inventory have been monitored and inserted in the specific column of the matrix. For this reason, it is worth to specify that for the fresh products without expiration date, the latter has been assumed according to the purchased date and the food category. In particular, it has been hypothesized that fish expires by 2 days from the purchase, meat by 3 days and vegetables by 4 days. The weights related to the products expiration and availability have been assigned as described in Figure 48. The rest of the cells has been filled in according to the rationale shown in Figure 49. The results are summarized in Figure 62 and Figure 63 respectively for the User 1 and the User 2.

| RECIPE / INGREDIENT | Expiration date [days] | Weight | Arista Di Maiale Al Forno | Arrosto di maiale | Cannelloni | Carciofi ripieni | Cotoletta panata | Farfalle con salmone, rucola e pomodorini | Fettine di pollo arrosto | Filetto di merluzzo | Frittata con asparagi | Frittata con cipolle | Frittata con patate | Frittura di calamari | Lasagna | Minestra di lenticchie | Orata | Pappardelle asparagi e gamberetti | Pasta Aglio Olio E Peperoncino | Pasta al ragù | Pasta e broccoli | Pasta e fagioli | Petti di pollo al prosciutto | Pollo arrosto | Pollo fritto | Risotto agli spinaci | Risotto ai calamaretti | Risotto ai funghi | Spaghetti alla carbonara | Tortellini alla boscaiola | Tortellini in brodo | Zuppa di ceci |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Artichoke | N/A | 9 | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Asparagus | 3 | 3 | | | | | | | | | 0,1 | | | | | | | 0,1 | | | | | | | | | | | | | | |
| Bacon | N/A | 9 | | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | 1,0 | | | |
| Barley | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 |
| Basil | > 3 | 9 | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Bay leaf | > 3 | 9 | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bean | N/A | 9 | | | | | | | | | | | | | | | | | | | | 1,0 | | | | | | | | | | |
| Beef | N/A | 9 | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Breadcrumbs | N/A | 9 | | | | 0,7 | 0,7 | | | | | | | | | | 0,1 | | | | | | | | 0,7 | | | | | | | |
| Broccoli | > 3 | 9 | | | | | | | | | | | | | | | | | | | 0,1 | | | | | | | | | | | |
| Butter | > 3 | 9 | | | 1,0 | | 1,0 | | | | | 1,0 | | | | | | | | | | | | | | 1,0 | | 1,0 | | | | |
| Calamari | N/A | 9 | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | 1,0 | | | | | |
| Carrot | > 3 | 9 | | | | | | | | | | | | | 0,8 | | | | | | | | | 1,0 | | | | | | | | |
| Celery | N/A | 9 | | | | | | | | | | | | | 0,7 | | | | | | | | | 0,1 | | | | | | | | |
| Cheese parmesan | > 3 | 9 | | | 0,8 | 0,8 | | | | | | | 1,0 | | 0,8 | | | | | | | | | | 0,8 | 0,8 | | 0,8 | | 1,0 | 1,0 | |
| Chicken | N/A | 9 | | | | | | | 1,0 | | | | | | | | | | | | | | 1,0 | 1,0 | 1,0 | | | | | | | |
| Chickpea | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,1 |
| Chili pepper | > 3 | 9 | | | | | | 1,0 | | | | | | | | | | | 0,8 | 1,0 | 1,0 | | | | | | | | | | | |
| Chives | N/A | 9 | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Cod | N/A | 9 | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | |
| Courgette | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | | | | | | |
| Cream | N/A | 9 | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | |
| Egg | > 3 | 9 | | | | 0,8 | 0,8 | | | | 0,1 | 0,1 | 0,1 | | | | | | | | | | | | 0,8 | | | | 0,1 | | | |
| Flour | > 3 | 9 | | | | | | | | | | | | 0,8 | | | | | | | | | | | 0,8 | | | | | | | |
| Garlic | > 3 | 9 | 1,0 | 1,0 | | 0,8 | 1,0 | | | | | | | | | | | | 0,1 | | 1,0 | | | | | | 1,0 | | | | | |
| Ham steak | N/A | 9 | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | |
| Lemon | > 3 | 9 | | | | | | | | | | | | | | | 1,0 | | | | | | | 1,0 | | | | | | | | |
| Lemon juice | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | 0,1 | | | | | | | |
| Lentils | > 3 | 9 | | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | |
| Milk | 1 | 1 | | | | | | | | | | | 1,0 | | 0,8 | | | | | | | | | 1,0 | | | | | | | | |
| Minced meat | N/A | 9 | | | | 1,0 | | | | | | | | | 1,0 | | | | | 1,0 | | | | | | | | | | | | |
| Mozzarella | 2 | 3 | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | | |
| Mushroom | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | | 0,1 | | |
| Nutmeg | N/A | 9 | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Oil | > 3 | 9 | | | | | | 0,8 | | 0,8 | 0,8 | | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,1 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | | | 0,8 | | 0,8 |
| Olives | N/A | 9 | | | | | | | | 0,1 | | | | | | | | | | | | | | | | | 0,1 | | | | | |
| Onion | > 3 | 9 | | | | | | | | | 1,0 | 0,1 | | | 1,0 | 1,0 | | | | 0,8 | | 0,8 | | 1,0 | | 0,8 | | 1,0 | | 0,8 | | |
| Orata | N/A | 9 | | | | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | | | |
| Parsley | > 3 | 9 | | | 1,0 | 0,8 | | | | | | | | | | | 1,0 | | | | | | | | 1,0 | | 1,0 | | | | | |
| Pasta | > 3 | 9 | | | | | | 0,1 | | | | | | | | | | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | | | | | | | 0,1 | | | |
| Peas | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | | |
| Pecorino | > 3 | 9 | | | | | | | | | | | | | | | | | | 1,0 | | | | | | | | | 0,8 | | | |
| Pepper | > 3 | 9 | 1,0 | 1,0 | 1,0 | 0,8 | | | 1,0 | | | | 1,0 | | 1,0 | 1,0 | 1,0 | 1,0 | | | | | | 1,0 | | 1,0 | | | 1,0 | 1,0 | | |
| Pork loin chop | 2 | 3 | 0,1 | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Potatoes | > 3 | 9 | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | |
| Prawn | N/A | 9 | | | | | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | | |
| Puff pastry | N/A | 9 | | | 1,0 | | | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | |
| Raw ham | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | 0,1 | | | | | | | | | |
| Rice | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | 0,1 | 0,1 | | | | |
| Ricotta | N/A | 9 | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rocket | 3 | 3 | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Rosemary | > 3 | 9 | 1,0 | 1,0 | | | | | 1,0 | | | | | | | 1,0 | | | | | | | | 1,0 | | | | | | | | |
| Salmon | N/A | 9 | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Salt | > 3 | 9 | 0,8 | 0,8 | 0,8 | 0,8 | | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | | 0,8 | 0,8 | 0,8 | | 0,8 | | 0,8 | | 0,8 | | 0,8 | | 0,8 |
| Sausage | N/A | 9 | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | | |
| Soup | > 3 | 9 | | | | 1,0 | | | | | | | | | | 0,1 | | | | | | | | | | 0,1 | | 0,1 | | | 0,1 | |
| Spinach | > 3 | 9 | | | 0,1 | | | | | | | | | | | | | | | | | | | | | 0,1 | | | | | | |
| Thyme | N/A | 9 | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tomato cherry | > 3 | 9 | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tomatoes sauce | > 3 | 9 | | | | | | | | | | | | | 0,1 | | | | | 0,1 | | | | | | | | | | | | |
| Tortellini | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | 0,1 | |
| Vinegar | > 3 | 9 | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | |
| Wine | > 3 | 9 | 1,0 | | | | | | | | | | | | 1,0 | | | | | 0,8 | | | | | | | | | | 1,0 | | |
| ***Priority Indicator PI*** | | | 53 | 35 | 63 | 77 | 41 | 44 | 34 | 33 | 25 | 18 | 35 | 31 | 83 | 44 | 51 | 34 | 9,9 | 58 | 34 | 32 | 27 | 60 | 54 | 50 | 36 | 28 | 34 | 61 | 10 | 24 |

*Figure 62 - Priority Indicator assignment for the User 1*

| RECIPE / INGREDIENT | Expiration date [days] | Weight | Arista Di Maiale Al Forno | Arrosto di maiale | Cannelloni | Carciofi ripieni | Cotoletta panata | Farfalle con salmone, rucola e pomodorini | Fettine di pollo arrosto | Filetto di merluzzo | Frittata con asparagi | Frittata con cipolle | Frittata con patate | Frittura di calamari | Lasagna | Minestra di lenticchie | Orata | Pappardelle asparagi e gamberetti | Pasta aglio, olio e peperoncino | Pasta al ragù | Pasta e broccoli | Pasta e fagioli | Petti di pollo al prosciutto | Pollo arrosto | Pollo fritto | Risotto agli spinaci | Risotto ai calamaretti | Risotto ai funghi | Spaghetti alla carbonara | Tortellini alla boscaiola | Tortellini in brodo | Zuppa di ceci |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Artichoke | 2 | 3 | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Asparagus | 2 | 3 | | | | | | | | | 0,1 | | | | | | | 0,1 | | | | | | | | | | | | | | |
| Bacon | > 3 | 9 | | | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | 0,1 | | | |
| Barley | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,1 |
| Basil | > 3 | 9 | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Bay leaf | > 3 | 9 | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bean | N/A | 9 | | | | | | | | | | | | | | | | | | | | 1,0 | | | | | | | | | | |
| Beef | 2 | 3 | | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Breadcrumbs | > 3 | 9 | | | | 0,8 | 0,8 | | | | | | | | | | 1,0 | | | | | | | | 0,8 | | | | | | | |
| Broccoli | N/A | 9 | | | | | | | | | | | | | | | | | | | 1,0 | | | | | | | | | | | |
| Butter | > 3 | 9 | | | 1,0 | | 1,0 | | | | | 1,0 | | | | | | | | | | | | | | 1,0 | | 1,0 | | | | |
| Calamari | N/A | 9 | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | 1,0 | | | | | |
| Carrot | > 3 | 9 | | | | | | | | | | | | | 0,8 | | | | | | | | | 1,0 | | | | | | | | |
| Celery | N/A | 9 | | | | | | | | | | | | | 0,7 | | | | | | | | | 0,1 | | | | | | | | |
| Cheese parmesan | > 3 | 9 | | | 0,8 | 0,8 | | | | | | | 1,0 | | 0,8 | | | | | | | | | | 0,8 | 0,8 | | 0,8 | | 1,0 | 1,0 | |
| Chicken | N/A | 9 | | | | | | | 1,0 | | | | | | | | | | | | | | 1,0 | 1,0 | 1,0 | | | | | | | |
| Chickpea | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 |
| Chili pepper | > 3 | 9 | | | | | | 1,0 | | | | | | | | | | | 0,8 | 1,0 | 1,0 | | | | | | | | | | | |
| Chives | N/A | 9 | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Cod | N/A | 9 | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | |
| Courgette | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | | | | | |
| Cream | 1 | 1 | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | | | |
| Egg | 3 | 3 | | | | 0,8 | 0,8 | | | | 0,1 | 0,1 | 0,1 | | | | | | | | | | | | 0,8 | | | | 0,1 | | | |
| Flour | > 3 | 9 | | | | | | | | | | | | 0,8 | | | | | | | | | | | 0,8 | | | | | | | |
| Garlic | > 3 | 9 | 1,0 | 1,0 | | 0,8 | 1,0 | | | | | | | | | | | | 0,1 | | 1,0 | | | | | | 1,0 | | | | | |
| Ham steak | N/A | 9 | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | | |
| Lemon | N/A | 9 | | | | | | | | | | | | | | 0,1 | | | | | | | 0,1 | | | | | | | | | |
| Lemon juice | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | | | | | | |
| Lentils | > 3 | 9 | | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | |
| Milk | 2 | 3 | | | | | | | | | | 1,0 | | | 0,8 | | | | | | | | 1,0 | | | | | | | | | |
| Minced meat | N/A | 9 | | | | 1,0 | | | | | | | | | 1,0 | | | | | 1,0 | | | | | | | | | | | | |
| Mozzarella | > 3 | 9 | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | | |
| Mushroom | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | 1,0 | | |
| Nutmeg | > 3 | 9 | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Oil | > 3 | 9 | | | | | | 0,8 | | 0,8 | 0,8 | | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,1 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | | | 0,8 | | 0,8 |
| Olives | > 3 | 9 | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | 1,0 | | | | | |
| Onion | > 3 | 9 | | | | | | | | | 1,0 | 0,1 | | | 1,0 | 1,0 | | | | 0,8 | | 0,8 | | 1,0 | | 0,8 | | 1,0 | | 0,8 | | | |
| Orata | N/A | 9 | | | | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | | | |
| Parsley | > 3 | 9 | | | 1,0 | 0,8 | | | | | | | | | | | 1,0 | | | | | | | | 1,0 | | 1,0 | | | | | |
| Pasta | > 3 | 9 | | | | | | 0,1 | | | | | | | | | | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | | | | | | | 0,1 | | | |
| Peas | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | | |
| Pecorino | N/A | 9 | | | | | | | | | | | | | | | | | | 0,1 | | | | | | | | | 0,7 | | | |
| Pepper | > 3 | 9 | 1,0 | 1,0 | 1,0 | 0,8 | | | 1,0 | | | | 1,0 | | 1,0 | 1,0 | 1,0 | 1,0 | | | | | | 1,0 | | 1,0 | | | 1,0 | 1,0 | | | |
| Pork loin chop | N/A | 9 | 1,0 | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Potatoes | > 3 | 9 | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | |
| Prawn | 1 | 1 | | | | | | | | | | | | | | | | 0,1 | | | | | | | | | | | | | | |
| Puff pastry | N/A | 9 | | | 1,0 | | | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | |
| Raw ham | 3 | 3 | | | | | | | | | | | | | | | | | | | | 0,1 | | | | | | | | | | |
| Rice | > 3 | 9 | | | | | | | | | | | | | | | | | | | | | | | | 0,1 | 0,1 | 0,1 | | | | |
| Ricotta | N/A | 9 | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rocket | N/A | 9 | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Rosemary | N/A | 9 | 0,1 | 0,1 | | | | | 0,1 | | | | | | | 0,1 | | | | | | | | 0,1 | | | | | | | | |
| Salmon | N/A | 9 | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | | | |
| Salt | > 3 | 9 | 0,8 | 0,8 | 0,8 | 0,8 | | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 | | 0,8 | 0,8 | 0,8 | | 0,8 | | 0,8 | | 0,8 | | 0,8 | | 0,8 |
| Sausage | > 3 | 9 | | | | | | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | |
| Soup | N/A | 9 | | | | 0,1 | | | | | | | | | | 1,0 | | | | | | | | | | 1,0 | | 1,0 | | | 1,0 | |
| Spinach | N/A | 9 | | | 1,0 | | | | | | | | | | | | | | | | | | | | | 1,0 | | | | | | |
| Thyme | N/A | 9 | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tomato cherry | > 3 | 9 | | | | | | 0,1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tomatoes sauce | > 3 | 9 | | | | | | | | | | | | | 0,1 | | | | | 0,1 | | | | | | | | | | | | |
| Tortellini | N/A | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,0 | 1,0 | |
| Vinegar | > 3 | 9 | | | | | | | | 1,0 | | | | | | | | | | | | | | | | | | | | | | |
| Wine | > 3 | 9 | 1,0 | | | | | | | | | | | | 1,0 | | | | | 0,8 | | | | | | | | | | 1,0 | | |
| ***Priority Indicator PI*** | | | 53 | 35 | 79 | 57 | 28 | 53 | 26 | 41 | 24 | 17 | 37 | 31 | 93 | 52 | 51 | 25 | 9,9 | 50 | 42 | 32 | 20 | 52 | 58 | 69 | 44 | 44 | 25 | 78 | 27 | 24 |

*Figure 63 - Priority Indicator assignment for the User 2*

Finally, all indicators has been normalized according to the rules described in the Chapter 4 and the absolute and relative performances of each recipes have been calculated. The latter have been ranked according to the relative performances.

As shown by Figure 64, the first three recipes to suggest to the User 1 are:

1. Tortellini in brodo;
2. Pasta aglio, olio e peperoncino;
3. Risotto ai funghi.

All of them have not been consumed in the three days before Day 10, need available ingredients and satisfy the energy requirements with a maximum Δkcal of 54%. Furthermore, the first recipe allows consuming "tortellini" that expire in one day.

| | **Weight** | Tortellini in brodo | Pasta Aglio Olio E Peperoncino | Risotto ai funghi | Risotto agli spinaci | Minestra di lenticchie | Cannelloni | Farfalle con salmone, rucola e pomodorini | Lasagna | Risotto ai calamaretti | Tortellini alla boscaiola |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Conformity Indicator | 0,1 | 1 | 10 | 1 | 3 | 1 | 0 | 3 | 1 | 1 | 1 |
| Similarity Indicator | 0,4 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Priority Indicator | 0,5 | 4 | 3 | 5 | 6 | 6 | 6 | 5 | 7 | 7 | 7 |
| ***Absolute performance AP*** | | **5** | **13** | **6** | **9** | **7** | **6** | **9** | **8** | **8** | **8** |
| ***Relative performance RP*** | | **2** | **3** | **3** | **3** | **3** | **3** | **3** | **3** | **3** | **4** |
| ***Ranking*** | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |

*Figure 64 – Recipes suggested to the User 1*

Also the results related to the User 2 are satisfactory, as shown in Figure 65. In this case, the recipes suggested are:

1. Pasta aglio, olio e peperoncino;
2. Pappardelle asparagi e gamberetti;

3. Spaghetti alla carbonara.

All of them have not been consumed in the three days before Day 10, need available ingredients and satisfy the energy requirements with a maximum Δkcal of 20%. Furthermore, two of them allow consuming ingredients close to their expiration (e.g., asparagus expire in two days and eggs in three days).

In the same way, the results obtained for the other meals of the test period satisfied the requirements and allowed validating the algorithm.

| | Weight | Pasta Aglio Olio E Peperoncino | Pappardelle asparagi e gamberetti | Spaghetti alla carbonara | Pasta al ragù | Cotoletta panata | Farfalle con salmone, rucola e pomodorini | Petti di pollo al prosciutto | Frittata con cipolle | Zuppa di ceci | Pasta e fagioli |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Conformity Indicator | 0,1 | 0 | 0 | 1 | 1 | 1 | 1 | 10 | 10 | 3 | 3 |
| Similarity Indicator | 0,4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Priority Indicator | 0,5 | 3 | 5 | 5 | 6 | 6 | 7 | 5 | 5 | 7 | 7 |
| ***Absolute performance AP*** | | **3** | **5** | **6** | **7** | **7** | **8** | **15** | **15** | **10** | **10** |
| ***Relative performance RP*** | | **1** | **2** | **3** | **3** | **3** | **3** | **3** | **4** | **4** | **4** |
| ***Ranking*** | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |

*Figure 65 – Recipes suggested to the User 2*

It is worth to specify that the results obtained can change if specific filters are enabled by the user.

### 5.1.2 System usability

The system evaluation cannot disregard the usability perceived by system users, which can be defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and

satisfaction in a specified context of use" [119]. For this reason, a dedicated protocol has been defined according to the international standards [119] [120] [121] and the Rubin's model [122].

As far as the effectiveness and efficiency are concerned, the most common objective metrics have been used to verify the achievement of the predefined targets. In particular, it has been evaluated if the app performances complies with the average ones in terms of:

- App responsiveness, which is evaluated by means of the response time that is the time it takes to deliver the result of the screen. It emerged that the app responds to user requests within 1 second. Therefore, it is competitive with the majority of the applications;
- App uptime that represents the percent of app usage that did not experience a crash. The crash rate of the proposed app resulted less than 2% and complies with the typical values of the application world.

On the other hand, the satisfaction dimension is related to the users' subjective impression and preferences. Therefore, subjective metrics have to be collected by means of questionnaires and interviews. In particular, the usability evaluation process consisted of six main phases:

- Definition of the objectives of the tests, the entities to measure and the related metrics;
- Definition of the user sample that has to be large enough to have a proper statistical weight but, at the same time, not too big not to be dispersed, and it must be representative of the target market segment;
- Definition of the tasks according to the system functionalities and properties and direct observation of users during their interaction with the system;
- Interview to the users, after the task performing, on the basis of an ad-hoc questionnaire to collect subjective impressions;
- Elaboration and analysis of collected data in order to identify aspects that need to be improved.

For the implementation of the proposed protocol, a set of main tasks has been defined according to the system functionalities and a sample of 10 users has been involved. It is worth to specify that the users, tasks and environment used for the test were representative of the intended context of use. In particular, both

single users (e.g., student, people who live alone or with colleagues, etc.) and families have been involved. However, in the second case only the user that is the family member responsible of the food management executed the tasks.

The main users' characteristics are summarized by the graphics of Figure 66. In general, females manages food at home and this justify their predominance in the sample. The majority of users is between 26 and 35 years old since they are the most probable users of the system. The level of confidence with the technology is variegated and it almost always related to the age. Furthermore, only one user in 10 has food allergies. The most of users lives with their family except one that lives alone and two that live with two housemates. About the occupations, they are: 2 office workers, 1 student, 1 PhD student, 1 waiter , 1 lawyer, 1 insurance agent, 1 consultant, 1 accountant and 1 beautician.

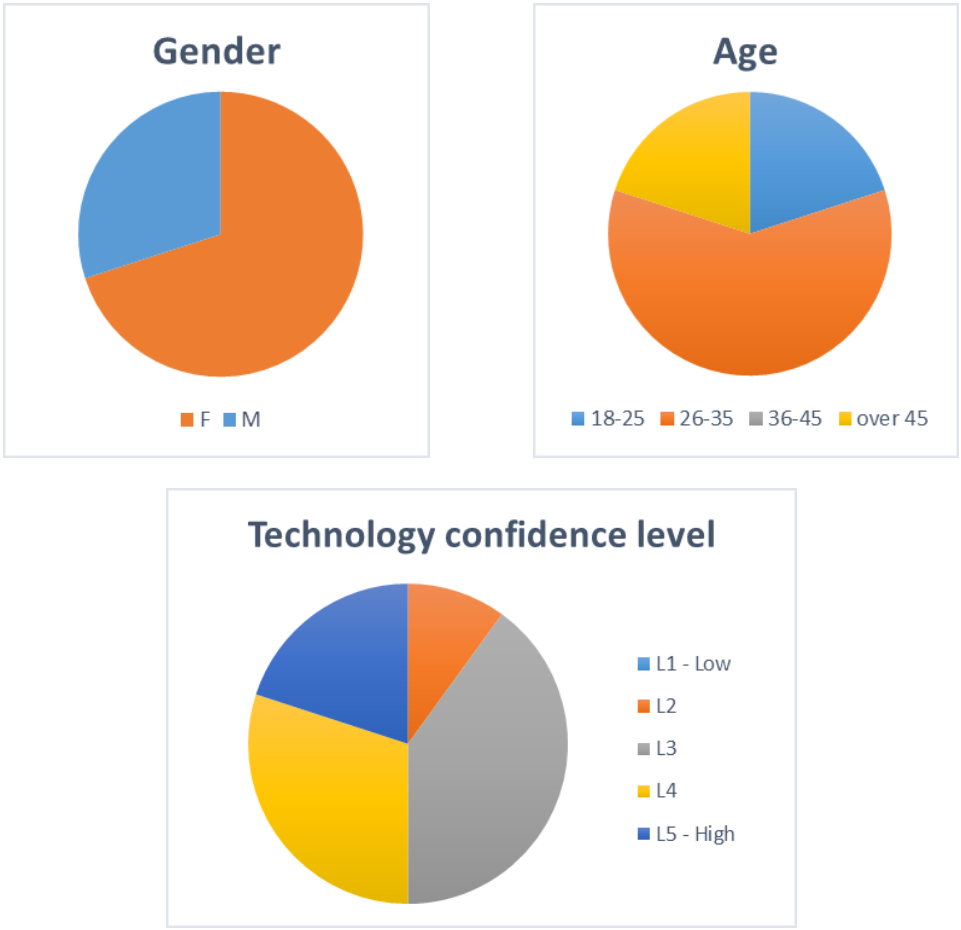



*Figure 66 – Users' characteristics*

The tasks underwent to the sample refer to the main features of the application and are summarized in Table 14.

*Table 14 – Tasks to execute during the usability test*

| TASK | DESCRIPTION |
|---|---|
| Task 1 | To execute the check-in of carrots and read where they have to be stored |
| Task 2 | To reduce the quantity of eggs of two |
| Task 3 | To read the ingredients that have to be purchased to prepare the recipe “pollo arrosto” |
| Task 4 | To add the raw ham in the shopping list |
| Task 5 | To check the opening pharmacies at the current date and time |

Before starting, a brief introduction of the system has been done to the user and he/she has been encouraged to express any comments during the test. The user behaviour and the mode of interaction with the system have been observed during the task execution. At the end of each task, it has been asked to the user to evaluate the level of satisfaction and the easy of execution according to a 5-point scale (1-Low and 5-High). At the end of the testing session, the user has been interviewed about the level of satisfaction achieved by interacting with the system and the preference data are expressed in form of judges according to a 7-point scale (1-Not at all and 7-Extremely). In Figure 67 the testing protocol adopted for the user satisfaction assessment is shown. It is based on the User Experience Questionnaires (UEQ) [123].

| USER 1 | 1 (Not at all) | 2 | 3 | 4 | 5 | 6 | 7 (Extremely) |
|---|---|---|---|---|---|---|---|
| *Enjoyable* | | | | | | | |
| *Understandable* | | | | | | | |
| *Motivating* | | | | | | | |
| *Efficient* | | | | | | | |
| *User-friendly* | | | | | | | |
| *Attractive* | | | | | | | |
| *Meets expectations* | | | | | | | |
| *Easy to use* | | | | | | | |
| *Clear* | | | | | | | |
| *Innovative* | | | | | | | |

| Task 1 | | |
|---|---|---|
| | Completed | |
| | Completed without consultation | |
| | Completed in time | |
| | Easy of execution [1-Low and 5-High] | |
| | Satisfaction [1-Low and 5-High] | |

*Figure 67 – Usability evaluation protocol*

The results show a very high success of tasks (Figure 68). Indeed, all the users completed the five tasks without asking a consultation. For each task, a reference time has been set to have a feedback about the effective load and ease of the task. In particular, only one user exceeded it in the execution of task 1, task 2 and task 3.

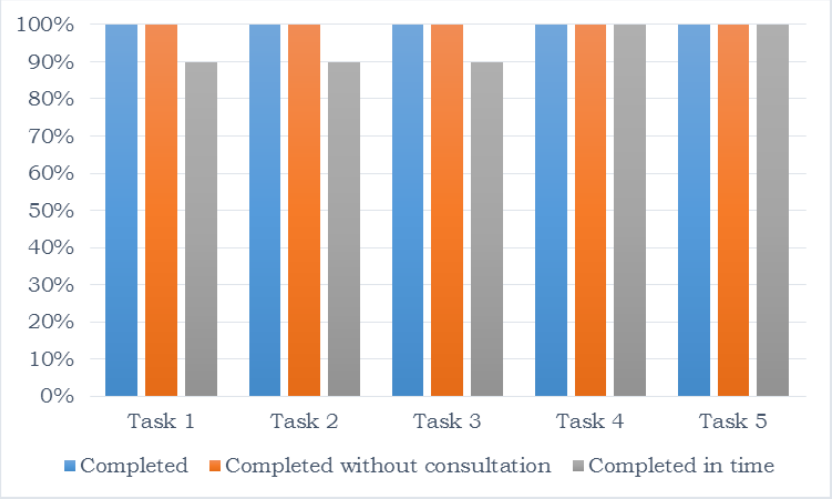



*Figure 68 – Tasks success*

The Figure 69 summarizes the users' judgments about the ease of execution and the satisfaction of the tasks. All of them exceed the 3-value and it highlights a good usability of the system. In particular, only the score related to the task 3, which is the most complex, is not greater than 4. This is due to the

confusion about the symbols related to the shopping list (i.e., cart with a plus sign and full cart).

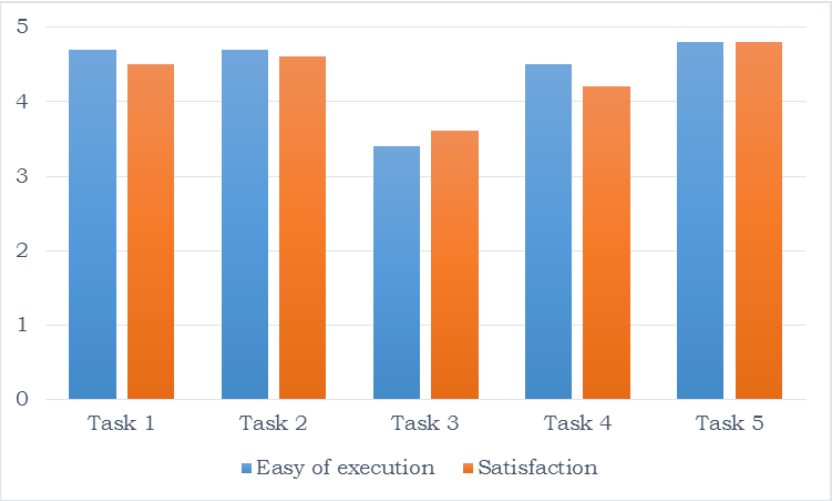



*Figure 69 – Easy of execution of tasks and users' satisfaction*

The evaluation of the system as a whole is summarized by the radar chart of Figure 70. All the score are greater than 5 except the "user-friendly" one. This is due to the necessity to manually register the product data. Indeed, nine users in ten stated that they would prefer that the system was able to read the bar code or a TAG already integrated in the product packaging. This evidence should push the FSC to insert the expiration date in the bar code or to adopt other traceability systems. Another comment that it is worth to specify is the importance to give a feedback to the users related to the benefits that originate from their actions. This could encourage them to use the system consistently.

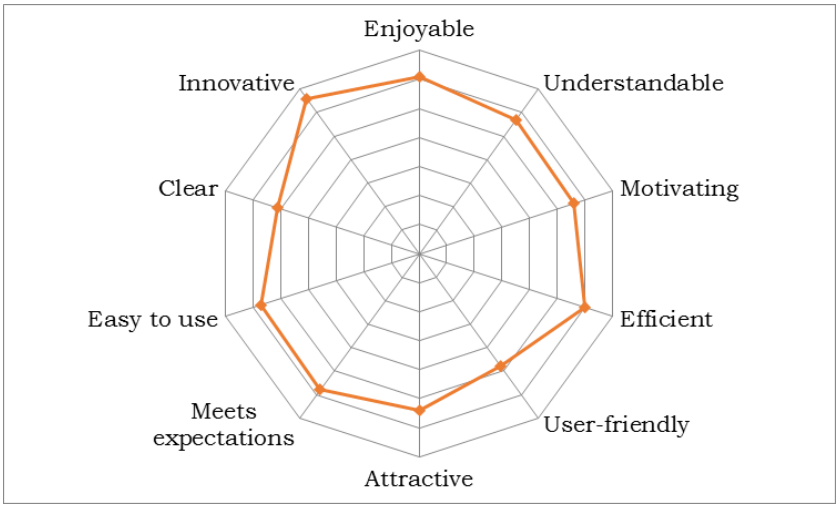



*Figure 70 – System evaluation by the users sample*

In conclusion, the results obtained are fully satisfactory. However, they highlight the necessity of a common attempt to do a step forward the state of the art in terms of traceability. Indeed, such aspect is seen as one of the most important by consumers, especially, in the food world.

## 5.2 Life Cycle Assessment analysis

As anticipated in the context description, the majority of consumers is not aware about the extent of the environmental impacts of food waste. Consequently, the benefits related to its reduction are often neglected. For this reason, a Life Cycle Assessment analysis has been carried out in order to preliminarily evaluate the proposed system from an environmental perspective. Indeed, the LCA is considered by researchers the most successful tool to assess environmental sustainability of a product/process/service. In particular, it is a "cradle-to-grave" systematic approach and consists of four main phases:

1. Goal and scope definition;
2. Life Cycle Inventory (LCI);
3. Life Cycle Impact Assessment (LCIA);
4. Results interpretation.

The first step allows defining the purpose of the study, the system boundaries and the selection of suitable functional unit. The second step consists in the data collection and organization. These data mainly refer to the resources

consumption, materials usage, emissions, wastes, etc., and can be measured on site (primary data) or derived from other sources such as literature or databases (secondary data). The third step exploits the data identified in the inventory analysis to build the model and assess its environmental impacts by means of a specific tool (e.g., SimaPro, Gabi, etc.). The last phase allows identifying critical aspects and hot spots that has to be improved in order to define a set of guidelines and make the product/service more sustainable.

### 5.2.1 Goal and scope definition

According to ISO 14044 [124], the system boundaries identify which processes should be included within the LCA analysis on the basis of the study goal. In this case, the objective is to investigate the environmental impacts related to the household food consumption and waste. In particular, a comparison between two different case studies is carried out in order to estimate the potentialities of the proposed technology. The first one is the reference situation: a common family that uses the existing applications and household appliances to manage food (Scenario 1). The second one refers to a family that interacts with smart fridge and is supported by the described smart services in the daily food-related practices (Scenario 2). Although the focus is the household environment, several stages of the FSC have to be considered. Indeed, food has to be produced, processed, distributed, sold and prepared to be consumed (Figure 71). Consequently, the analysis boundaries include all the three macro-phases of the life cycle such as production, use and end of life. The functional unit has been defined as the food consumed and wasted by a common Italian family of four members (two adults and two children) during a week. For this aim, a regular and common Italian diet has been considered.

It is worth to specify that it is not the main goal of the thesis, but a preliminary analysis to roughly evaluate the system potentialities. Therefore, it has some limitations related to the assumptions effectuated. In particular, only food typology (e.g., beef meat, pasta, egg, etc.) has been considered instead of specific recipes. This choice is mainly related to the insufficient availability of data. However, fruits could not be considered because no specific datasets are in the database. Consumptions and portions has been defined according to the recommended ones by national and international research institutes and waste

quantities has been assumed according to the statistics. The goods transportation has been taken into account until retails. It means that the itinerary between the supermarket and home has been neglected because often integrated in the daily itinerary of the user according to other plans and activities. The use phase focuses on the resources consumption of the household appliances used to store and prepare food such as fridge, oven, hob, and hood. These devices usually have an average life cycle of ten years so their manufacturing phase can be neglected because less significant when circumscribed to a very limited period of time. Finally, the incineration process has been considered as end-of-life of food waste.


*Figure 71 – Food Supply Chain*

On the other hand, the reduction of impacts at household level should be compared with the implications of the new manufacturing process of the proposed system. Therefore, a second LCA analysis has been executed to evaluate the sustainability of the new smart fridge. In particular, a comparison between the impacts of a normal fridge and those of the new model has been carried out. The boundaries of the analysis go from the manufacturing to the end of life so include the production of energy needed for the different processes; the production and transport of semi-finished products and components; their assembly; the transport of the final product to the first intermediate customer (Distribution center); the use and the product disposal. The functional unit is one household refrigerator where the reference model is the fridge HOTPOINT XH8 T2Z POJZV and DIALOGIC is its connected version. Both fridges are in the A++ energy

efficiency class. In this case, the collaboration with the company and the full knowledge of the product ensure a greater accuracy and availability of data. Information about materials, quantities, processes and suppliers have been gathered by correlating the product Bill of Material (BoM) with data provided by the corporate management software. However, detailed information about the transportation were not available so the road transport has been assumed as preferred according to the geographical characteristic of the productive site (Łódź in Poland) and an average distance of 1500 km has been considered for the transportation from the productive site to a general Italian vendor. As far as the choice of the mean of transport is concerned, the following criteria has been considered:

- Delivery van for distance less than 50 km;
- Lorry 3.5-7.5t for distance between 50 km and 250 km;
- Truck 16t for distance between 250 km and 1000 km;
- Truck 28t for distance greater than 1000 km.

Other assumptions refer to the modelling of some components. In particular, small components such as screws, rivet, bolt, sealing tape, etc., have not been considered because of the negligible mass. Complex components such as the compressor and the condenser has been modelled in a simplified way. The refrigerant R600a has been approximate to its isomer R600. However, all these assumptions do not influence the analysis accuracy since they are the same for both products.

### 5.2.2 Life Cycle Inventory

According to the considerations derived from the first phase, the diagram shown in Figure 72 has been created. For each LCA analysis, it summarizes the main flow and guides the data collection.

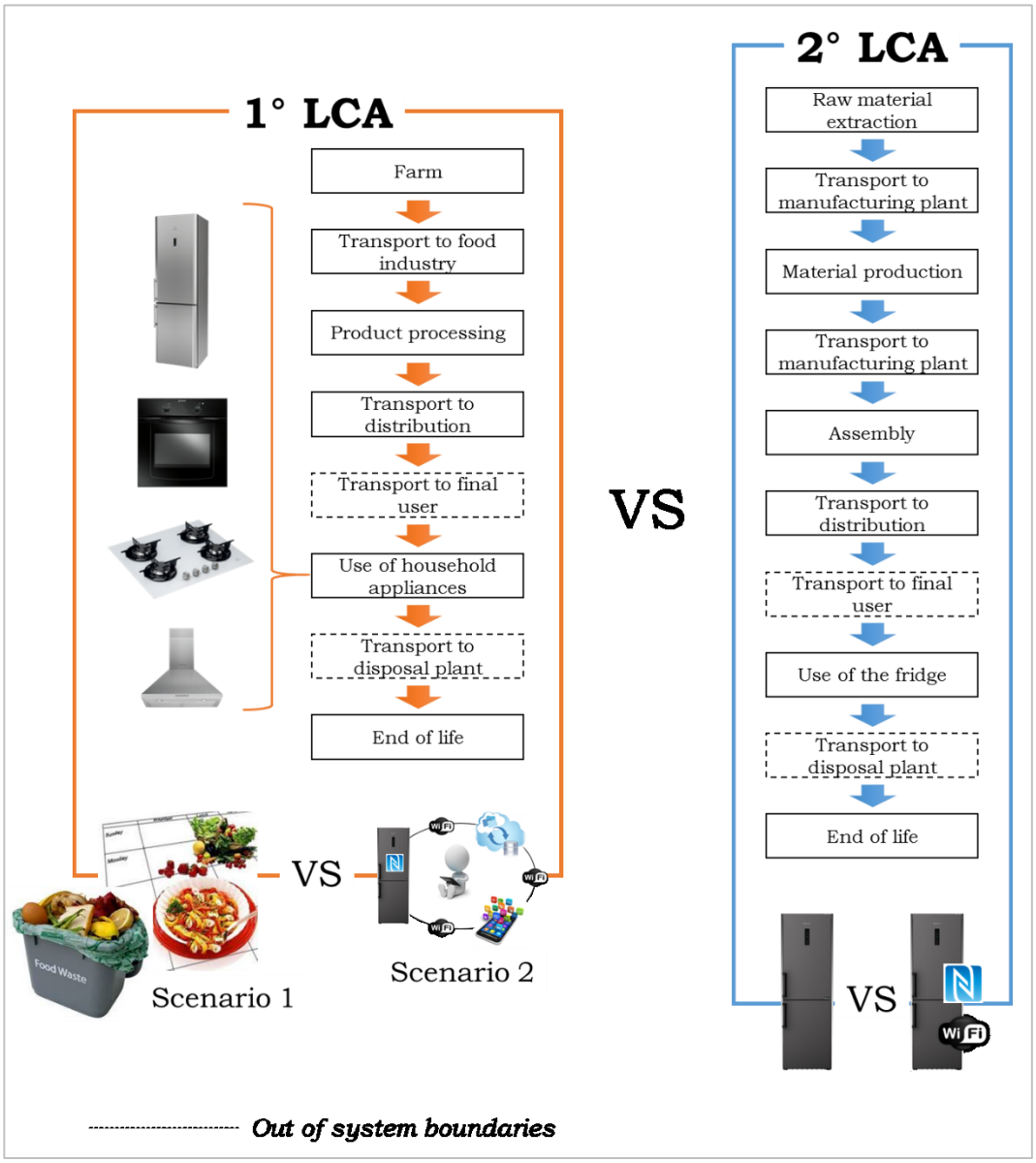



*Figure 72 – LCA analysis flow chart*

About the first LCA, the data used to perform the analysis are summarized in Table 15. In particular, the main food categories except fruits has been considered. For some categories such as meat, fish and vegetables several food products have been taken into account according to the secondary data availability. To estimate the quantity of food consumed and wasted, different research studies has been consulted. The recommended diet and relative portions have been hypothesized according to the reports of the Italian research institute

of food and nutrition (i.e., INRAN - Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione) [125] and BCFN [126]. The percentages of avoidable food waste have been defined by elaborating the data provided by the Waste Watcher Permanent Observatory on Household Food Waste, BCFN [15] and FAO [13]. On the other hand, the food composition table of INRAN [127] has been consulted to hypothesize the percentages of unavoidable waste.

*Table 15 – Hypothesis of foods quantities and relative percentages of consumption and waste*

| FOOD | | QUANTITY [kg/week] | CONSUMED | AVOIDABLE WASTE | UNAVOIDABLE WASTE |
|---|---|---|---|---|---|
| Meat | | | | | |
| | Bovine | 0,47 | 67% | 28% | 5% |
| | Pork | 0,49 | 70% | 30% | 0% |
| | Poultry | 1,72 | 54% | 23% | 23% |
| Fish | | | | | |
| | Flatfish | 1,22 | 43% | 7% | 50% |
| | Shrimps | 0,63 | 38% | 7% | 55% |
| | Trout | 0,90 | 47% | 8% | 45% |
| Cheese | | 1,78 | 68% | 32% | 0% |
| Butter | | 0,20 | 68% | 32% | 0% |
| Milk | | 4,62 | 68% | 32% | 0% |
| Eggs | | 0,60 | 62% | 25% | 13% |
| Rice | | 0,61 | 80% | 20% | 0% |
| Pasta | | 1,57 | 91% | 9% | 0% |
| Bread | | 2,67 | 81% | 19% | 0% |
| Potatoes | | 1,61 | 76% | 7% | 17% |
| Legumes | | | | | |
| | Peas | 1,57 | 28% | 3% | 69% |
| Vegetables | | | | | |
| | Tomatoes | 6,14 | 83% | 17% | 0% |
| | Carrots | 6,39 | 79% | 16% | 5% |
| | Cucumber | 4,87 | 64% | 13% | 23% |
| | Onion | 0,70 | 69% | 14% | 17% |

To model the Scenario 2, a possible reduction of the avoidable waste that could be obtained thanks to the functionalities of the proposed system has been assumed (Table 16). In particular, four different percentages have been

hypothesized according to the food waste causes, the user expectations about the new technologies and the food categories [128] [129]. In particular, the products that have to be stored in the fridge and usually have an expiration date could be the biggest beneficiaries (e.g., dairy) with a reduction of about 20%. Fresh products that generally do not have a known expiration date (e.g., vegetables, meat, and fish) could see its waste reduced of 15%. Percentages of 10% and 5% have been set respectively for products stored at environmental temperature or packaged (e.g., potatoes, legumes) and products that are wasted because they went left over (e.g., pasta, rice, bread). Obviously, the unavoidable waste remains unchanged in the Scenario 2.

*Table 16 – Hypothetical reduction of the percentage of avoidable food waste by category*

| FOOD | HYPOTHETICAL WASTE REDUCTION |
|---|---|
| Meat | 15% |
| Fish | 15% |
| Dairy | 20% |
| Rice | 5% |
| Pasta | 5% |
| Bread | 5% |
| Potatoes | 10% |
| Legumes | 10% |
| Vegetables | 15% |

Once defined the weekly diet, secondary data from the commercial databases “LCA food DK” and “Ecoinvent v2” have been used to perform the analysis. The former has been exploited for foods and the latter for the transportations and the resources consumed by the household appliances.

About the use phase, Table 17 summarizes the data related to the use of fridge, hob, hood, and oven to storage and prepare meals. In particular, the operating time and the energy or natural gas consumption is shown for each household appliance. These data have been directly provided by the company.

To evaluate the end of life, the percentages shown in Table 15 have been considered. In particular, the incineration process has been associated to the wasted food and, obviously, no dataset has been selected for the food consumed.

*Table 17 – Resources consumption by the household appliances*

| HOUSEHOLD APPLIANCE | OPERATING TIME | | ENERGY CONSUMPTION | NATURAL GAS CONSUMPTION |
|---|---|---|---|---|
| Hob (auxiliary burner) | 0,5 | hours/day | | 108,00 l/h |
| Hob (semi rapid burner) | 2 | hours/day | | 192,02 l/h |
| Hob (rapid burner) | 1 | hours/day | | 289,75 l/h |
| Oven | 2,3 | cycles/week | 0,840 kWh | |
| Hood | 3 | hours/day | 0,156 kWh | |
| Fridge | 24 | hours/day | 0,032 kWh | |

As far as the fridge LCA is concerned, the product architecture in terms of assemblies, sub-assemblies and single components has been recreated in order to make the data collection phase more efficient. In particular, the main fridge assemblies are: assembly components, freezer door, freezer internal accessories, external accessories, fridge door, fridge internal accessories, cabinet, condenser/compressor, refrigerant, and packaging. For each component the materials, quantities, processes and transports have been defined, as shown in Table 18 for the freezer door assembly.

*Table 18 – Detail of "Assembly freezer door"*

| LEVEL | COMPONENT | QUANTITY | WEIGHT [kg] | MATERIAL | PROCESS | TRANSPORT [km] |
|---|---|---|---|---|---|---|
| 1 | Assembly freezer door | 1 | | | | |
| 2 | Magnetic gasket | 1 | 0,588 | PVC | Extrusion, thermoforming | 183 |
| 2 | Closing support | 1 | 0,00704 | PA 6 | Injection molding | 1537 |
| 2 | Foamed door | 1 | | | | |
| 3 | Cover | 1 | 0,222 | ABS | Injection molding | 2322 |
| 3 | Inner door | 1 | 0,5938<br>(0,57+0,0238) | HIPS<br>Titanium dioxide | Extrusion, thermoforming | 785<br>125 |
| 3 | Polyurethane foam | 1 | 1,4349<br>(0,828+0,537+0,0699) | Toluene diisocyanate<br>Polyol<br>Pentane | Foaming | 1163<br>1163<br>1661 |
| 3 | External panel | 1 | 2,24 | AISI 430 | Sheet rolling, pressing, powder coating | 1658 |
| 3 | Upper cover | 1 | 0,156 | ABS | Injection molding | 1077 |

It is worth to specify that the assemblies such as components, freezer door, freezer internal accessories, condenser/compressor, refrigerant, and packaging are the same for both fridges so they are not relevant in the comparison analysis. Conversely, the assemblies "external accessories", "fridge door", "fridge internal accessories", and "cabinet" underwent some changes. In particular, the components of the fridge Dialogic that have been added, deleted or changed (different size and weight) in respect to the "as is" model are listed in Table 19.

*Table 19 – Differences between the fridge "as is" and the fridge "dialogic"*

| LEVEL | COMPONENT | QUANTITY | FRIDGE DIALOGIC |
|---|---|---|---|
| 1 | Assembly external accessories | 1 | |
| 2 | Main board | 1 | Changed |
| 2 | Main board box | 1 | Changed |
| 2 | Main board cover box | 1 | Changed |
| 2 | Board Dialogic node | 1 | Added |
| 2 | Dialogic node box | 1 | Added |
| 2 | Dialogic node cover | 1 | Added |
| 2 | Wiring | 1 | Added |
| 1 | Assembly fridge door | 1 | |
| 2 | Display | 1 | |
| 3 | Wi-Fi Board | 1 | Added |
| 3 | Wi-Fi Board cover | 1 | Added |
| 1 | Assembly fridge internal accessories | 1 | |
| 2 | Foamed door | 1 | |
| 3 | Display board | 1 | Changed |
| 3 | Display board support | 1 | Changed |
| 3 | Display board box | 1 | Changed |
| 3 | Wiring | 1 | Changed |
| 1 | Assembly cabinet | 1 | |
| 2 | Fridge-Freezer cell | 1 | |
| 3 | Light box | 1 | Deleted |
| 3 | Dialogic foamed box | 1 | Added |
| 2 | Fridge base | 1 | |
| 3 | Wiring | 1 | Added |

The energy consumption in the use phase is the same for both fridges and it is about 282,15 kWh per year. For this reason, it is worth to specify that the fridge lifetime has been esteemed equal to 10 years. At the end of life, the fridge is delivered to the Waste Electrical and Electronic Equipment (WEEE) Centre where undergoes the disposal treatment according to the WEEE Directive (Directive 2002/96/EC). Based on this, a general disposal scenario that consists in the shredding, recycling of plastics, metals and glass, dedicated disposal for cables, LCD and LED and PUR incineration has been created and associated to the majority of components. In addition, specific scenario have been defined for the compressor, the condenser, the electronic boards and the refrigerant.

To perform the LCA analysis, for each components of the BoM a proper set of datasets of the commercial database "Ecoinvent v2" has been identified taking into account the information collected.

### 5.2.3 Life Cycle Impact Assessment

In this phase, the results obtained from the LCI have been modelled into the simulation tool "SimaPro 7". In this way, it was possible to calculate the environmental impacts of the functional units. For both analysis, the "Ecoindicator 99 H/A" method has been used and all the relative indicators have been selected for the evaluations (Figure 73).

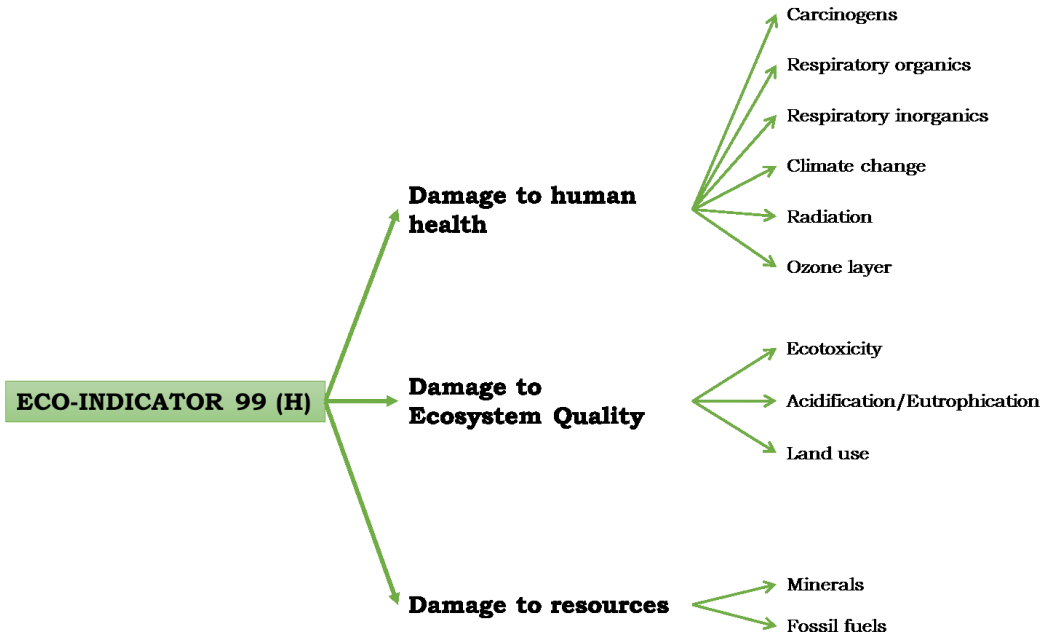



*Figure 73 – Ecoindicator 99 (H) impact categories*

The results related to the impact of food consumed and wasted in a week by one family that do not have the proposed system (Scenario 1) are summarized in Table 20.

*Table 20 – Results of the LCA analysis referred to the Scenario 1*

| IMPACT CATEGORY | UNIT | FOOD PRODUCTION | USE | | | | END OF LIFE | TOTAL |
|---|---|---|---|---|---|---|---|---|
| | | | FRIDGE | HOB | HOOD | OVEN | | |
| Carcinogens | Pt | 0,008681438 | 0,002189605 | 0,000650926 | 0,001334291 | 0,000786889 | 0,24880876 | 0,262451909 |
| Resp. organics | Pt | 0,022956616 | 3,87804E-05 | 0,000181843 | 2,36318E-05 | 1,39367E-05 | 8,16807E-05 | 0,023296489 |
| Resp. inorganics | Pt | 1,180075825 | 0,042731183 | 0,022930469 | 0,026039315 | 0,015356519 | 0,0037902 | 1,29092351 |
| Climate change | Pt | 0,465424343 | 0,018768582 | 0,014821133 | 0,011437105 | 0,006744959 | 0,03620878 | 0,553404902 |
| Radiation | Pt | 0,001158954 | 0,000344546 | 2,34893E-05 | 0,000209957 | 0,000123821 | 4,49627E-05 | 0,00190573 |
| Ozone layer | Pt | 0,000522018 | 7,43661E-06 | 5,02128E-05 | 4,53169E-06 | 2,67253E-06 | 2,54352E-07 | 0,000587126 |
| Ecotoxicity | Pt | 0,021535117 | 0,006752604 | 0,000781248 | 0,004114868 | 0,002426717 | 0,188459121 | 0,224069675 |
| Acidification/ Eutrophication | Pt | 0,326334055 | 0,004114581 | 0,002594722 | 0,002507323 | 0,001478678 | 0,000376982 | 0,337406341 |
| Land use | Pt | 3,312271603 | 0,001809916 | 0,003155347 | 0,001102918 | 0,000650439 | 0,000117101 | 3,319107324 |
| Minerals | Pt | 0,002394798 | 0,002395123 | 0,000491961 | 0,001459528 | 0,000860747 | 1,66455E-06 | 0,007603822 |
| Fossil fuels | Pt | 3,194010663 | 0,121465793 | 0,740782591 | 0,074018218 | 0,043651769 | 0,002474171 | 4,176403206 |
| **Totale** | **Pt** | **8,535365431** | **0,200618151** | **0,786463943** | **0,122251685** | **0,072097148** | **0,480363677** | **10,19716003** |

Table 21 presents the results related to the impact of food consumed and wasted in a week by the family that exploits the proposed services (Scenario 2).

*Table 21 – Results of the LCA analysis referred to the Scenario 2*

| IMPACT CATEGORY | UNIT | FOOD PRODUCTION | USE | | | | END OF LIFE | TOTAL |
|---|---|---|---|---|---|---|---|---|
| | | | FRIDGE | HOB | HOOD | OVEN | | |
| Carcinogens | Pt | 0,008681438 | 0,002189605 | 0,000650926 | 0,001334291 | 0,000786889 | 0,226891483 | 0,240534632 |
| Resp. organics | Pt | 0,022956616 | 3,87804E-05 | 0,000181843 | 2,36318E-05 | 1,39367E-05 | 7,44855E-05 | 0,023289293 |
| Resp. inorganics | Pt | 1,180075825 | 0,042731183 | 0,022930469 | 0,026039315 | 0,015356519 | 0,003456325 | 1,290589636 |
| Climate change | Pt | 0,465424343 | 0,018768582 | 0,014821133 | 0,011437105 | 0,006744959 | 0,03301919 | 0,550215312 |
| Radiation | Pt | 0,001158954 | 0,000344546 | 2,34893E-05 | 0,000209957 | 0,000123821 | 4,1002E-05 | 0,001901769 |
| Ozone layer | Pt | 0,000522018 | 7,43661E-06 | 5,02128E-05 | 4,53169E-06 | 2,67253E-06 | 2,31947E-07 | 0,000587104 |
| Ecotoxicity | Pt | 0,021535117 | 0,006752604 | 0,000781248 | 0,004114868 | 0,002426717 | 0,171857974 | 0,207468528 |
| Acidification/ Eutrophication | Pt | 0,326334055 | 0,004114581 | 0,002594722 | 0,002507323 | 0,001478678 | 0,000343774 | 0,337373133 |
| Land use | Pt | 3,312271603 | 0,001809916 | 0,003155347 | 0,001102918 | 0,000650439 | 0,000106786 | 3,319097009 |
| Minerals | Pt | 0,002394798 | 0,002395123 | 0,000491961 | 0,001459528 | 0,000860747 | 1,51792E-06 | 0,007603676 |
| Fossil fuels | Pt | 3,194010663 | 0,121465793 | 0,740782591 | 0,074018218 | 0,043651769 | 0,002256224 | 4,176185259 |
| **Totale** | **Pt** | **8,535365431** | **0,200618151** | **0,786463943** | **0,122251685** | **0,072097148** | **0,438048994** | **10,15484535** |

The results related to the fridge “as is” are presented in Table 22.

*Table 22 – Results of the LCA analysis related to the fridge “as is”*

| IMPACT CATEGORY | UNIT | MANUFACTURING | USE | END OF LIFE | TOTAL |
|---|---|---|---|---|---|
| Carcinogens | Pt | 1,900528227 | 1,149176171 | 0,649167739 | 3,698872138 |
| Resp. organics | Pt | 0,02660752 | 0,020353193 | -0,002805921 | 0,044154792 |
| Resp. inorganics | Pt | 10,42942375 | 22,42671747 | 0,720943825 | 33,57708505 |
| Climate change | Pt | 2,783591905 | 9,85036359 | 1,014052395 | 13,64800789 |
| Radiation | Pt | 0,054745912 | 0,180828731 | 0,002561944 | 0,238136587 |
| Ozone layer | Pt | 0,001591649 | 0,003902976 | -0,000643242 | 0,004851384 |
| Ecotoxicity | Pt | 2,974976256 | 3,543986674 | 1,480204593 | 7,999167523 |
| Acidification/ Eutrophication | Pt | 0,819451522 | 2,159466451 | 0,093517551 | 3,072435524 |
| Land use | Pt | 0,58364248 | 0,949902951 | 0,207633509 | 1,74117894 |
| Minerals | Pt | 4,022468995 | 1,257038592 | -0,22052174 | 5,058985847 |
| Fossil fuels | Pt | 22,717805 | 63,74920659 | -4,215132699 | 82,25187889 |
| **Total** | **Pt** | **46,31483322** | **105,2909434** | **-0,271022046** | **151,3347546** |

In Table 23 the results related to the fridge Dialogic are shown.

*Table 23 - Results of the LCA analysis related to the fridge Dialogic*

| IMPACT CATEGORY | UNIT | MANUFACTURING | USE | END OF LIFE | TOTAL |
|---|---|---|---|---|---|
| Carcinogens | Pt | 1,97835363 | 1,149176171 | 0,660884108 | 3,78841391 |
| Resp. organics | Pt | 0,027379958 | 0,020353193 | -0,002776696 | 0,044956455 |
| Resp. inorganics | Pt | 10,6801681 | 22,42671747 | 0,756461463 | 33,86334703 |
| Climate change | Pt | 2,843398032 | 9,85036359 | 1,04145992 | 13,73522154 |
| Radiation | Pt | 0,057365129 | 0,180828731 | 0,002716448 | 0,240910309 |
| Ozone layer | Pt | 0,001618249 | 0,003902976 | -0,000640226 | 0,004880999 |
| Ecotoxicity | Pt | 3,033632956 | 3,543986674 | 1,605577414 | 8,183197044 |
| Acidification/ Eutrophication | Pt | 0,837713139 | 2,159466451 | 0,097951998 | 3,095131587 |
| Land use | Pt | 0,611709898 | 0,949902951 | 0,212518539 | 1,774131388 |
| Minerals | Pt | 4,232684331 | 1,257038592 | -0,220011605 | 5,269711318 |
| Fossil fuels | Pt | 23,01405061 | 63,74920659 | -4,159945012 | 82,60331219 |
| **Total** | **Pt** | **47,31807403** | **105,2909434** | **-0,005803649** | **152,6032138** |

## 5.2.4 Results interpretation

As expected, the food production is most critical phase of the food life cycle from an environmental point of view (Figure 74). The use phase is responsible of the 12% of the overall impact. It is mainly due to the use of natural gas to prepare meals. Finally, the 5% of the environmental damage originates from the end of life phase.

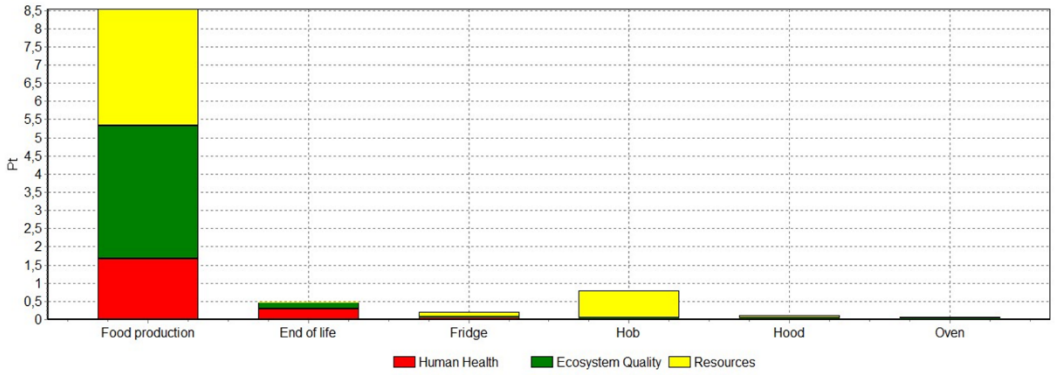



*Figure 74 – Environmental impact of Scenario 1 by lifecycle phase*

Analysing the food production in more detail, it is possible to notice which food category is less sustainable. As shown in Figure 75, meat, vegetables and fish are the most critical ones. It is worth to specify that cheese has a negative indicator because of the by-products. Indeed, the relative dataset includes, between the waste records, the milk sent to the production of milk-powder.

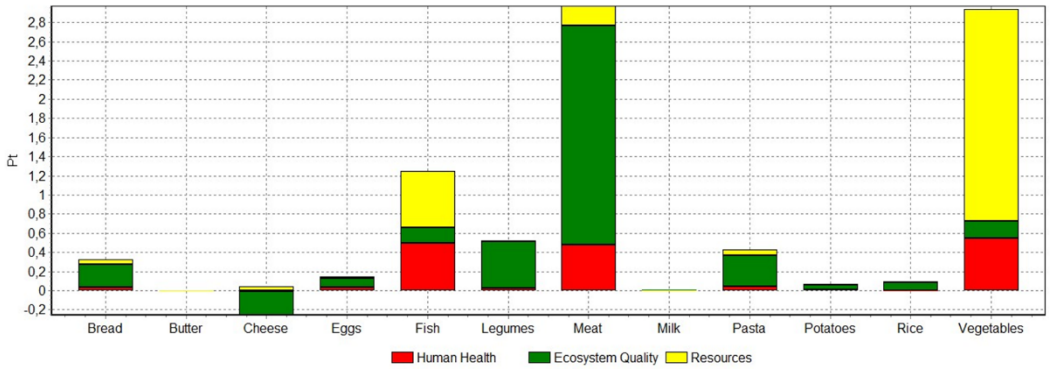



*Figure 75 – Detail of the food production environmental impact*

Figure 76 shows the comparison between the lifecycle environmental impacts related to the Scenario 1 and the Scenario 2. It emerges that the proposed system allows reducing the eco-indicator of 0,41% (-0,0423 EcoPt). This benefit only refers to the end of life phase, however, also the food production impact could be reduced by considering the implications of the waste reduction on the shopping list. This means that a more ambitious target could be reached. For this aim, a deeper analysis will be carried out in the next future.

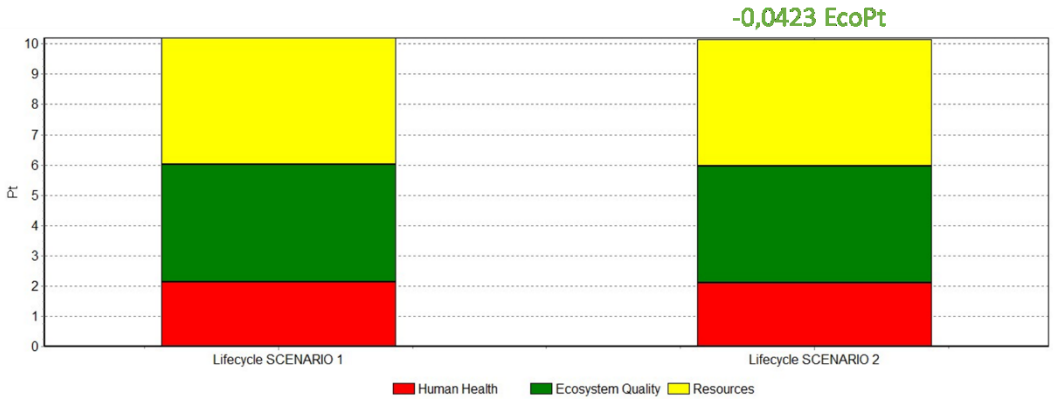



*Figure 76 – Comparison of the environmental impact between Scenario 1 and Scenario 2*

By comparing the environmental impacts related to the lifecycle of the two fridges it is possible to notice that the Dialogic is less sustainable. The result is not a surprise considering the greater number of components. In particular, the Dialogic model impacts 0,84% (1,2685 EcoPt) more than the normal one, as shown by the chart of Figure 77.


*Figure 77 – Fridge "as is" vs Fridge Dialogic, comparison of lifecycle environmental impacts*

Going into more detail, it is possible to observe that the manufacturing phase of the fridge Dialogic has an environmental impact 2,17% higher in respect to the fridge "as is" (Figure 78).


*Figure 78 – Fridge "as is" vs Fridge Dialogic, comparison of manufacturing environmental impacts*

As expected the environmental impact related to the use phase remained unchanged between the two model and it is equal to 105,29 EcoPt (Figure 79).


*Figure 79 – Fridge "as is" vs Fridge Dialogic, comparison of use phase environmental impacts*

As far as the end of life is concerned, the fridge Dialogic is responsible of a delta-impact of 0,2652 EcoPt as shown by the graphic of Figure 80.


*Figure 80 – Fridge "as is" vs Fridge Dialogic, comparison of end of life environmental impacts*

To compare the results of the two LCA analysis it is necessary to refer the benefit of the Scenario 2 in terms of environmental impact to the fridge lifetime (i.e., 10 years), as follows:

$$-0{,}0423\ \frac{EcoPt}{week} * 52\ weeks * 10\ years = -21{,}996\ \frac{EcoPt}{10 years}\ .$$

According to this, it is possible to affirm that the global ΔEcoPt is equal to -21,7308. Taking into account that it refers to only one family it can be considered a satisfying result and should encourage research and industrial investments in this field.

## 5.3 Life Cycle Costing analysis

As discussed in the first chapters, the reduction of household costs could represent an important driver that pushes consumers to reduce the food waste. For this reason, the potential benefits of the proposed system have also to be evaluated from an economic point of view. For this aim, a Life Cycle Costing analysis has been carried out. In particular, the LCC could be defined as "an assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle (supplier, producer, user/consumer, EOL-actor) with complimentary inclusion of externalities that are anticipated to be internalised in the decision-relevant future" [130].

As for the LCA, the goal, the boundaries and the objective of the analysis have been defined. In particular, the study aims to evaluate how much money a four-members family can save by adopting the proposed system. The functional unit is the food consumed and wasted in a week by the considered family. Also in this case, the analysis includes the entire lifecycle: production, use, and end of life. However, it is worth to specify which cost typology has been considered for each phase. About the production phase, the average market price of foods has been taken into account (Table 24). For this aim, data provided by two Italian institutes, ISTAT (Istituto nazionale di statistica) and ISMEA (Istituto di servizi per il mercato agricolo alimentare), have been consulted. The cost related to the gas and energy consumption due to the use of the household appliances has been considered for the use phase (Table 25). Finally, the indirect cost related to the food purchased, but not consumed has been associated to the end of life phase. For this aim, the same percentages of avoidable waste hypothesized for the LCA have used for the LCC analysis. The disposal cost has been neglected because it is included in the citizens' annual taxes and not change according to the quantity of waste.

*Table 24 – Food products cost*

| FOOD | | AVERAGE PRICE | | QUANTITY [kg/week] | WEEKLY COST | |
|---|---|---|---|---|---|---|
| Meat | | | | | | |
| | Bovine | 16,57 | €/kg | 0,47 | € | 7,79 |
| | Pork | 7,70 | €/kg | 0,49 | € | 3,80 |
| | Poultry | 10,71 | €/kg | 1,72 | € | 18,44 |
| Fish | | | | | | |
| | Flatfish | 17,92 | €/kg | 1,22 | € | 21,86 |
| | Shrimps | 25,63 | €/kg | 0,63 | € | 16,18 |
| | Trout | 8,92 | €/kg | 0,90 | € | 8,00 |
| Cheese | | 14,45 | €/kg | 1,78 | € | 25,75 |
| Butter | | 11,06 | €/kg | 0,20 | € | 2,19 |
| Milk | | 1,28 | €/l | 4,62 | € | 1,32 |
| Eggs | | 0,26 | €/pc | 0,60 | € | 2,08 |
| Rice | | 2,84 | €/kg | 0,61 | € | 1,74 |
| Pasta | | 1,99 | €/kg | 1,57 | € | 3,12 |
| Bread | | 3,14 | €/kg | 2,67 | € | 8,37 |
| Potatoes | | 1,21 | €/kg | 1,61 | € | 1,94 |
| Legumes | | | | | | |
| | Bean | 2,40 | €/kg | 0,47 | € | 1,13 |
| | Chickpea | 1,90 | €/kg | 0,31 | € | 0,59 |
| | Lentils | 1,40 | €/kg | 0,31 | € | 0,44 |
| | Peas | 1,30 | €/kg | 0,47 | € | 0,61 |
| Vegetables | | | | | | |
| | Carrots | 1,50 | €/kg | 2,71 | € | 4,07 |
| | Courgette | 2,92 | €/kg | 1,81 | € | 5,29 |
| | Cucumber | 1,58 | €/kg | 2,35 | € | 3,72 |
| | Garlic | 6,46 | €/kg | 0,18 | € | 1,17 |
| | Onion | 1,55 | €/kg | 0,18 | € | 0,28 |
| | Pepper | 2,86 | €/kg | 1,81 | € | 5,18 |
| | Salad | 2,10 | €/kg | 5,43 | € | 11,40 |
| | Tomatoes | 2,47 | €/kg | 3,62 | € | 8,94 |
| Fruits | | | | | | |
| | Apple | 1,82 | €/kg | 4,19 | € | 7,62 |
| | Grapes | 2,87 | €/kg | 1,80 | € | 5,15 |
| | Kiwi | 3,17 | €/kg | 1,20 | € | 3,79 |
| | Mandarin | 2,18 | €/kg | 2,39 | € | 5,22 |
| | Pear | 2,39 | €/kg | 2,39 | € | 5,72 |

*Table 25 – Costs related to the use of household appliances*

| HOUSEHOLD APPLIANCE | WEEKLY CONSUMPTIONS | | ENERGY COST 0,25 €/kWh | NATURAL GAS COST 1€/m$^3$ |
|---|---|---|---|---|
| Hob | 5094,53 | l | - | € 5,09 |
| Oven | 1,932 | kWh | € 0,48 | - |
| Hood | 3,276 | kWh | € 0,82 | - |
| Fridge | 5,376 | kWh | € 1,34 | - |

The results of the analysis are shown in Table 26. As expected the cost related to the purchase of food is the highest one, but it also emerges that the waste has a very significant impact from the economic point of view. Indeed, the cost associated to the avoidable waste is about the 17% of the total.

*Table 26 – Weekly cost related to the food consumed and wasted by a four-members family*

| PHASE | WEEKLY COST | DESCRIPTION |
|---|---|---|
| Food production | € 192,91 | Cost related to the purchase of food |
| Use | € 7,74 | Cost related to the use of the household appliances to store and prepare meals |
| End of life | € 33,06 | Cost related to the food purchased, but not consumed |

In order to evaluate the economic benefit that originates from the use of the proposed services, the same analysis has been carried out considering the Scenario 2. Therefore, the quantity of food waste has been reduced according to the percentages hypothesized before. The results are shown in Table 27. It emerges that the family can save about 5,22€ per week. Furthermore, also the saving related to the special offers suggestion has to be considered. For this aim, by considering to increase the user awareness about the supermarkets offers of 25% and hypothesizing an average discount of 20%, it possible to increase the weekly saving to 5,48€. It means an annual saving of about 285€.

*Table 27 – Weekly cost related to the food consumed and wasted by a four-members family that use the smart fridge and exploits the proposed services*

| PHASE | WEEKLY COST | DESCRIPTION |
|---|---|---|
| Food production | € 192,91 | Cost related to the purchase of food |
| Use | € 7,74 | Cost related to the use of the household appliances to store and prepare meals |
| End of life | € 27,84 | Cost related to the food purchased, but not consumed |

However, to complete the analysis, the cost of the proposed system has to be taken into account and the payback period (PBP) has to be calculated. In particular, the latter measures the amount of time it takes consumers to recover the assumed higher purchase expense of a more efficient or smarter system. In the specific case, the overall cost of the new fridge has been calculated in collaboration with the company and is equal to 40€. Consequently, hypothesizing an increase of the fridge price market of about 100€, the PBP can be assumed equal to 18 weeks and 2 days. It can be considered very good if compared to the fridge lifetime.

# *Chapter 6*

# System interoperability

The interoperability is one of the most critical issues that the smart world have to deal with. For this reason, the ability of the proposed system to be integrated in a wider smart environment has been investigated. The final aim is to enrich the system features and increase the users' benefits thanks to the extension of the context boundaries and the interaction with other smart devices.

This study has been carried out in collaboration with a Dutch company, Onmi, which is one of the partners of the European project Do CHANGE [131]. Such project aims to develop a health ecosystem for integrated disease management of citizens with high blood pressure and patients with ischemic heart disease or heart failure. The system will give them access to a set of personalized health services in a near real-time fashion. This disruptive system will incorporate the behaviour change methods, such as "Do Something Different", in conjunction with new innovative wearable/portable tools that can scan nature and volume of food and fluid intake and monitor behaviour and clinical parameters in normal living situations. In order to help patients to manage their own health and disease, new services based on behavioural insights have to be designed and developed. For this aim, smart tools able to monitor the users' behaviour and collect useful data that contribute to create the base for any rationale or algorithm has to be developed. In particular, the project also consists in designing wearable and portable devices that monitor the preparation and consumption of food and drinks and integrating them in a mHealth context. Such instruments are:

- An intelligent spatula or spoon that is able to immediately measure and give feedback on the amount of sodium when preparing food;
- A portable device with sensors that are able to immediately measure and give feedback on the amount of fluid intake;
- A portable spectrometer, for use at home or in a restaurant, that is able to immediately measure and give feedback on the concentration or certain key substances in food that is about to be consumed.

In this context, the proposed system can give a valid contribution by monitoring the eating habits of users' at home. For this reason, a methodology

able to ensure a proper information management has been defined. The expected results are the information model and the set of rules that allow to elaborate the data and to develop knowledge-based algorithms that encourage users' to improve their lifestyle.

## 6.1 The approach

In order to provide useful advices to the users that help them to change their behaviour and maintain a good state of health, data collected by the environment that surrounds the user have to be elaborated. For this aim, the methodology shown in Figure 81 has been defined. It consists in the following six main steps:

1. The general location analysis, which requires to monitor the users' movements and detect the locations they visited. Such analysis can help to identify the areas that the user visits more frequently in order to limit the context and simply the hot spot identification;
2. The hot spot identification, which means to identify what place is visited more frequently by users and, consequently, deserves more attention;
3. The hot spots analysis, which allows characterizing each hot spot in a more accurate way. For this aim, the information that could be associated to such places since taking place few minutes before, during or few minutes after the visit has to be collected. In particular, the personality, the mood, the feeling and the behaviour of the users could be considered as well as their eating habits, interaction with the smartphone, physical activity and movements. This step also includes the extraction of high-level information by combining data collected by different sources;
4. The correlation analysis, which allows detecting potential correlations between elements of a set of data in order to define tailored rules and, in the same time, make the system implementation feasible;
5. The user profile and rules definition according to the results obtained in the previous step. The output of this step should be an algorithm that suggests the most proper advice that has to be provided to the user, and the right instant to send it, according to his/her profile and the events occurring around him/her;

6. The Do's sending to the users by SMS text and/or email according to the "Do Something Different" principles [132]. Do's are small powerful actions designed to tempt the user outside his/her comfort zone and push him/her to try out new behaviours. In order to predict the effectiveness of interventions two key dimensions such as proximity to the target behaviour (P) and appropriateness to the person (A) have to be taken into account. The former indicates how responsive a Do can be and the latter how relevant it is to the individual's personality or situation. However, it is not possible to set fixed thresholds for these two indicators because they depend on the Dos typology (e.g., informative, general, personalised, etc.). For example, considering a 10-point scale (1=distant or inappropriate), the information message scores can be very low as P=1 and A=1, instead the scores associated to a personalised Dos based on diagnostic data could be P=4 and A=10.

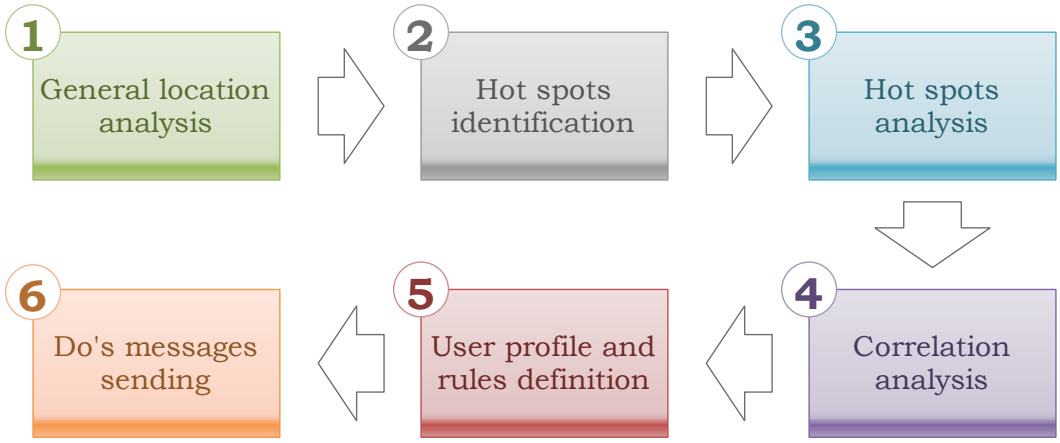



*Figure 81 – The approach*

In addition, a general schema to represent the information model has been created in order to ensure its consistency, readability, modularity, and usability. As shown in Figure 82, the data related to each location have to be inserted in the rectangles. They could derive from the analysis of the user behaviour (output) or could be a characteristic of the considered location (input). For example, considering the location "restaurant", the time at which the user has lunch is a possible output data and the restaurant menu is a typical input data.

At this point, all possible correlations between data categories have to be identified and the relative high-level information has to be inserted in the ovals. The high-level information usually consists in questions that can be answered only integrating different data classes. The use of different colours to represent the ovals allows grouping the information by topic (e.g., psychology, eating habits, movements, etc.). Both information and questions should include additional data such as sources (e.g., smart fridge, GPS, activity tracker, etc.), requirements (e.g., accuracy, constraint, thresholds, etc.) and specifications (e.g., unit of measure, evaluation scale, etc.).

In addition, to each oval should be associated the results of the data elaboration and the correlation analysis. Indeed, they allow answering to the related question. In general, they consist in charts and tables.

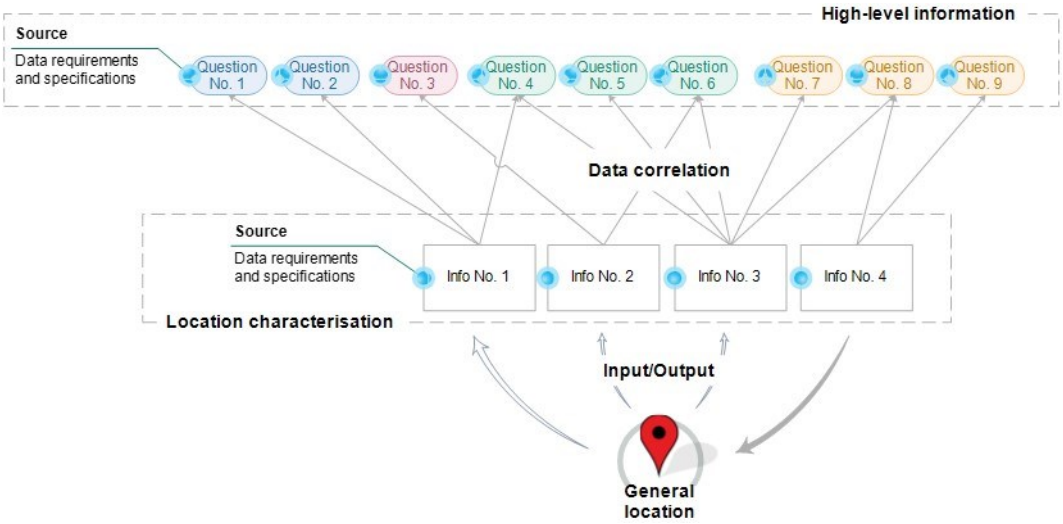



*Figure 82 – The information model schema*

## 6.2 The case study

According to the project goal to develop a life management ecosystem for improving health and wellbeing, all data that allow tracking users' behaviour over space and time have been mapped. In particular, users' between 18 and 70 have been involved and data coming from the several instruments (e.g., smartphone, activity tracker, survey, etc.) have been collected. The information related to the use of smart devices such as the spatula, the sleeve and the spectrometer has been inserted in the information model, but has not been gathered yet. This is due

to the fact that the development of these devices is an ongoing activity as expected by the project Gantt.

To demonstrate the interoperability of the proposed system, also the smart fridge have been integrated in the cited model by identifying all possible correlations with the other data. For this reason, the construction of the database and the data model, referred to the overall ecosystem, is presented in the next paragraph.

On the other hand, the methodology implementation is an ongoing activity, as expected by the project deadlines. Nevertheless, partial results are discussed as well as qualitative considerations. Obviously, they only focus on the part of the model related to the PhD topic that is the users' eating habits.

### 6.2.1 Data model

According to the data that have to be collected and the instruments characteristics, the database model has been created. It is worth to specify that it is the pillar of the proposed approach. In Figure 83 a simplified version of the schema is shown. In particular, all the entities and the relationships between them are represented. To ensure the schema readability the attributes have been omitted. Furthermore, the entities have been grouped according to the related topic. As far as the eating habits (orange layer) and the physical activity (light blue layer) are concerned, the database structure presented before have been exploited. However, it has been integrated with the data provided by the new smart tools (i.e., spatula, sleeve, and spectrometer) and those related to meals consumed at the restaurant. The green layer includes all the data coming from the smartphone such as SMS sent, calls made, events scheduled and when the user is around a conversation. The GPS coordinates allow tracking the user movements (violet layer) and associated them to public places (e.g., hospital, restaurants, university, etc.) or user's typical locations (e.g., home, office, etc.). In case of students, data related to the university, grade, classes and the relative deadlines in terms of projects, quiz, mid-terms exams and final exams have to be collected (red layer). In case of patients, health information has to be considered such as hospital, medications, visiting and medical records as well as the favourite pharmacies (grey layer). Finally, psychological information helps understanding the users' feeling, mood, level of stress and personality and better define their profiles (blue layer).

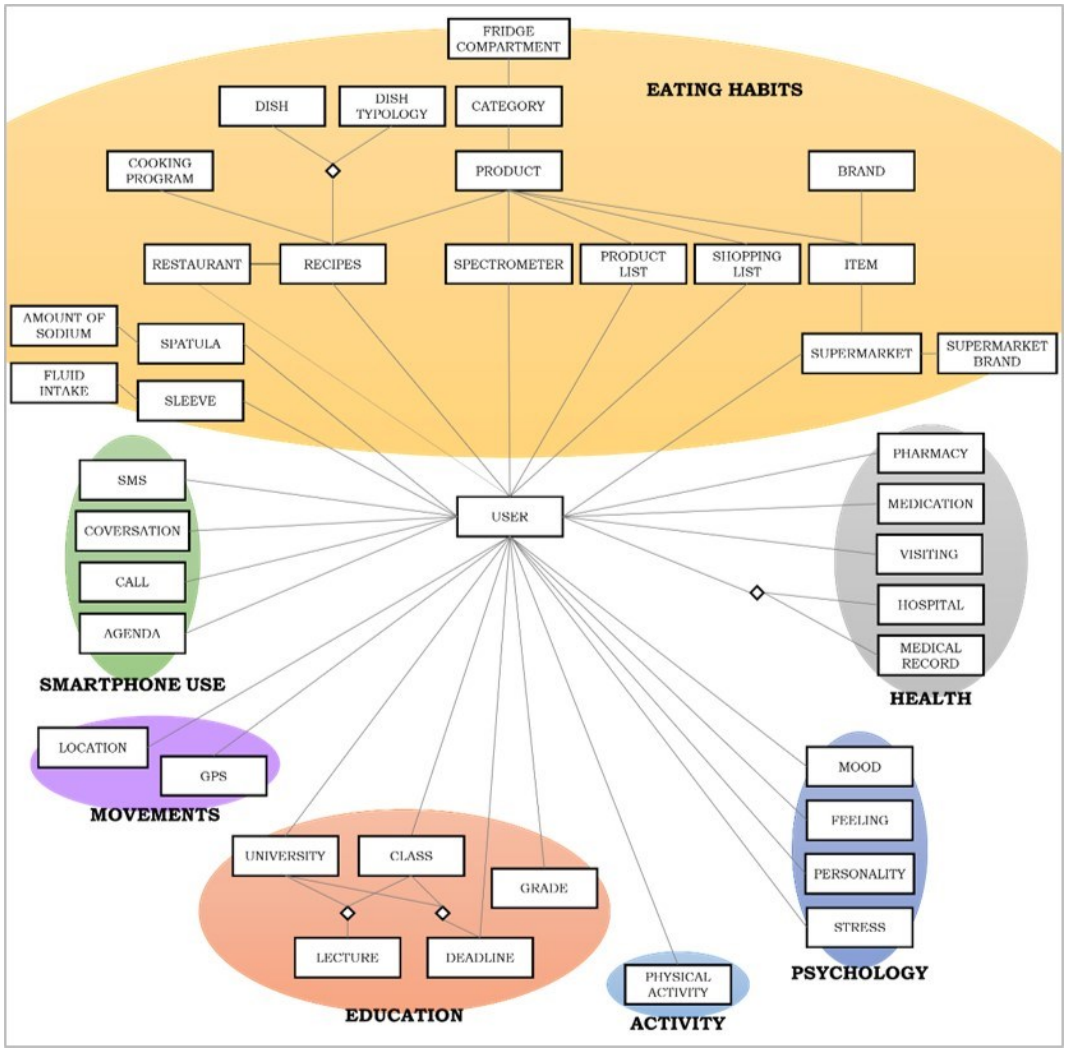



*Figure 83 – Simplified representation of the database model*

According to the schema of Figure 83, the information model related to the presented database has been created in order to guide the approach implementation. As shown in Figure 84, the model has been expanded for the locations where people usually spend most of the time such as home, office, supermarket, restaurant, university (in case of students) and hospital (in case of patients). However, the modularity of the schema allows adding new locations when they are relevant (e.g., gym, swimming pool, club, etc.). By means of the GPS coordinates, all the movements between the cited places have to be tracked in order to identify users' habitual paths. The matching between the GPS data, the location characteristics, the location input and possible other sources indicated in the detail allows obtaining the information contained in the rectangles. For

example, it is possible to know the food consumed by the user in the restaurant "X" only matching the GPS coordinates with the restaurant "X" coordinates and comparing the spectrometer data with the restaurant "X" menu. Therefore, each information derives from a join query that combines rows of the tables related to the sources indicated.

Going into more detail, the most important information related to the restaurant are the name of the place, the time and the duration of the meal, the food consumed and the fluid intake. It is worth to specify that the location "restaurant" refers to any place where people can have a meal (e.g., bar, fast food, etc.). Assuming that the user brings the sleeve with him/her it is possible to know the amount of fluid intake when he/she is working. About the time spent at home, it is possible to know when the user is preparing or consuming a meal, the amount of salt used and the amount of fluid intake. Where and what time the user does shopping as well as the duration of the latter are the most relevant data related to the supermarket. Information concerned the visiting time and the medications are collected when the patient is at the hospital. The possible lecture attendance and respect of deadlines are monitored by checking the presence of the student at the university in the scheduled days.

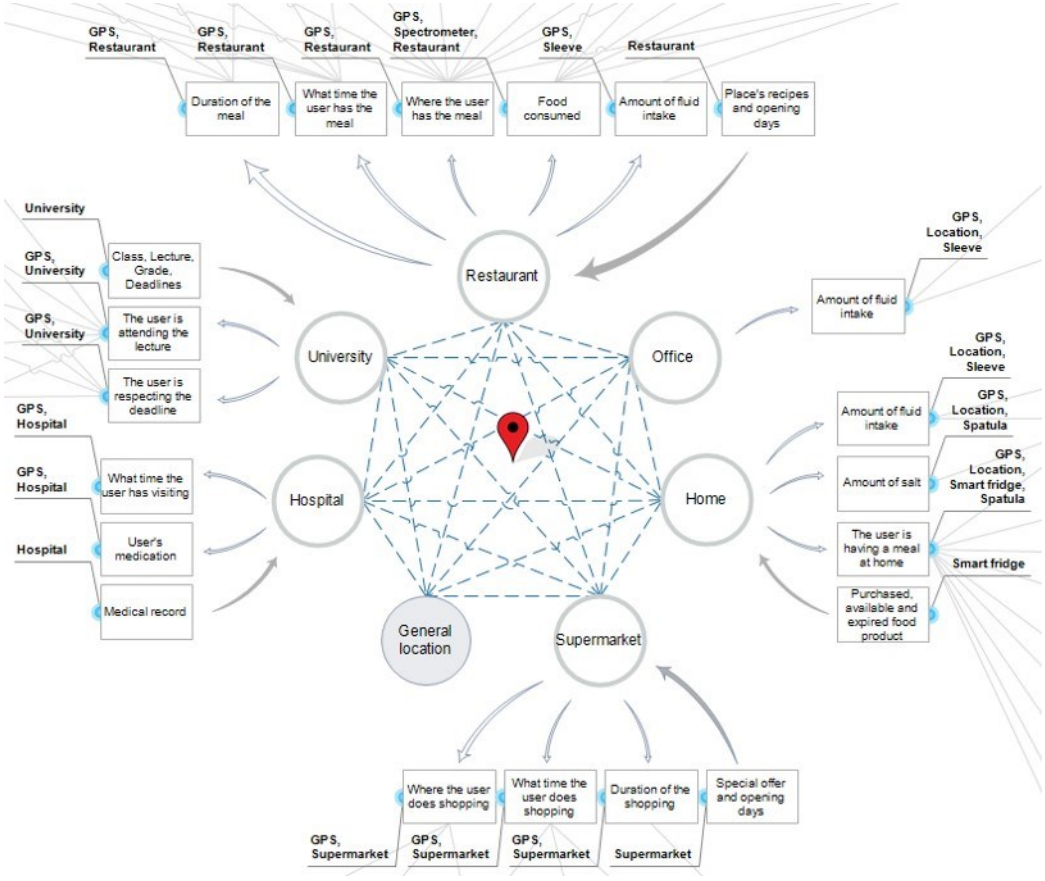



*Figure 84 – The case study data model*

Focusing on the thesis topic, only the locations *Restaurant* and *Home* will be presented. In particular, Figure 85 describes the high-level information that is possible to derive by combining the restaurant data with those coming from others sources. Thanks to the smartphone it is possible to know if the user usually send a message or has a call before or after dinning, for example, to decide the meeting point or take advantage of the break to keep in touch with family or friends. It could be useful to deduce the meal time. To eat in company and have a conversation during the meal can influence its duration. By consulting the agenda it is possible to correlate a specific location with some kind of events. Also the previous and future movements, the lecture and the deadlines can influence the choice of the restaurant. Different people usually have different preferences about dinning, in terms of food and location, also in relation to their mood, stress and feeling. Finally, the last recipes eaten and the daily physical activity can influence the fluid and food intake by the user.

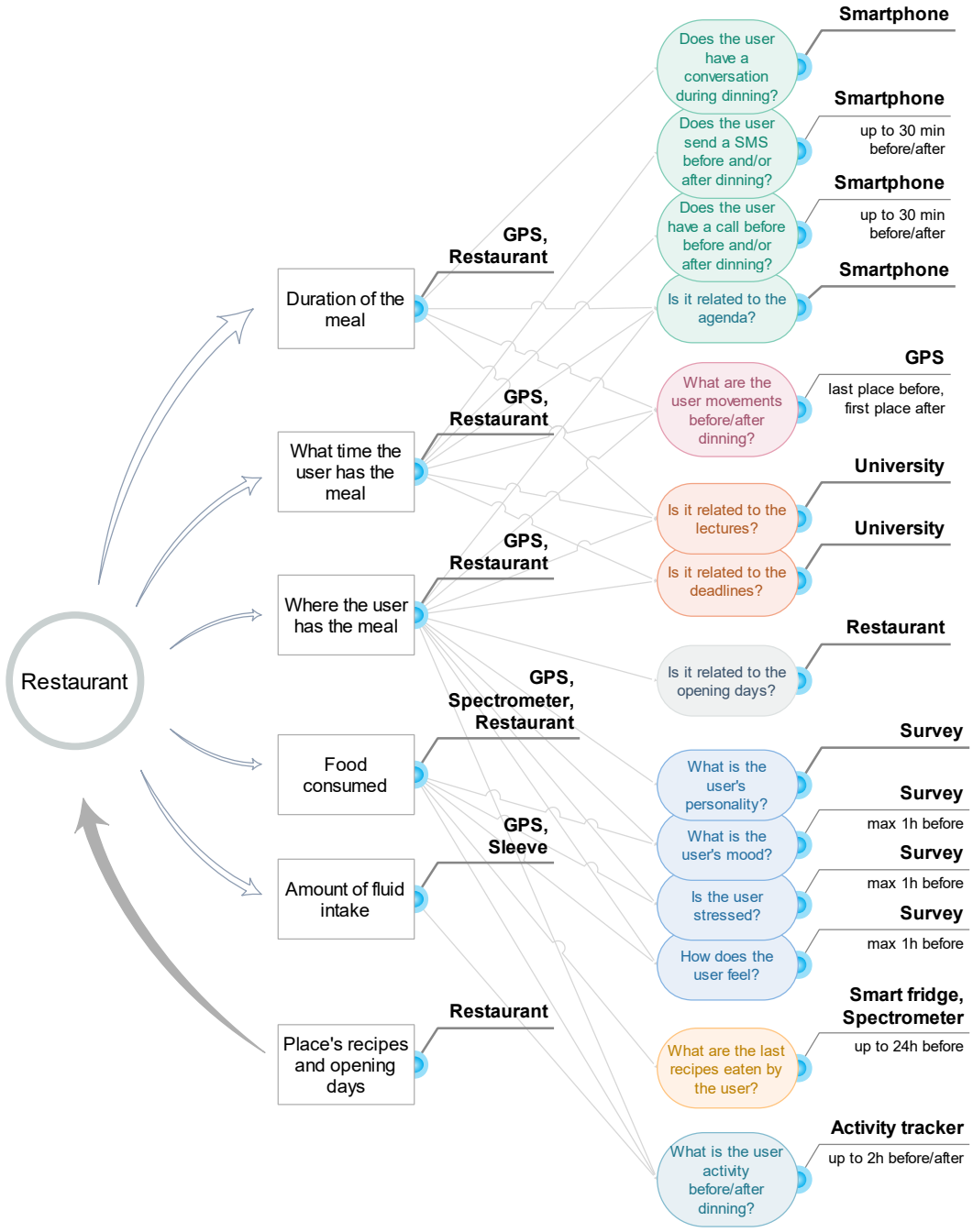



*Figure 85 – Data model of the location "Restaurant"*

In Figure 86 the home scenario is presented. In particular, the user could decide to eat at home because of the agenda, the lecture, the deadlines, the previous and future movements or for psychophysical reasons. The latter can also be one of the factors that influence the choice of the recipe as well as the daily

physical activity, the ingredients available at home or close to expire and the last recipes eaten. The amount of salt is usually related to the selected recipe and the amount of fluid intake can be associated to the food consumed or to the recent physical activity. Also in this case, the smartphone can help understanding if the user usually eat alone or in company.

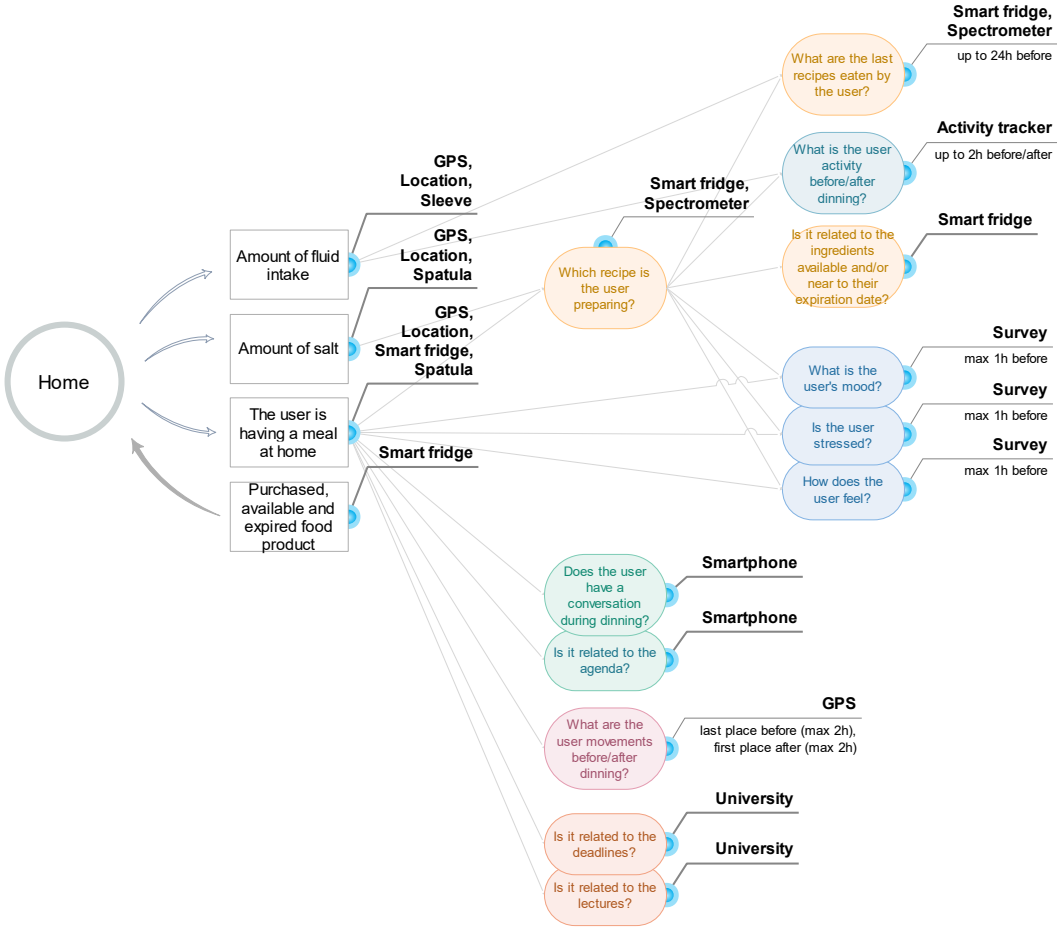



*Figure 86 – Data model of the location "Home"*

The described model allows a proper data management. Indeed, by answering the questions and carrying out the correlation analysis it is possible to define the user profile and identify the most proper Do's to send.

### 6.2.2 Data analysis

According to the approach defined, the first step of the analysis consisted in tracking the movements of a sample of 60 users. In particular, the coordinates provided by the GPS have been mapped and the most interesting areas have been identified for each user. The results have been improved by also identifying the most interesting sub-areas and inserting them in the timeline. In this way, it is possible to observe when the user moves from one sub-area to another one and how long he/she stays there. The Figure 87 shows the results obtained for the user 60, which is an American student. Firstly, the movements have been mapped (picture 1) and three areas have been identified (picture 2). After, the most interesting area has been zoomed in (picture 3) and the relative sub-areas identified (picture 4). Once completed the analysis of each area, it was possible to track the user movements between the sub-areas over the time as shown by the bar of Figure 87. In particular, it refers to one month and the bars have been filled with different colours to represent the sub-areas identified.

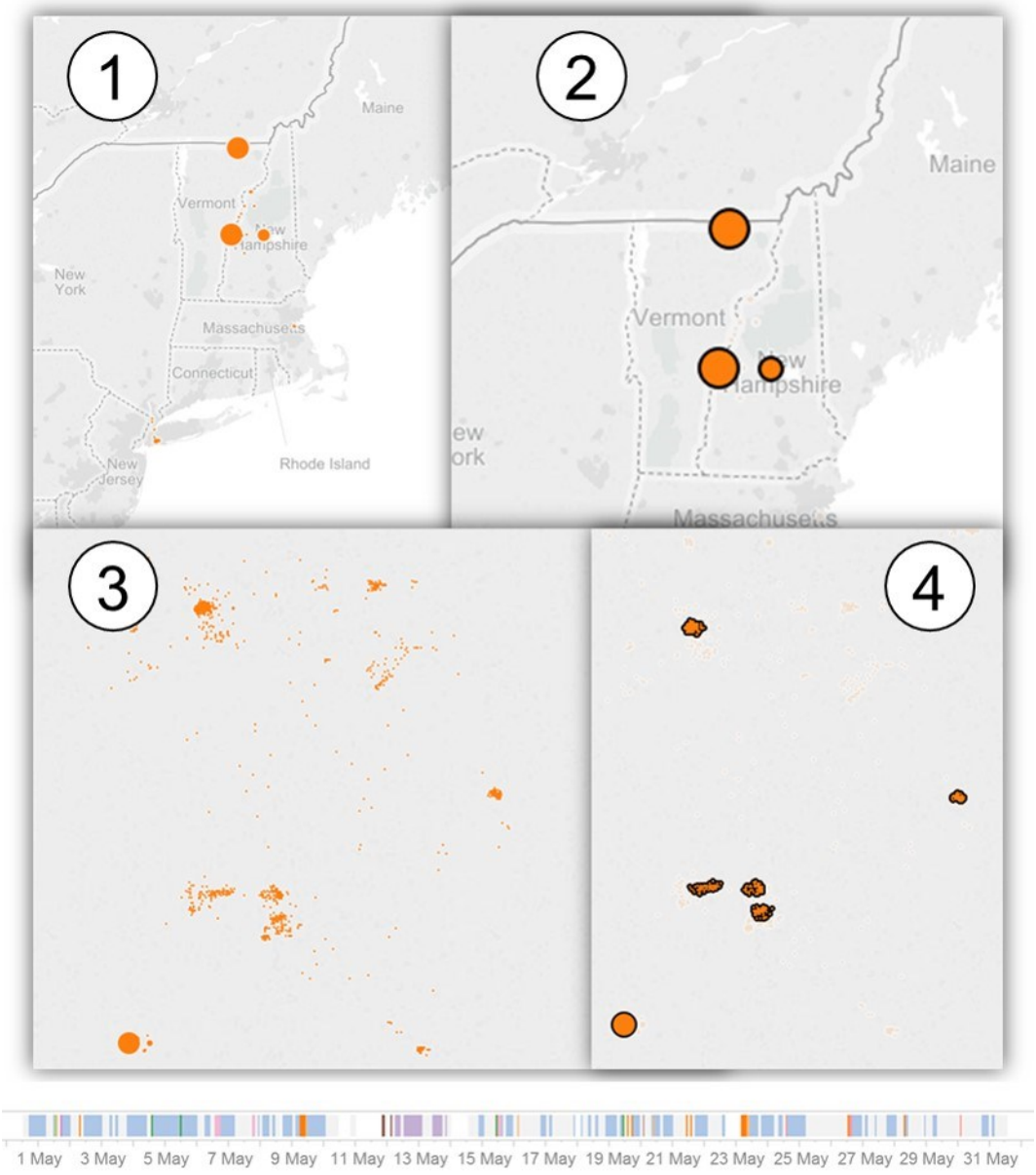



*Figure 87 – General location analysis for the User 60*

Each sub-area has been investigated to identify the locations that could be considered hot spots or points of interest because they are often visited by the user. For example, taking into account the most interesting sub-area of the user 60 and investigating the places where he had a meal, five restaurants emerged. To identify which ones are preferred by the user, proper thresholds have been set. In particular, a restaurant has been considered hot spot when its count of meal is greater than the *Average -25%* and it has been considered point of interest when

its count of meal is between *Average -75%* and *Average -25%*. In particular, it emerged that the restaurants B, C and E are hot spots for the user 60 as shown by the chart of Figure 88.

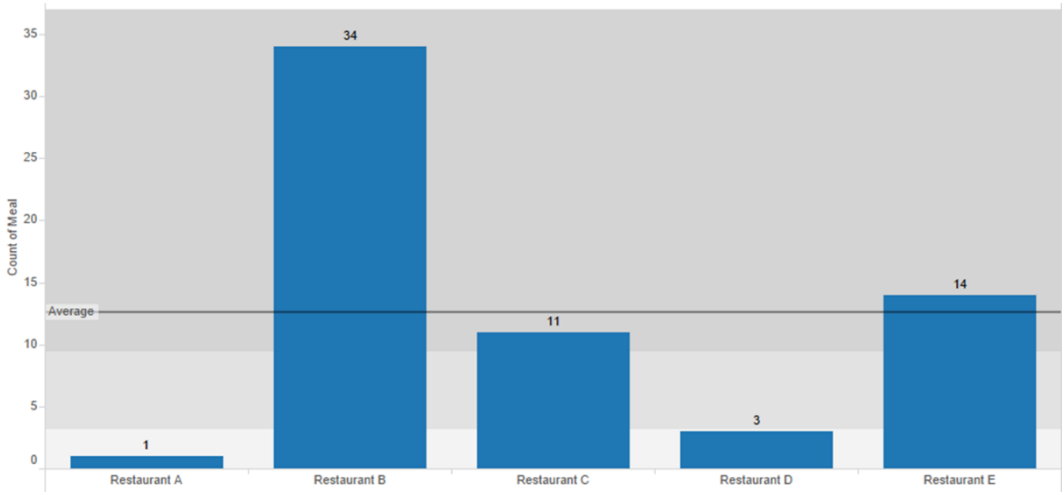



*Figure 88 – Hot spots identification for the User 60 related to the location "Restaurant"*

According to the results of the Step 2, the hot spots analysis has been carried out for the restaurants B, C and E. In particular, the use of smartphone, the educational issues and the psychological patterns that could be related to these locations has been analysed as well as the time and the duration of meals.

Some results of the Step 3 are summarized by the following charts. In particular, the chart of the Figure 89 helps answering to the question of the data model "Is the location of the meal related to the lectures?". Indeed, it shows the days when the student went in one of the three restaurants and had the lecture (filled circles). Different colours are used to represents the meal (i.e., breakfast, lunch, snack, and dinner).


*Figure 89 – Is the location of the meal related to the lectures?*

Figure 90 gives information about the habit of the User 60 to send SMS or have a call (grey circles) before or after dinning (blue cross), allowing answering to the relative questions of the data model.

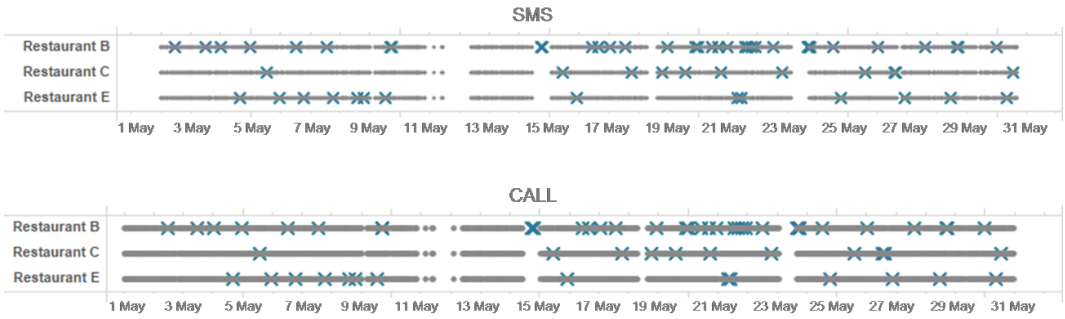



*Figure 90 – Does the User 60 send a SMS or have a call before and/or after dinning?*

Figure 91 tracks the conversations of the User 60 (grey bars) and allows verifying if there is a correspondence with dinning (blue cross).

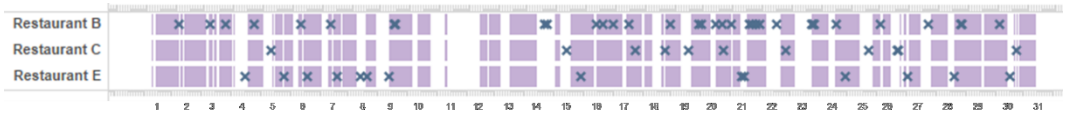



*Figure 91 – Does the User 60 have a conversation during dinning?*

The charts of Figure 92 allows observing the user mood (red circles mean that he is happy and orange circles mean that he is sad) and level of stress (green squares) in the days when he had a meal out of home (blue circles).

In the same way, for each user, all the questions of the data model have been answered in order to provide the basis for the correlation analysis.

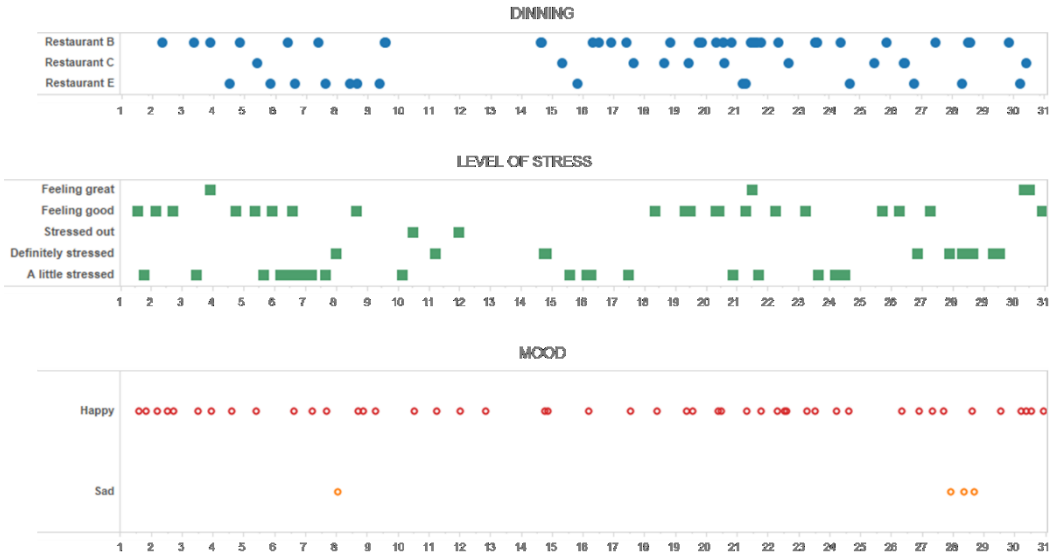



*Figure 92 – Which is the mood and the level of stress of User 60?*

The aim of Step 4 is to match the information obtained from the hot spots analysis in order to establish a potential correlation between data and events. It is an ongoing task so only few preliminary results are available. For example, the chart of Figure 93 shows that the User 60 had a call the 47%, 36% and 50% of times before (up to 30 minutes) going respectively in the restaurants B, C and E. Furthermore, in the 32%, 27% and 43% of cases he had a call after (up to 30 minutes) having a meal respectively in the restaurants B, C and E. Such percentages demonstrate that, in this case, is not possible to correlate the dinning event to the calls had. Similar results have been obtained for the SMS with the exception of the restaurant C. Indeed, in the 82% of cases the student sent a SMS before dinning and only the 18% of times sent a SMS after dinning. Based on these results, a potential correlation could be exist, which requires further investigation.

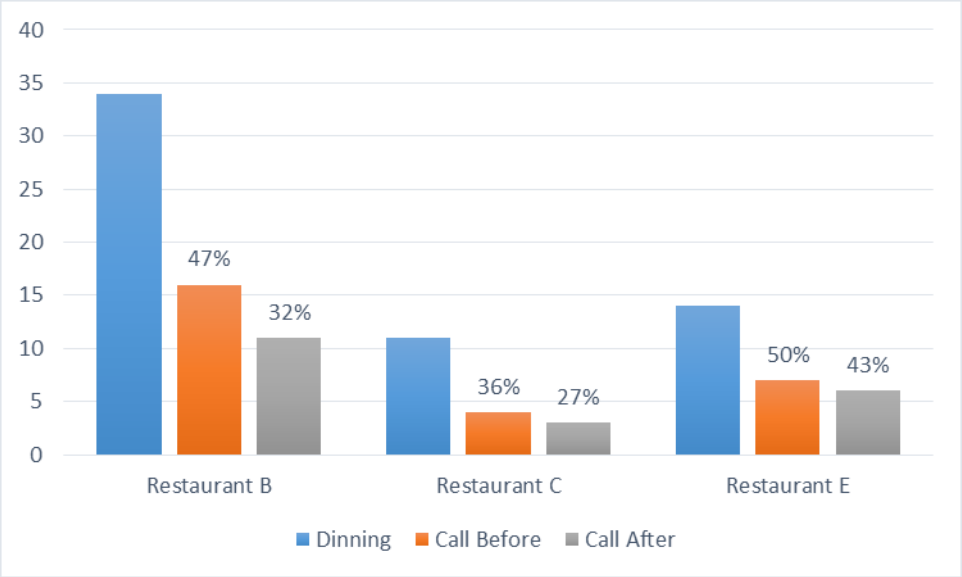



*Figure 93 – Is there a correlation between the user calls and dinning?*

The correlation analysis has also to be carried out on aggregated data. Indeed, it allows defining common patterns that could be useful to provided advises to new users since, in these cases, historical data to define the user profile are not available. Preliminary results, obtained by considering the cited users' sample, refer to the correlation between the user personality and the choice of the restaurant. As shown in Figure 94, a correspondence between these two parameters could be established.

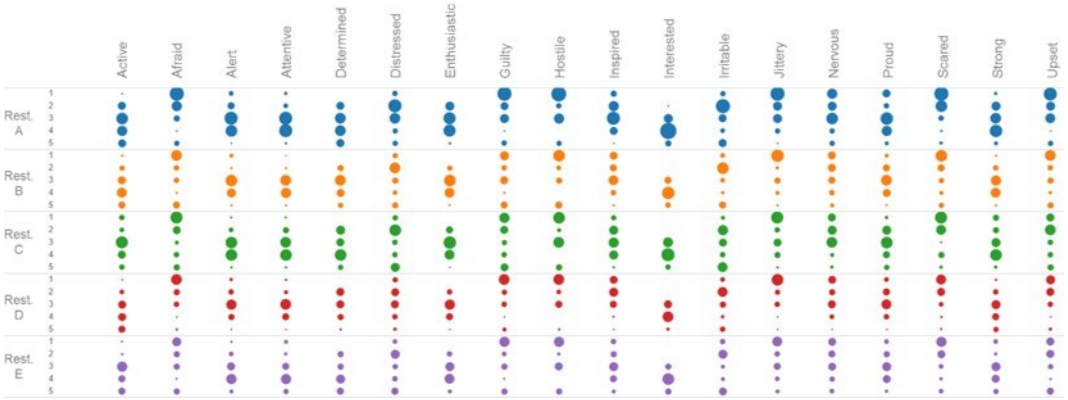



*Figure 94 – Correspondence between users' personality and the choice of the restaurant*

Once completed this step of the methodology, it will be possible to define the user profile, set the rules and send the Do's. According to the data model

developed and the first results obtained, Step 5 and Step 6 could aim to reach the following goals:

- To recognize when the user are going to the restaurant and to suggest possible recipes according to the last meals consumed at home;
- To add the information about recipes consumed at the restaurant to the inputs of the module that assigns the Similarity Indicator;
- To enrich the algorithm for the recipe suggestion by taking into account the user mood, stress and feeling.

They highlight how the smart fridge functionalities perfectly fit with the project ecosystem requirements. Indeed, its integration allows generating benefits for both tools by matching data coming from the inside and outside environment and covering the current weaknesses.

# Conclusions

In a context where consumers are urgently called to limit the food waste and improve their diet in order to reduce the environmental, social and health problems, the present research work would give a contribution by supporting users in this challenge. Indeed, the major outcome of this thesis is an ICT tool that allows monitoring the food stocks and the relative expiration dates in order to ensure better storage conditions of products, improve the purchase planning and suggest the most appropriate recipes. The proposed system moves forward the state of the art thanks to the integration of several aspects in one user-friendly application. In particular, the user is encouraged to follow the company recommendations about the food storage in a natural way thanks to the highlighting of the fridge compartment during the product check-in. If a product is close to the expiration, a favourite food is finished or a new special offer starts, non-intrusive feedbacks are provided to the user in order to allow him/her to properly manage the purchases and the meal preparation. The recipe feature is not a simple guide that shows to the user how to prepare a meal, but it is the result of a complex algorithm that aims to suggest the best recipes for the user by looking for the right balance between the waste reduction, a variegated diet and the user allergies and preferences. For this aim, it takes into account the stocks, the expiration dates, the daily energy requirements according to the user profile and physical activity, the last meals consumed and, in case of allergies, the substitutive ingredients for the "critical" ones. All these aspects make the proposed system a concrete and complete tool able to prevent the food waste at household level.

In order to evaluate the potentialities of the system, the analysis of its performances, usability, environmental and economic impact have been carried out. The following main results are emerged:

- App performances compliance with the average ones in terms of responsiveness (less than 1 second) and crash rate (less than 2%);
- High usability of the system as demonstrated by the tasks success: all the user completed them without consultation and judged the tasks easy of execute (score greater than 3 in a 5-point scale);

- High appreciation of the system operation and its features as demonstrated by the scores received, which are all greater than 4,5 in a 7-point scale;
- Reduction of the environmental impact equal to 21,7 EcoPt in 10 years;
- Reduction of weekly costs equal to 5,48€ per week and PBP equal to 18 weeks and 2 days.

On the other hand, the major limit of the system is related to the manual check-in. Indeed, the usability analysis highlighted that users would preferred the automatic reading of the product information, for example, by means of the barcode. Indeed, it would affect their perseverance in using the system and, consequently, increase its efficiency. This aspect should encourage further attempts by the FSC to implement traceability systems in order to track the expiration date of the products. For this reason, it is worth to specify that the rationales defined and developed are independent from the technologies used so it could be easily adapted.

As far as the LCA and LCC are concerned, the results obtained are only a rough estimation of the real benefits. This is mainly due to the availability of data. For this aim, more accurate data will be collected by carrying out a trial test and observing the user behaviour for a certain period of time. In this way, it will be possible to estimate more real percentages of waste and execute a deeper analysis. Furthermore, also the reduction of the environmental and economic impact related to the food production will be taken into account. Indeed, a better planning of purchases and the reduction of waste allow users to reduce the quantity of food to purchase. Therefore, it is worth to specify that the current results are an underestimation of the real benefits.

The interoperability of the system has been demonstrated by developing an information model that integrates it in a wider smart environment and showing the mutual benefits that could be achieved. Such study is enriched by the definition of a methodology that allows identifying the high-level information, define users profile and, consequently, provide advices to help them in improving their lifestyle. It allows extending the system boundaries to the environments that surround the user every day (e.g., home, office, university, restaurant, etc.) and enrich the system features. The implementation of the approach is an ongoing activity, therefore, the dissemination of the definitive results will be a future work.

Furthermore, new modules for the algorithm dedicated to the recipes will be developed as well as the consideration of other food allergies. For example, the nutritional value of foods and the management of leftovers could be two relevant aspects to be introduced in the selection process.

Finally, a deeper research activity is necessary in the field of sensors and packaging to estimate the shelf-life of fresh products (e.g., fruits, vegetables, fish, etc.) and give a more accurate feedback to the user. Indeed, currently, the expiration of such products are managed on the basis of existing guidelines and data from the literature about how long a specific food category can be storage in the fridge in terms of average days.

According to these considerations, the present research work not aims only to be a smarter fridge that users can buy to improve their daily food-related practices, but it wants to be a stimulus for several actors of the FSC to improve the sustainability of the entire network. Furthermore, it tries to suggest a valid approach that ensures the proper information management and improves the design process of new smart services.

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