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A Systemic Design Approach Applied to Rice and Wine Value Chains. The Case of the InnovaEcoFood Project in Piedmont (Italy)

Eleonora Fiore *, **Barbara Stabellini** and **Paolo Tamborrini**

Department of Architecture and Design, Politecnico di Torino, 10126 Torino, Italy; barbara.stabellini@polito.it (B.S.); paolo.tamborrini@polito.it (P.T.)

* Correspondence: eleonora.fiore@polito.it; Tel.: +39-3287303068

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Abstract: Attention to food waste is an increasingly growing phenomenon today, especially in the context of a circular economy. The InnovaEcoFood project investigates the use of by-products of the Piedmontese rice and wine production chains to valorize their untapped potential in the food sector by applying the Systemic Design approach. We collected, systematized, and visualized a range of solutions for exploiting these by-products, starting from an in-depth literature review on the two value chains. With the support of a consortium of partners from both multidisciplinary industrial and academic sectors, it was possible to validate the links that have been generated. Eventually, the project created food products that integrated these outputs as ingredients (like flour and butter) because they have antioxidant properties and are rich in proteins. InnovaEcoFood has successfully tested how value could be created from waste. Moreover, using rice hull, marc flour, and bran lipid (butter) is of immediate technical and economic feasibility. It could be considered a viable way that deserves further experimentation.

Keywords: systemic design; rice; wine; value chains; by-products; circular economy

1. Introduction

Attention to food waste is an increasingly growing phenomenon today, especially in the context of a circular economy. Considering the entire supply chain, food waste can occur at every stage of the process: during production and processing, distribution and storage, and eventually during preparation and final consumption [1,2]. Europe's agro-food industry has an important share in the economy [3]. However, around 88 million tons of food waste is generated yearly [4].

On this premise, the InnovaEcoFood project explores the use of the outputs of the Piedmontese rice and wine production chains, which are two centuries-old production activities with a cultural and gastronomic tradition recognized and appreciated at an international level. The project aims to demonstrate that the competitiveness of companies can be improved using Systemic Design (SD) as an approach, going beyond the concept of recycling waste, by promoting the creation of value from by-products considering them as value-added raw materials. This project also applies the latest technologies to enhance the unexploited qualities of agricultural waste, production processes and transformation by-products of the two supply chains to obtain environmental, economic and social benefits.

Technological integration applied to an important sector such as grape growing and rice cultivation is an objective to pursue to increase regional and national economic resilience. InnovaEcoFood promotes industrial development and aims to create zero waste supply chains according to the principles of the circular economy, with the design purpose of aligning with EU policy, following Global Goal 12 of

Agenda 2030 (responsible consumption and production), including the creation of value from waste deriving from the production processes. The project brings together multidisciplinary skills ranging from SD to chemical engineering, from food science and technology to communication, intending to develop guidelines that can become the basis for sustainable and efficient production. Making a production chain that is historically and culturally recognized, as part of a system is essential. On the one hand, it aims to minimize the impact due to the disposal of outputs, on the other hand, it develops resilient, sustainable and competitive innovations with strong implications on the economy, society and culture by activating relationships with the territory itself.

The development of new activities and products in the food (additives and functional foods) and pharmaceutical (formulation of supplements or natural products with antioxidant activity) sectors, increase regional competitiveness, generating new revenues from waste products and the exploitation of local know-how.

Section 2 includes a literature review related to the circular economy (CE) and its connection with the SD approach to establish similarities and differences between the two approaches. The importance of using SD as an approach to address the two value chains is defined at the end of that section. In this research, SD approach is used to investigate the two traditional Piedmontese supply chains, comparing the current state of exploitation of the outputs or by-products of the production processes with the value creation obtained with the systemic approach. For this reason, Sections 3 and 4 provide an in-depth analysis of the two value chains, explaining their importance at the regional level, describing their by-products and the potential arising from their use in an SD perspective. Section 5 includes the results of the InnovaEcoFood project, which experiments the production of flours for human nutrition and the extraction of high value-added oils and molecules from the vegetable matrices of the two agricultural activities. It uses both mechanical and chemical processes, involving the fractionation and micronzation of by-products and the extraction of the active substances contained in them. Section 6 is dedicated to discussing the results, the impact at the European level, limits, and further research. In Section 7, we draw conclusions.

2. Circular Economy Strategies and Systemic Design Approach

2.1. Circular Economy

In the last few years, CE is receiving increasing attention worldwide as a way to overcome the current production and consumption model, the so-called 'take, make and dispose' [5] or linear model, based on continuous growth and increasing resource throughput. By promoting the adoption of closing-the-loop production patterns within an economic system, CE aims to increase the efficiency of resource use, to achieve a better balance and harmony between economy, environment and society [6]. Many studies have been conducted on this topic [7–9] mainly rooted in environmental and political aspects [10] as well as economic and business ones [6,9].

Generally known as the 'Reduce, Reuse, Recycle' (3R) strategy, now these strategies have extended to nine, from refuse to recover [11]: the so-called R-strategies or R-list (Figure 1).

Results evidence that CE origins are mainly rooted in ecological and environmental economics and industrial ecology (IE) [6,12–18]. Some authors attribute the origins of the CE in General System theory [19,20]. Nevertheless, more often the origins of the CE are attributed to more recent theories such as regenerative design, performance economy, cradle to cradle, biomimicry and blue economy, that contribute to the further refinement and development of the concept of CE [6,21]. In Europe, CE primarily emerged in Germany in 1976 with the Waste Disposal Act, while at European Community level CE was promoted much later, through the Waste Directive 2008/98/EC [22] and more specifically with the Circular Economy Package [6,23,24].

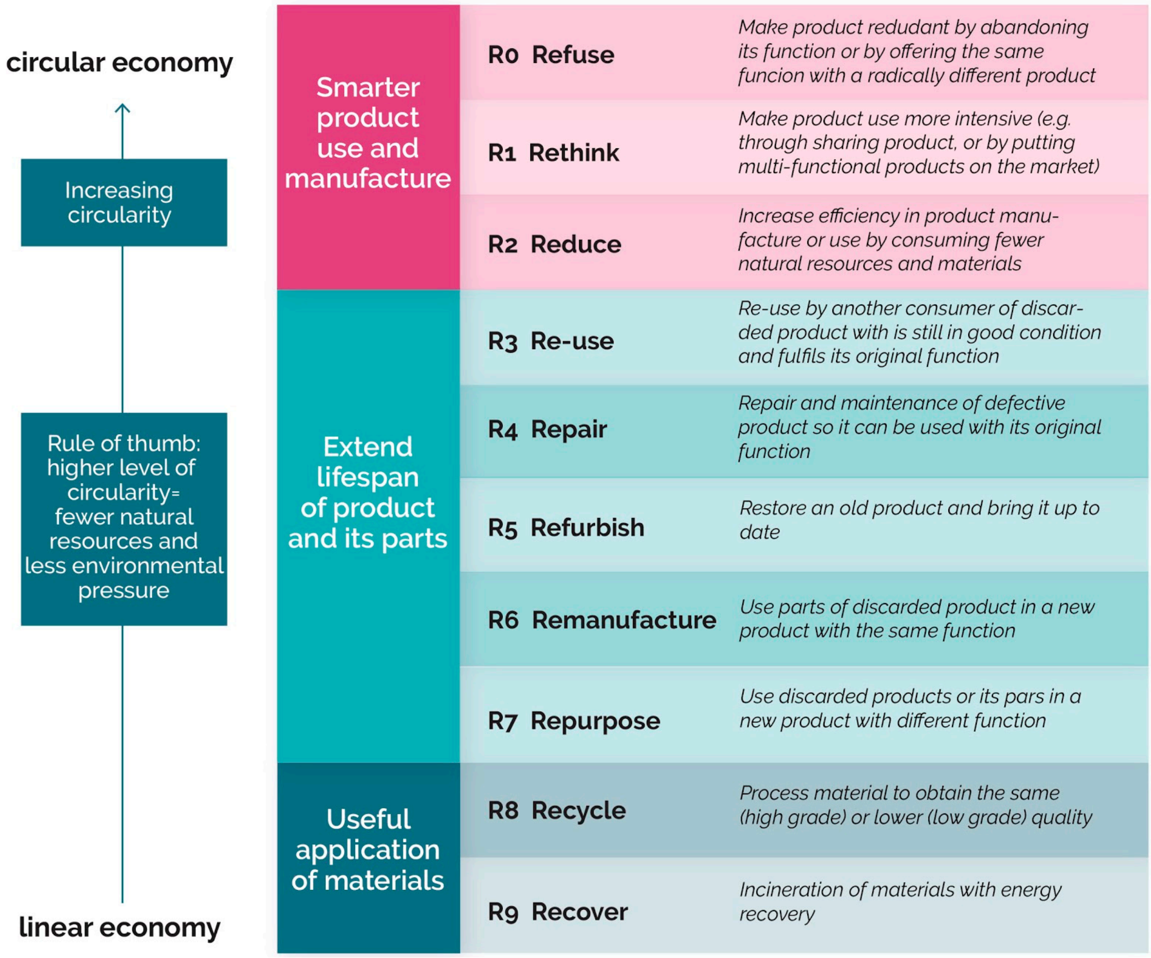

Figure 1. Circularity strategies within the production chain in order of priority (credit).

'Reduce, Reuse and Recycle' are three principles that, with some modifications, are also included in the waste hierarchy of European Waste Directive 2008/98/EC [25] since 1989 as well as in United States solid waste Agenda [6,26–28]. It must be pointed out that the CE in the European Union is a tool to design bottom-up environmental and waste management policies [6]. According to Ghisellini and colleagues [6] "CE implies the adoption of cleaner production patterns at company level, an increase of producers' and consumers' responsibility and awareness, the use of renewable technologies and materials (wherever possible) as well as the adoption of suitable, clear and stable policies and tools".

CE principles and limits have been widely discussed [5–8,10,22,26–49], and this is not the space to give further evidence. This short preamble is, instead, instrumental in pointing out similarities and differences between the principles and aims of the CE and the SD.

2.2. Systemic Design: Similarity and Differences with CE

The growing interest of the EU in CE has renewed interest in the SD as an approach that can lead to new business models. SD approach applies mainly to the industrial sector and is particularly suitable and declinable on value chains in the agri-food field. A systemic vision requires designing radically alternative solutions, as well as growing attention towards the interaction between the processes involved and the environment and the actor of a specific area. This way, the regeneration does not consist solely to material or energy recovery but, instead, it becomes an improvement of the entire living and economic model compared to previous business-as-usual economy and resource management [6]. Moreover, treating the productive systems as complex systems of complementary and symbiotic activities rather than disconnected entities is fundamental to share resources, know-how and technologies. It means there is no longer any reason for the growth of the single reality to the detriment of another. The relationships generated within the system make it becomes autopoietic [50–52], i.e., a system that produces itself and tends to evolve autonomously on the onset of change.

Regarding productive organizations as complex adaptive systems allows a new management model to generate economic, social and environmental benefits [53]. It is interesting to notice how complex entities interact openly with their environments and evolve continually by acquiring new, 'emergent' properties [54]. Complex systems are generally dynamic, nonlinear and capable of self-organization to sustain their existence. This approach is patterned after the self-organizing behavior of living systems. These systems show inherent 'resilience' by taking advantage of fundamental properties such diversity (existence of multiple forms and behaviors), efficiency (performance with modest resources consumption), adaptability (flexibility to change in response to new pressures) and cohesion (existence of unifying forces or linkages) [55,56].

While CE proved to be rather rigidly linked to product manufacturing and the concept of the life cycle of industrial processes, SD seems to accommodate the concept of value chains better, also introducing the idea of material and energy flows.

Therefore, the five principles for the application of SD are the following [57]:

(1) The output (waste) of one system becomes the input (resource) for another, which creates an increase in cash flow and new job opportunities;
(2) relationships generate the system itself: each relationship contributes to the system, and it can be within or outside of the system;
(3) self-producing systems support and reproduce themselves, thus allowing them to define their own paths of action and jointly co-evolve; it means that industries connected each other in a systemic approach are in dynamic balance and will change their sets easily to adapt themselves to the continuous changes of the environmental conditions (market, supply chains, . . .);
(4) act locally: acting locally values local resources (human, culture and material) and helps to solve local problems by creating new opportunities. The innovative solutions can come from all over the world, but they should be appropriate for the local context, and the real values should come from the expertise, resources, knowledge of a specific area;
(5) people at the center of the project to be connected to their own environmental, social and cultural context. The real needs of people are the focus of the design process and not generate false longing to satisfy the companies' wishes.

Rather than focusing on waste, the SD treats by-products as outputs that become input for other processes, mainly new processes, so rather than closing the loop like the CE, the SD connects different loops and creates open systems made of relationships and connections between local realities.

Although biological nutrients, that in general are nontoxic, "can return safely to the biosphere or in a cascade of consecutive uses" [6] SD intends to generate as much value as possible from these by-products, before returning them to the ground and closing the loop. InnovaEcoFood project, indeed, will go further from the current CE methodology as it opens a collaboration between knowledge from diverse sources. Moreover, different flows will be considered in a proximity environment, making a profit from local partners and easing materials and information exchange. The SD is also responsible for granting the sustainability of the circular value chain model around Piedmont. Furthermore, this will boost bio-economy in the Piedmontese territory.

SD theory is rooted in the General System Theory, the generative science [56] and cybernetics [56,58], sharing a similar multidisciplinary approach. SD also derives from other eco-management theories, such as the open living systems [56], Cluster Theory [14,59], IE [60] and Industrial Symbiosis [14,61–63]. Among the pioneers of this approach, we counted the Austrian biologist Karl Ludwig von Bertalanffy and the physicist Fritjof Capra. The theories about complexity help the management of the entire food systems and the design approaches help the planning of different divergent elements. Those theories are the lens that SD research team at Politecnico di Torino applies to value chains' analysis, including them in complex systems made of people, resources and relationship among the activities. It is interesting to note that the CE and SD have common roots [21,33,39,64–70] like IE and according to some authors [6] also the General Systems Theory [19,20].

To summarize, CE and SD share several principles and goals, despite the existence of some differences:

- SD opens the use of output in different sectors, not only the one from which it comes;
- SD aims territorial valorization and not just a geographical concentration of industries;
- SD goes over the competition among enterprises, in favor of real collaboration.

Furthermore, SD is very close to the IE [60] and industrial symbiosis [61], even if SD considers some more flows (like information) and acts in open systems instead of just in a closed loop. SD aims to redesign human production systems to imitate natural ones, efficient par excellence [57]. The geographic proximity is neither necessary nor sufficient; turn waste in business opportunities reduces demands on the earth's resources and provides a stepping-stone towards creating a CE [64].

Preferable CE strategies such as reuse, repair, refurbish, remanufacturing, repurpose, find no agri-food application. In the project, we will detail later on, by-product valorization seems to fall along with the guideline 'recycle' rather than 'reuse', which is considered one of the less preferable strategies for products [11,71] according to the R-list (Figure 1), in which it is the penultimate strategy listed.

Unlike other sectors, in agri-food, recycling is not meant to be a downcycling, as waste generates economic value. In the systemic processes implemented, recycling is not comparable to recycling materials that either remain unchanged or lose performance. Indeed, it implies the creation of value from agricultural or process waste that cannot be framed within the rigid CE grid. It is a matter of transforming value chains and building systems able to consolidate relationships between companies in the reuse of outputs. Therefore, it is not correct to consider this kind of strategy as mere recycling. For this reason, for the InnovaEcoFood project, we proposed the SD theoretical framework, which is more complex because it follows the logic of complex systems, deals with open loop, and leaves room for creating relationships between companies and the dynamics managed at a local level.

3. Case Study: The Rice Supply Chain

Italy, with an annual rice consumption per capita of about 5.5 kg, is the largest rice producer in Europe. In Italy, rice cultivation covers about 220,000 hectares. It is mainly located in the lower Po Valley and the narrow strip reaching as far as the Pre-Alps between Lombardy and Piedmont. It that areas, large quantities of water are available for irrigation. The provinces of Vercelli, Pavia, Novara, Milano, which alone account for 90% of the total Italian area invested in rice, are the most rice-growing provinces. Sporadic traces of rice cultivation are also present in central Italy (Siena, Grosseto) and on the islands (mainly Sardinia), which means that rice can be grown anywhere, provided there is plenty of water. However, Piedmont is the first rice-producer in Italy with a wide selection of rice varieties due to its wide range of paddy fields covering about 217,195 hectares in the territory (all data on production and cultivation of rice, grapes and wine come from the Istat database (http://dati.istat.it), regarding the year 2018) and with nearly 2,000 companies involved in its production, which amounts to several million quintals (1 quintal = 100 kilos) per year. The Piedmontese province of Novara and Vercelli alone cover 52.7% of Italian production. Vercelli is the capital of rice production and alone produces more than a third of the national total and the entire province accounts for three million quintals of cultivated, produced and processed rice. The history of rice in Piedmont is linked to two main factors. One is the need to exploit clayey soils, which are sterile. The other is the possibility of using the water resources of the large glacial snowy rivers that flow down from the Aosta Valley, Monte Rosa and several smaller rivers of resurgent or mountain origin.

3.1. Analysis of Rice Supply Chain Waste

Rice production generates large quantities of waste, co-products and by-products (about 40%) compared to the total raw material entering the supply chain, which are not currently valorized.

The cultivation of rice and its processing thus results in a series of by-products that are considered waste for the food industry.

This analysis, performed in the Piedmont region (Italy), shows in detail the process of rice transformation and the characteristics of every output. In detail:

- Straw: it is obtained even before harvesting, during threshing in the field; it is composed of cellulose, lignin, waxes, minerals and silicates, and is used as compost, fertilizer [72], feed, fuel [73] or is used in the construction sector, or for the creation of new packaging material or cloths [74–76].
- Husk: the woody part of the seed is almost totally used in combustion plants to produce electricity, thanks to its adequate calorific power [77]. From combustion, 16% ash residue, rich in carbon and silica, is obtained and used in the production of refractory bricks, tyres and steelworks as thermal insulation and antioxidant in castings [78–80]. The adsorption potential of rice husk allows its use for the treatment and purification of drinking water [81–83].
- Broken rice: the size of the broken rice varies depending on the variety of rice from which it comes: relatively small breaks are obtained from round rice, much larger from long rice, but in any case, the size of the piece is variable because the grains of rice can break at any point or even in multiple parts. Broken rice is largely used to obtain rice flour [84], but it is also used as it is for example in the production of beer, puffed products and animal feed, and a large part is added to rice destined for the poorest countries, where it reaches even 50% of the product.
- Green grain and stained grains: they are used exclusively in animal feed.
- Gem: it has a low ash content and a high content of proteins, vitamins and fats, and it is possible to obtain an oil that is used in niche foods; its primary use remains, however, animal feed.
- Hull or bran: it is an abundant and underutilized by-product of rice milling and polishing (Figure 2a). It is rich of bioactive components and emerging evidence reveals rice bran (and its extraction products) as a functional food supplement with broad health benefits. Bran is used primarily for animal feed and in the pharmaceutical industry, by extracting calcium, magnesium oesophosphates, gamma-oryzanols, phenolics, flavonoids, tocopherols and inositols [85].
- Flour (rice middlings): a by-product of the first polishing of de-husked rice (Figure 2b). It mainly consists of particles of the aleuron layer, endosperm and germ. It is obtained after hulling, and it is rich in protein, potassium, iron and zinc. It is intended for animal feed.

(**a**)

(**b**)

Figure 2. (**a**) Hull (right) (**b**) Rice middlings. Source: Agrindustria.

It should be noted that, in the literature, the terms hull and husk are often confused and used one in place of the other.

Applications and Critical Issues

In this contribution, we will focus on post-threshing by-products from what is called paddy rice (or rice in the husk). Therefore, from the data obtained during the field visit to the Vercelli farm 'Gli Aironi' (http://www.gliaironi.it/) and supported by literature evidence [86–88], we derive that the production of 1 kg of rice generates 200 g of husk, 50–70 g of hulls, and up to 60 g of broken rice that can be valorized. The inadequate disposal of these by-products generates negative environmental impacts, as well as an important cost for the companies, even though some of these by-products have a minimum economic recognition when used as feed.

If we consider 100% of paddy rice, the percentages of products and by-products are detailed as follows:

- rice 62%;
- husk 20%;
- broken rice 6%;
- green grain 4%;
- gem, hulls and flour 7%;
- stained grains 1%.

The main critical points of the process can be summarized as follows:

- the wastewater generated by the food processing of rice and the cleaning of machinery is rich in organic compounds characterized by high BOD levels as a pollutant load.
- the husk produced is thrown into a landfill or waste-to-energy plant to produce silica, with high air emissions that are filtered but produce particles and ashes that are pressed and delivered to the landfill.
- hulls and flour are used only as animal feed while they have characteristics suitable for human consumption.

In this paper, we will deal with the last point in detail.

3.2. Potential and Scalability

Currently, the outputs deriving from the rice transformation are resold and reused, but not fully exploited. Indeed, they are very rich in nutrients and chemical-physical characteristics that could be valorized for other uses in sectors where they would acquire greater value (food, bioplastics, building materials, . . .). Considering that Italian rice production is about 14.7 million quintals, the total amount of residues can be estimated at 0.7 million quintals of hulls and 2.94 million quintals of husks. Hull is a seasonal by-product obtained in the post-harvest period of rice, which goes from October to June of the following year, through various processes that divide the rice into various parts (husks, hull and rice). Hull is listed on the feed market with a price of 170.00 €/ton (2018). This residue, however, represents a significant source of organic matter, gamma-oryzanol and lipid substances.

4. Case Study: Wine Supply Chain

In Italy, the cultivation of wine grapes is widespread in almost all regions of the country, but is mainly concentrated in the following regions: Puglia, Tuscany, Piedmont. With about 44 thousand hectares of vineyards, Piedmont is the sixth largest region by extension, and annually about 2.6 million hectoliters of wine are produced from the roughly 20,000 wineries in the area. It has a wide selection of varieties (more than 60) and it produces 17 DOCG and 42 types of DOC wines recognized as Piedmontese products [89]. As regards the value of wine production, Piedmont is the fourth region with almost 460 million euros in 2018, after Veneto (900 million euros), Puglia (600 million) and Tuscany (500 million) [90].

The geography of the Piedmontese territory, e.g., orography and morphological feautures, are fundamental factors for the identity of the wine and the production of numerous types of wine, thanks in particular to the creation of microclimates in the different production areas (hills, Alpine and pre-alpine regions). Piedmontese wines, with few exceptions, are monovarietal, i.e., produced with a single grape. In Piedmont, the first examples of zoning of wine-growing areas began, defining concepts such as terroir and cru: a specific wine is produced exclusively with grapes from a single vineyard or parcel whose name appears on the label.

It is convenient to state a difference between the process of making red wine and the process of white and rosé wines. There are little differences among these processes, which generate different by-products in the process. In white and rosé winemaking process, the pressing operation is taken before the alcoholic fermentation. However, in red winemaking process the pressing is taken after alcoholic fermentation, thus the marc is fermented and alcoholic, while for white and rosè processes, marcs are non-alcoholic and sugar-rich. Through this process, wineries generate a large amount of solid waste, estimated around 30% of the material used. Wine production entails the generation of large amounts of by-products mainly consisting of organic matter (grape pomace containing seeds, pulp and skins, stalks, vine pruning and grape leaves) and wastewater.

The implementation of waste management and its subsequent by-products valorization is a pending task in the Wine Industry. Disposal of such amount of waste induces significant environmental effects similar to all food-processing waste.

4.1. Analysis of the Wine Supply Chain Waste

Composition of grapes is variable depending on its variety and climatic or vinicultural factors. Still, it is important to consider in nature and composition on the organic by-products and waste generated during the winery process, to understand the potential added value of innovative technologies in the process. The outputs of the wine production chain can be divided into:

- crop residues (vine shoots, pruning and stalks);
- organic residues from the winery (grape seeds, grapes skins, pomaces, lees and distillation residues);
- wastewater that contains solid processing residues (seeds, skins etc.), traces of products used in wine treatment (fining agents) and residues of cleaning and disinfection products.

Wooden residues from vineyards are often burnt to avoid the transmission of diseases from year to year. Waste from the winery is usually destined for distillation or pressed and disposed of in landfills. The components of wastewater are easily biodegradable elements, except for polyphenols [91].

Applications and Critical Issues

Organic matter is generated from the vineyard until the end of the process when the wine is bottled. First, when grapes are collected, approximately 2–3% of the total weight is lost in branches, stems and stalks. In detail:

- Vine shoots and pruning: branches and stems (i.e., woody parts) are usually disposed of generating environmental problems because they are burned in the field. This operation is nowadays more and more sporadic because it is considered ecologically incorrect. Indeed, it causes the emission of fumes and the mineralization of the organic substance, precluding the formation of humus. As a replacement for this practice, the vine shoots are chopped and buried, thus constituting a source of organic matter in the soil (with an annual replenishment equal to about a quarter of the required quota) and of natural nutrients coming from slow mineralization. An alternative is their use for energy production as biomass. Vineyard pruning residues can amount to a few tons per hectare, with production varying according to the vigor of the vine and the form of training adopted; the energy yield also varies according to numerous factors. The annual biomass per hectare is between 1.5 and 3 tons and provides energy equivalent to 0.5–0.9 tons of diesel.
- Stalks: the stems of the white and rosé grapes come from the destemming phase. They have high fiber content, mainly lignin and cellulose, as well as a high percentage of nutritive mineral

elements such as nitrogen and potassium. They are primarily used for composting [92–94] and are subsequently spread in the soil. The resulting compost can also be used as a substrate for the cultivation of Agaricus Bisporus, the most widely used species of mushroom in traditional cooking [95]. Another similar waste is obtained through thinning, i.e., the pruning of some ripe bunches that are abandoned in the field to reduce fruit production in favor of a higher quality finished product, wine.

- Marcs: After pressing, in the white and rosé wines, the remaining solid parts are not fermented marc (grapes skins, pomaces). This marc (Figure 3a) is a high moisture content mixture, which is also rich in sugar (around 14%). In red wine processing, indeed, are produced fermented marc, reverting sugars into alcohol This output has a variable chemical composition depending on various factors, such as the seasonal trend, the place of origin, the variety of grape, the time of harvest and the different techniques used in winemaking. Among the main uses are: direct spreading on the land for agronomic use; composting and subsequent agronomic use [96]; energy use as biomass through biogas or combustion plant, pharmaceutical and/or cosmetic use [97,98], food use, enocyanin extraction, zootechnical use, in the preparation of animal diets, animal feed [99], production of tannin-based materials and textile dye [100–105].
- The marc also contains the seeds (grape pips or 'vinaccioli' in Italian) which may be separated later by drying and centrifuging. By cold pressing grape seeds, an oil can be obtained without the use of chemical solvents, used both in food and cosmetics [106]. Grape seeds are rich in calcium, phosphorus and flavonoids and organic acids with high lightening properties. More precisely, they contain a good quantity of linoleic acid, an essential fatty acid, rich in omega 6, a well-known antioxidant and anti-cholesterol. Rich in polyphenols, it is modest in vitamin E content, especially when compared to other vegetable oils, such as corn, soybean, wheat germ or sunflower oil.
- The lees are the solid waste that remains after the fermentation. They are a mixture of dead yeasts and other solid wastes like tartaric acid and pigments (Figure 3b). Lees are traditionally an essential raw material to produce ethanol and tartaric acid [107,108]. The latter has many applications in the food industry, as it is an excellent stabilizer, replacing citric acid [109]. Lees can be used for the recovery of high value-added products [110], among which phenolic compounds stand out. It consists of yeasts, potassium salts, calcium and tartaric acid.

(a)

(b)

Figure 3. (**a**) Grape marc from crushing (right) (**b**) Solid by-products. Source: Deta webpage [111].

The composition of organic waste from wine is shown in Table 1.

Table 1. Composition of organic waste from wine.

Marcs	Skins and Seeds	Lees
Sugar (14%) High moisture (65%)	Lipids (15%) Proteins (10%) Fiber, as cellulose, pectin, hemicellulose, lignin, polyphenols (65%)	Tartaric acid (12%) Proteins (20%) Fiber, as cellulose, pectin, hemicellulose, lignin, polyphenols (25%) Sugar and pigments (10%) Lipids (4%)

Moreover, as mentioned before, water is used in several steps of the winery process: in cleaning operations (of harvesting tools, trucks, hoppers, boxes and destemmers, presses, deposits, boots and barrels), but also in the clarification process. Wastewater in winery processes is also rich in organic and inorganic matter. This is a problem when organic matter's natural decomposition process takes place, as it consumes the dissolved oxygen in water affecting the aquatic biota. The large volume of wastewater generated, and its seasonality is also a problem for its management.

Sewage sludge from wastewater can contain many nutrients, including nitrogen and phosphorus. As with civil sewage sludge, composting in combination with other substrates of wine origin is the most common use [92]. The Italian legislation also allows its direct use in agriculture if it complies with the limits [112]. The sludge has also been used as a co-substrate in anaerobic co-digestion, together with wine lees, under both mesophilic and thermophilic conditions, to produce biogas and bio-stabilized effluent [113]. The list of products that can be obtained from the by-products of winemaking is very rich:

- from the lees, it is possible to obtain alcohol for food and industrial use, grappa (in association with marc), calcium tartrate, natural tartaric acid, colorants, ethanol, beta-glucans, food;
- from the marc it is possible to obtain grappa or alcohols (for food and/or industrial use), natural tartaric acid, lactic acid, proteins, bioemulsifiers, biotensives, tannins, polyphenols, antiallergens, hydrolytic enzymes, bioethanol, fertilizers, soil improvers, compost (in association with pruning residues) absorbents for decontamination of heavy metals, substrates for human food or micro-organisms (in association with pruning residues), biocontrol agents, electricity (in association with pruning residues), resveratrol, anthocyanins;
- from grape pips, it is possible to obtain tannins, antioxidants, antimicrobials, flour, edible oil, cosmetics, biodiesel, lubricants.

In this paper, we will focus on the by-products of winemaking, without considering the residues from the field. Therefore, from the analysis carried out through field visits at the Asti winery Bocchino (www.vinibocchino.it) and supported by some evidence in the literature [86–88] the production of 1 kg of wine grapes generates about 100 g of marc and up to 60 g of grape seeds that can be exploited.

As reported above, the inadequate disposal of these by-products generates negative environmental impacts, as well as a relevant cost for companies. From 100% fresh grapes, the percentages of products and by-products are detailed as follows:

- 80% wine and must;
- 10% of grape marc;
- 6% of grape pips (seeds);
- 4% of stalks.

The main critical points of the process can be summarized as follows:

- the vine pruning currently has no specific use, but are managed by each farm to reduce the damage (both environmental and economic);
- the marc, skins, stalks and seeds of the grapes are currently destined for distillation, where they lose the organoleptic qualities that would allow them to be reused in the food sector;

- the lees, a residue deposited after the fermentation of the wine, is currently disposed of.

During the InnovaEcoFood project, we dealt with the second point, focusing on the marc.

4.2. Potential and Scalability

These residues represent a significant source of organic matter, polyphenols, nitrogen, macro- and trace elements. According to current legislation, the by-products of winemaking are subjected to management methods that, with defined timeframes, provide for the obligation of total or partial delivery to the distillery, or their controlled reuse for alternative uses, mainly in the feed sector. In fact, at present, grape marc is usually sold to the large distilleries that store the product. Then they perform classifications, separations and distillations. After distillation, the remaining (grape skin) has a market for feed use of about 200 €/ton, while the grape seeds can reach 500.00 €/ton. The grape marc or pomace is a seasonal by-product. It is produced from the end of August to the end of September, after pressing. The pomace is conferred to distillation companies from September onwards; it is stored and processed throughout the year. The pomace obtained from winery can be 'fermented' or 'virgin' (the latter also called 'sweet'). In fermented grape pomace, yeasts have transformed sugars into alcohol. Usually, fermented grape pomace is obtained during the production of red wine, as the grape pomace remains in contact with the must for at least 5/6 days. The virgin (or sweet) grape pomace has not yet undergone fermentation. It comes from white/rosè wine processing, in which the skins and grape seeds are separated from the must before alcoholic fermentation. A completely different type of marc is obtained after distillation, which varies considerably, especially in organoleptic properties.

Innovative and sustainable systems for the management of this kind of waste as valuable resources are an opportunity for Europe in terms of reduction of environmental impacts and the creation of new jobs. Moreover, the reduction of waste production and the management of it as resources is part of the path towards sustainability defined in the Europe 2020 Resource-efficient Europe Flagship.

Italian production is approximately 75 million quintals of wine grape or 54 million hectoliters of wine. Based on an estimation performed in the Piedmont region, 5% of Italian wine comes from wineries that produce annually no more than 25 hL. In this case, they are not required to deliver the marc to distillery nor alternative use. The national quantity of residues can be estimated about 7.5 million quintals of marc and 2.5 million quintals of grape seeds. The Piedmont Region potential of marc and lees available every year, instead, can be estimated at 0.4 million quintals of marc and 0.2 million quintals of grape seeds. The EU is a leading global producer of wine, producing 167 million hectolitres every year (https://ec.europa.eu/info/food-farming-fisheries/plants-and-plant-products/plant-products/wine_en). Waste, coproducts and by-products of these productions are rarely valued, and their improper disposal generates negative environmental impacts, as well as an important cost for EU. Besides, the application of this strategy in this specific agri-food system offers a high potential of replicability. Moreover, other value chains (e.g., olive oil industry) could be suitable for applying this approach, but it can also be applied in a wide variety of territories. Waste and by-products represent about 20% in weight of the produced wine.

5. InnovaEcoFood Project

The project took place in Piedmont, an important wine and rice producer region. Rural areas have great potential to include new and interesting business models that create new opportunities and quality jobs, including social and economic aspects, and tackle Europe's limited resources. InnovaEcoFood project will upgrade two current value chains to a more circular value chain that expands to other sectors revalorizing agriculture and process by-products. This multi-actor approach can reach other sectors like food, textile, polymers, or bioactive compounds, diversifying and revitalizing the economy, considering the reality of local needs. In general, the agri-food sector and agri-communities are integrated systems requiring a holistic approach to face major current challenges and avoid economic and social decadence. At the same time, Italian producers are still not benefitting from the untapped potential of agri-food by-products valorization.

5.1. Objectives

InnovaEcoFood aims to create value from rice and vine waste, typical of the Piedmontese culture, by obtaining food products. This project's overall goal is to boost rural development by demonstrating and rolling out innovative 'small-scale' 'bioeconomy-based' 'systemic design-enabled' sustainable business models.

InnovaEcoFood aims to demonstrate that linear winery and rice value chains can be analyzed and transformed into progressively more systemic value chains. Subsequently, these can be integrated into circular networks of value-generating rural business cases considering other bio-based processes and expanding toward other sectors, such as construction, textile, polymers.

Within the InnovaEcoFood project, the research team contributes to experimenting with the residues of Piedmontese rice and wine-winery production value chain using the SD approach. The project aims to show that companies' competitiveness can be improved by applying SD and integrating the latest technology to valorize unused agricultural residues. For that reason, technological partners of this project own technologies capable of processing by-products or extracting bioactive compounds that could be reintroduced in the process being applied to food.

5.2. Technological Partners

A sample of this new player in the value chain is one of the partners of InnovaEcoFood project: Agrindustria di Tecco (Cuneo, Italy; www.agrind.it), an SME operating since 1985 in the field of the valorization of secondary plant products deriving from regional value chains. It produces vegetable granules and micronized products for successive chemical extraction; it processes vegetable matrices and biomaterials for different production sectors (Figure 4).

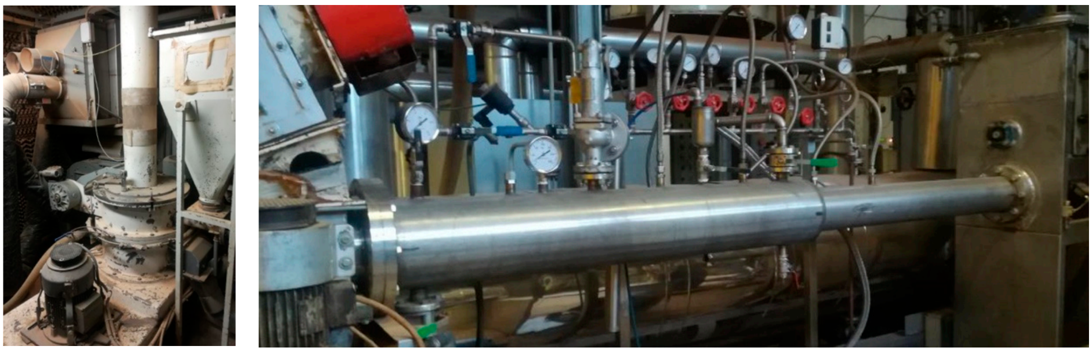

Figure 4. Illustration of Agrindustria processes (cryogenic mill and steam auger). Source: Agrindustria.

In this project, Agrindustria dealt with mechanical treatment (mainly drying, grinding and micronization) of grape marc and rice hull to obtain flours that can act as an alternative to wheat flour, with high protein content (Figure 5). On the other hand, a new actor like Exenia Group (www.exeniagroup.it)from the province of Turin (Italy), deals with tech applications in biotechnology. Exenia was founded in November 1995 with the specific entrepreneurial project to become one of the first examples, in Italy, of a company able to combine high-tech technologies and new products for highly dynamic markets. The constant investment in R&D responds to a model widely spread in the USA (e.g., Dedicated Biotechnology Companies), Japan and Northern Europe. Exenia Group is involved in research and experimental development: extraction of active ingredients from plants, extracts and production of essential oils, research and development on 'clean' technologies for the extraction of raw materials for food, cosmetics, nutraceutical and pharmaceutical products, research and development on photosynthetic microorganisms, cultivation, study, research, development and industrial use, also on behalf of third parties, of new products in the field of biotechnology and natural products. Exenia uses supercritical fluids (CO_2) for food, pharmaceutical and cosmetic applications. Extraction conducted with fluids under supercritical conditions is a valid alternative to traditional separation systems, such as fractional distillation, steam current extraction, solvent extraction. This type of extraction offers the possibility to continuously vary the fluid's solvent power to conduct the extraction with little pressure and/or temperature variations.

Figure 5. Mechanical treatment of wine and rice by-products from Agrindustria to obtain flours. Source: DISAT.

During the project, Exenia obtained the physical-chemical refining of high value-added molecules from rice hull (or bran), cooperating with the Department of Applied Science and Technology (DISAT) of the Politecnico of Torino and the production of a butter (rice bran lipid) rich in gamma-oryzanol for food or nutraceutical use.

5.3. Systemic Design Method and Schemes

As can be found in the Appendix A, a desk research highlighted several possible applications of by-products. The applications were collected, summarized and schematized in Figure 6 for the rice supply chain and Figure 7 for the wine sector, combined with field data collected from Aironi and Bocchino companies in 2018. These are two systemic visualizations that have been subsequently submitted to different actors for validation.

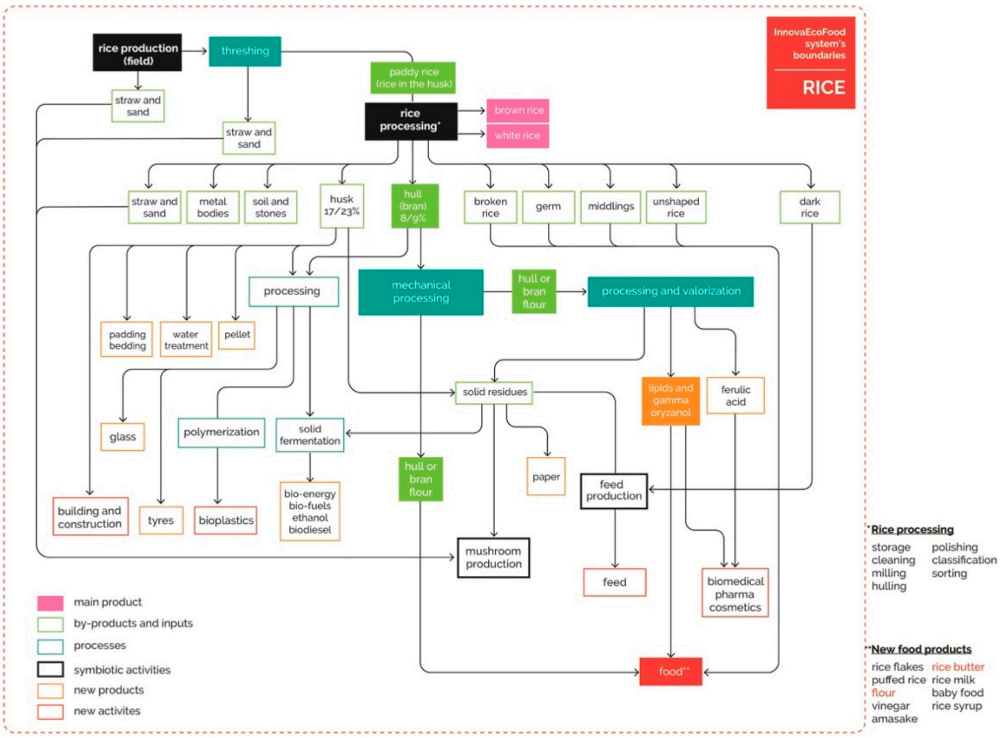

Figure 6. A systemic value chain proposed for rice.

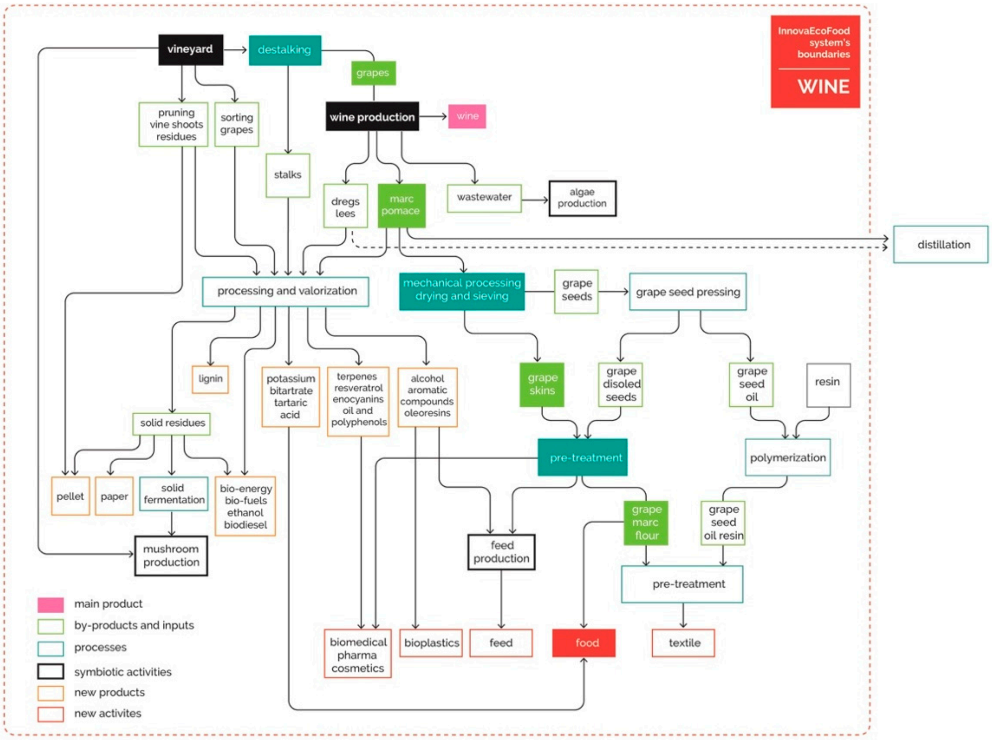

Figure 7. A systemic value chain proposed for wine.

The diagrams shown in Figures 6 and 7 are intended to provide a general overview of all the Piedmont applications for the by-products (output) of these specific sectors. By-products are generated at various levels in the cultivation and processing of rice (Figure 6), as well as during viticulture and winemaking (Figure 7).

To provide readers with a shared legend, we attribute some color codes. The two supply chains share one phase of harvesting and processing, indicated in the figures as full black boxes. The main products obtained are highlighted in pink, i.e., refined and whole-grain rice in one case, wine in the other. Green is for the outputs treated as new inputs (e.g., husks, bran, straw, etc. for rice; marc, lees, grape seeds, pruning waste, etc. for wine) and the products circulating as flows through the processing (paddy rice, bran, and bran flour, but also bunches, marc and so on). In blue, instead, are reported the processing. The orange boxes distinguish the new products (finished products, or molecules with high added value). The red boxes are the sectors and other production activities with which the project could relate. Instead, the black frame indicates possible symbiotic activities, intending to achieve an industrial symbiosis.

Finally, the full boxes distinguish the processes that have been activated during the InnovaEcoFood project. In contrast, the framed or outlined box indicates the processes and products that could be obtained, which have not been thoroughly investigated yet during this project but are reported in the scientific literature as viable solutions. We indicate the boundaries of the InnovaEcoFood project system with a red dotted line. For the rice value chain, we can see that all the activities fall within the system's boundaries activated by the project. In the case of the wine value chain, instead, distillation (the current linear process for marcs) has not been included within the system boundaries, as its outputs that are difficult to exploit on a systemic level. For this reason, it is considered outside the project. The production of the food products resulting from the project is detailed in the following paragraph.

5.4. Production of Food from Waste

During the InnovaEcoFood project, we decided to operate in human nutrition, in particular for the study and development of food products with high added value such as creams and bakery products. Indeed, the project investigates the production of new ingredients to produce new food products. The two companies mentioned above have provided know-how and technologies to enable the food company Quasani - Fattoria della Mandorla (www.fattoriadellamandorla.it/progetto-quasani) to develop foods with high nutritional, organic and health value supported by scientific literature and primary prevention guidelines. Within the project, they have been involved in integrating these outputs as ingredients, creating ad hoc recipes containing hull flour, marc flour and rice butter rich in gamma-oryzanol. The products are all processed without lactose, animal milk protein, hydrogenated fats, GMOs, cholesterol and gluten. The company has integrated the by-products supplied by Agrindustria and Exenia into foods such as food creams (core business), but also crackers and taralli, thus inserting the rice bran resulting from hulling, flour derived from post-winery grape skins, and rice butter from supercritical CO_2 extraction from rice hull. The company evaluates the expansion of its creams and other products, integrating processed waste from rice and wine production chains and high value-added molecules. Rice is a product widespread in the territory and has high organoleptic qualities but is scarcely used in the cream sector due to the greater difficulty of processing compared to other vegetable products such as soy. However, the use of rice and its by-products offers interesting potential for food innovation, as well as the possibility to trace the raw material. Bran is a by-product containing vitamins, minerals, essential fatty acids, dietary fiber, and other sterols that make it suitable for human nutrition. As already mentioned, numerous studies already tested its healthy properties, such as rebalancing thyroid hormones, improving muscle endurance, regulating cholesterol levels, preventing heart disease, and the formation of kidney stones. It has anti-carcinogenic properties, regulates the intestine, stabilizes blood sugar.

5.5. The Relationships Implemented by the Project

Regarding the processes activated by the InnovaEcoFood project and the relationships established, the project has experimented with flour from grape marc and rice hull, and rice butter produced through supercritical CO_2 extraction. The project partner Agrindustria Tecco Srl supplied the grape pomace and rice hulls by activating new relationships with unusual suppliers to find the material to be tested. The dry and moist grape pomace and hulls have been found in the Piedmont area. InnovaEcoFood aims to create new products for the food sector and no longer feed, as it is not very profitable. The cooperation activated during the project suggests that it is possible to create clusters of companies dedicated to valorizing specific by-products, providing for symbiotic activities and cascade approaches. Agrindustria partner provided the connection between the producers and the high-tech partner (Exenia), effectively collecting, storing and preparing the secondary raw materials for subsequent applications. Indeed, mechanical processing was carried out by Agrindustria, including cryogenic grinding, bacterial load reduction, and final drying. In the scheme, we refer to these activities as ‘mechanical processing’. The rice hull was then transferred to Exenia’s site (60 km), where the supercritical CO_2 extraction process took place. In the scheme, we refer to these processes by indicating them as ‘processing and valorization’. The hull and grape pomace flour obtained from the project were sent to Quasani—Fattoria della Mandorla (1000 km away) to produce crackers, ‘taralli’, and creams. The rice butter obtained from the experimentation was also sent to Quasani. Evaluating these interactions with a circular economy view supports the hypothesis that we cannot refer to this process as recycling. We like the idea of being part of the CE strategy that rethink supply chains to be more circular. Systemizing activities and possible solutions allow anyone to visualize the connections between them and identify the gaps for connecting activities at the national or even EU levels, as discussed in the next section. One strength of the SD approach is the ease of changing scale, from micro to macro and vice versa.

6. Discussions

6.1. Study Limitations & Recommendations for Future Research

The project aimed to valorize some materials destined for zootechnical use, investigating whether hull and pre-distillation marc, correctly processed, could be valorized in a food market production. Post-distillation marc has lower organoleptic characteristics comparing to winemaking by-products, thus its use in the food market is not advisable. Indeed, to create a production process for the food sector, distillation should be avoided, and pomace should be processed as soon as possible, after pressing and winemaking. The fundamental process to be done immediately after pressing should be the stabilization (dehydration/drying) of the byproduct, to stabilize and process it over time.

During the project, an economic analysis was carried out by the Department of Management and Production of Politecnico di Torino based on data provided by partners through a survey. It highlighted the creation of value in the various processes on the material, which suggests that using the by-product in the food sector is of immediate technical and economic feasibility and could be considered a viable way that deserves further experimentation. In this regard, the project investigates also obtaining high added value molecules from marc flour by performing extraction with supercritical CO_2 to obtain polyphenols, anthocyanins, and resveratrol. However, the flour turned out not to be as rich in these molecules as it was forecasted. This mismatch could be attributed to the grape variety. More likely, it can be attributed to the volatility and sensitivity of these compounds that degrade in contact with light or heat. The extracts, therefore, prove to be even more deficient in these components compared to literature. Anthocyanins, polyphenols and trans-resveratrol are, in any case, present in the flour, which can be used as it is, and without prior extraction, for the preparation of food. On the other hand, as far as hull flour is concerned, it has also been successfully tested to obtain rice oil/rice butter, rich in gamma-oryzanol, a molecule with antioxidant properties. In particular, 20 g of butter is extracted from 1 kg of rice flour. The concentration of gamma-oryzanol is 0.6% of the extracted oil component according to the analysis carried out by the Department of Applied Science and Technology of Politecnico di Torino. The presence of gamma-oryzanol inside the rice butter gives unique properties to the final product, compared to typical milk-derived butter. Several experimental studies demonstrated that gamma-oryzanol, introduced in the diet, even if in minimal quantities, has powerful antioxidant and anti-inflammatory effects and has a positive effect on lipid metabolism and cholesterol levels regulation. Butter derived from rice hull was used in all three final products. In the final composition of 'taralli', crackers and cream produced, gamma-oryzanol content varies between 336 and 360 mg every 500 g of product. There are no real exact recommended doses at the time of writing, but the daily amounts vary in the wide range between 50 mg per day and 800 mg because experimental studies on these molecules are still in progress. The final products fit perfectly within this range, making them excellent allies for health. However, the project would require further analysis to understand how to optimize the supercritical CO_2 extraction process to reduce costs and make it economically feasible in the food sector. There are no real impediments for its use except its cost: the final rice butter price is about 250 €/kg, already considering an industrial process at full production capacity. At this stage, the use of rice butter in pharmaceuticals could be investigated in more detail, given the relatively high gamma-oryzanol concentration.

6.2. Impacts

In Europe, the food and drink industry is one of the most significant sectors with a turnover of around 1100 billion euros and 4.24 million people employed [114]. The reduction of food waste is a problem that the sector faces for ethical, economical and limitation of natural resources [1]. Around 88 million tons of food waste are generated annually within the EU, with an estimated cost of 143 billion euros [4]. The United Nations has settled its Sustainable Development Goals (SDGs) in which they firmly bet for food waste and loses reduction [2,3]. Therefore, the InnovaEcoFood project is part of the Sustainable Development Goal n.12-responsible consumption and production.

Grape is a product rich in sugars and antioxidants of high nutritious interest. The partners' technological capability made it possible to diversify the sector, introducing new actors that will find an added value to by-products. On the other hand, rice is rich in lipids and gamma-oryzanol, with antioxidant, anti-inflammatory effects, acting positively on lipid metabolism and cholesterol regulation.

In this project, the partners developed a new methodology to incorporate new players in the value chain of rice and wine processing to jump from a linear system to a circular one using the SD as a basis. Another EU's priority is diversifying and revitalizing the economy to create quality jobs in a rural environment. In Europe, 19.8% of the population lives in rural areas, but the reality shows a negative trend since decades ago with the examples of the aging of the population, low birth rate, and most companies in cities [115]. The InnovaEcoFood project presents a new approach to transforming the rice and wine sector's linear value chains into a systemic approach that can generate value in rural environments, expanding to other sectors like food, biopolymers, and textiles. On the one hand, focusing on the wine sector is interesting to maximize its impact and replicability among the European territory. On the other hand, focusing on the rice sector helps give importance to territorial/local cultivation. Beyond the rice and wine sectors, the InnovaEcoFood project will also reach other value chains, enhancing its impact.

The project could have an impact at the European level, especially considering wine waste. Indeed, grape crops are one of the main extended agro-economic activities globally. Currently, up to 210 million tons of grapes (*Vitis vinifera* L.) are produced annually, and 15% are addressed to the wine industry. Figure 8 shows the distribution of crops. Within the agro-food industry, grapes and wine productions generate one of the most valued products worldwide. As we already mentioned in Section 4.2, waste and by-products represent approximately 20% of the produced wine. The wine sector has specific importance in Europe's food and drinks sector as the region is one of the leaders in production. The sector has a revenue of more than 40 billion euros [116] and for some European areas revenues from wine represent a high share compared to other agricultural activities as indicated in Figure 9. Currently, the European wine industry's supply chain is a linear one in which by-products are considered waste, or they either meet minimum economic value and value is created by maximizing the number of end products produced/sold only. InnovaEcoFood has developed a pilot plant, including three different small enterprises. It is considered as a first milestone to boost the development of a bio-based economy in Europe.

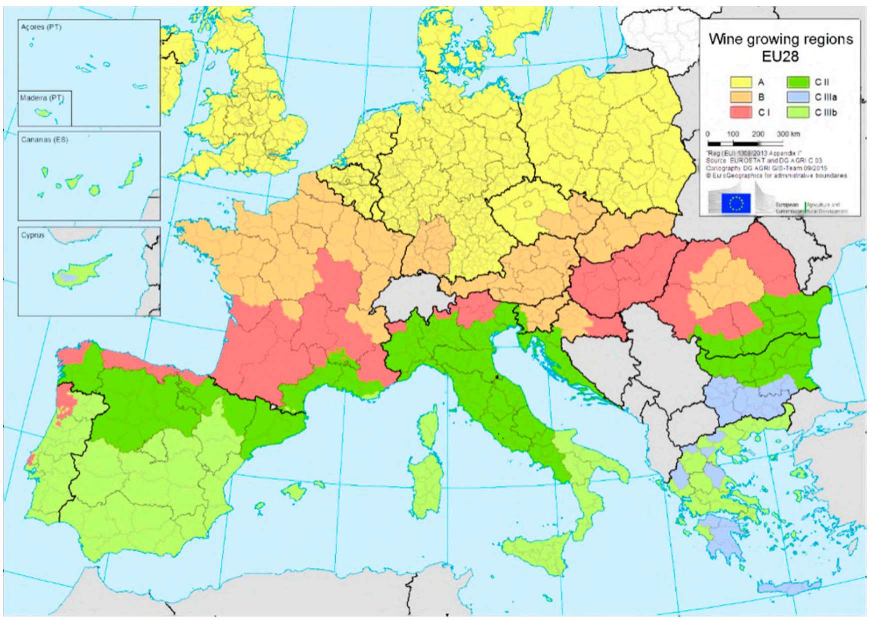

Figure 8. Winegrowing regions. Source: EU Wine Market Data Portal [117].

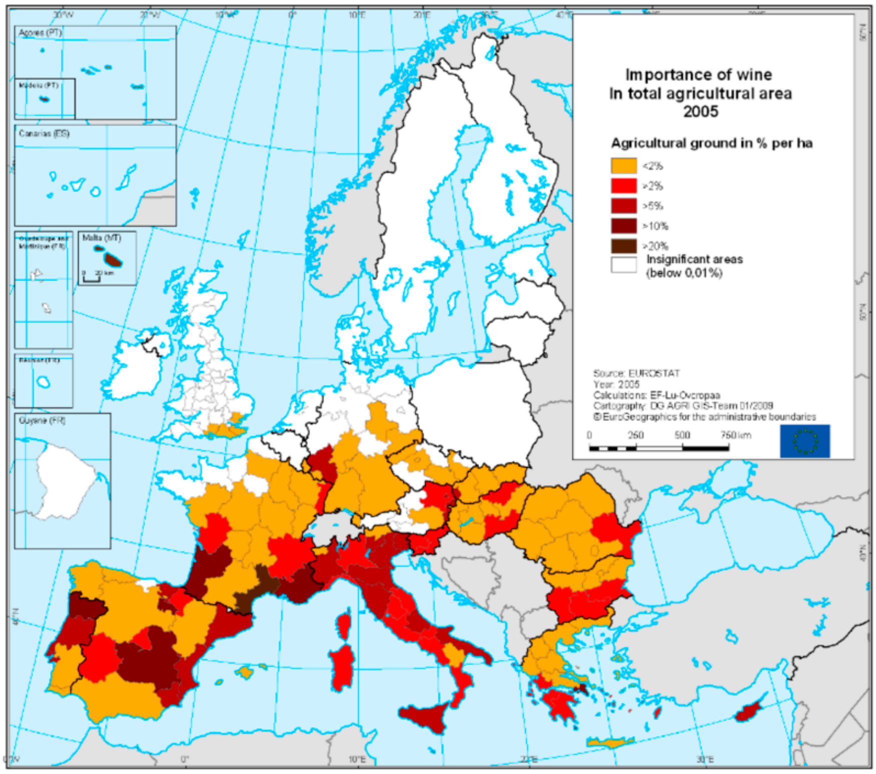

Figure 9. The importance of wine in total agricultural area (2005). Source: EU Wine Market Data Portal [117].

On the other hand, rice cultivation is not so diffused in Europe. As can be noticed from the map in Figure 10, Italy is the largest producer of rice in Europe. Italy alone accounts about 49% of all EU production [118], and the two regions mentioned above (Piedmont and Lombardy) are two regions that produce between 400 and 800 MT/year each. However, this value chain gives us an example of how it is possible to enhance regional peculiarities and their by-products with the use of SD.

Therefore, this paper presents two very different value chains, which have in common their relevance for the Piedmont region:

- in the case of the wine value chain, the vine is a widely-extended crop in the whole Europe territory, as a grant for replicability of the generated model, (it has European relevance and offers the possibility to think about its scalability and the replicability of the approach);
- in the case of the rice value chain, on the other hand, it is a local/regional value chain. Re-integrating them into local food and diet provides an example of how the approach allows the valorization of regional by-products.

Nowadays, agricultural by-products' valorization is still a great challenge, especially in a small-scale setting in rural areas. These by-products represent great potential for the generation of high added-value products. In this context, it is necessary to create and develop new business models adapted to rural areas that diversify the income sources of these small producers, creating jobs and ultimately revitalizing rural areas thanks to the bio-economy.

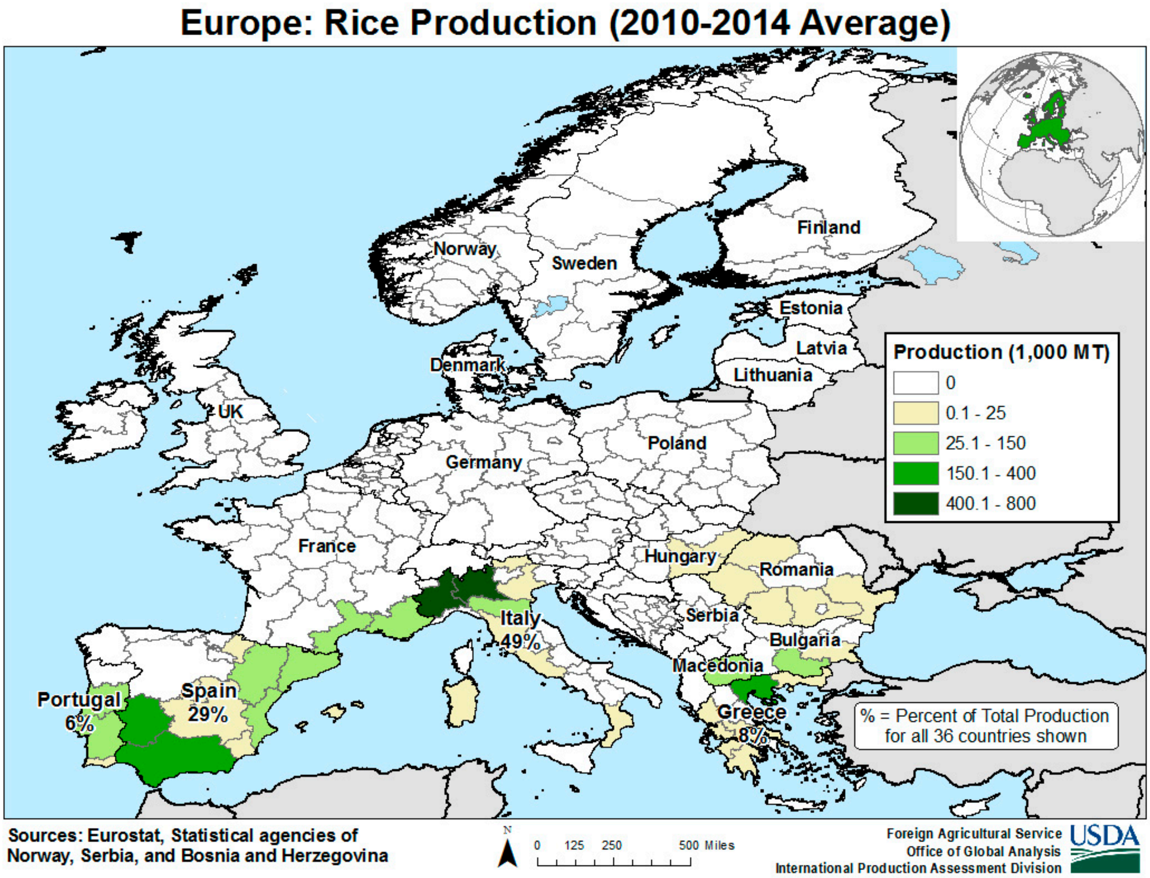

Figure 10. Rice production (2010–2014 average). Source: Eurostat [118].

6.3. Limitations of the SD Approach

The diffusion of SD is often limited by national/regional policies that do not support its development. Another limit is the difficulty of connecting companies and promoting dialogue for a common goal. The difficulty of stimulating systemic changes emerges when economic benefits are not immediately measurable, but positive effects will be measurable in a few years. The experience shows how many CE opportunities can be found. However, we are aware that each connection of the scheme and consequent valorization should face regulatory, technical, cultural, and financial barriers, so policymakers can play a crucial role in helping businesses overcome these barriers. Regulatory barriers include, for example, the definitions of waste that hinder trade and transport of by-products, the tight division in sectors, and so on. Technical barriers are related to the innovations that allow giving higher quality to the waste (for example, the quality of recycled materials requires R&D actions), and the ability to scale them up at the industrial level. In other cases, the value chains are not complete, especially from the supply of agricultural by-products. How to guarantee constant quality and quantity of supply is another key issue related to seasonality and other variables. At a cultural level, the is the need to increase the awareness of the potential use of secondary materials, especially in the food sector. The Complex Systems approach defines:

- Non-linear problems-the whole is greater than the sum of its parts
- Adaptive behavior-both the system and its constituent parts adjust over time to the changes in the environment, within the system, and within the components
- Self-organizing capacity-components self-organize without central direction
- Emergent properties-it is hard to anticipate the system outcome of interventions carried out at the component level [119].

These properties set the difference with 'closing the famous circles of production', or finding alternative waste destinations to landfills. The goal is to shift the focus from the product to the territory [119]. However, there is a lack of successful case studies history in each sector able to ensure that the application of SD will bring assured economic benefits since each project is tailored to a specific value-chain. The complex dynamics involved have often prevented the comparison of different business models.

6.4. Future Research

The project focused only on a tiny portion of the overall system since the regional funds from which it drew were limited. However, the project can start from this first part and extend suddenly to fill some current experimentation gaps. For the wine supply chain, the continuation of the project should include experimentation in the direction of:

- using different types of grapes, possibly of biological origin, to evaluate the differences in the extraction phase, but also the organoleptic differences when flour is used directly in food formulation;
- introducing variations in the storage phase and the transport of the output (immediate, refrigerated, and without exposure to light), at the same time of bottling for red wine or destemming for white wine. In fact, in the white winemaking process, stalks, grape seeds, and skins are removed before fermentation. Evaluating the differences between the output of the red and white wines would be of great interest, as they have radically different characteristics;
- introducing small machinery for the treatment of the output on-site (at winemakers and social cellars) to preserve the characteristics as much as possible and optimize storage while reducing costs and impacts. It would be possible to transport the dehydrated product without transporting the liquid component, which is unused.
- modifying the processes that use heat (such as dehydration) preferring processes at low temperatures to avoid incurring the degradation of compounds, which deteriorate in contact with heat.

Another step forward could be to expand and diversify the sector by mobilizing a more comprehensive range of players in the consortium, including small businesses, farmers, and their associations. Indeed, the scalability discussed in Sections 5.5 and 6.2 would deserve further investigation, proposing pilot cases in other EU wine-producing regions. It would also be interesting to see how different value chains can be connected in other regions.

7. Conclusions

The project took place in Piedmont, an important wine and rice producer region. Rural areas have great potential to include new and interesting business models that create new opportunities and quality jobs. The InnovaEcoFood project has addressed more circular value chains expanding to other sectors (food, pharma, textile, polymers), valorizing agriculture and process by-products by connecting the actors on a territory, diversifying and revitalizing the economy, considering the reality of local needs. The project starts from the current value chains highlighting the by-products generated in each step, either in the field or during transformation processes. For each output, it highlighted different scenarios that lead to their valorization and the creation of connections between the different activities, finally focusing on the valorization of marc and hull for food purposes. Thanks to the project consortium, the use of these by-products has been successfully experimented—after mechanical processing and extraction with supercritical CO_2-ingredients inside bakery products and creams. At present, their use in the food sector is limited due, among the other things, to legislative limitations regarding the classification of by-products as waste and the impossibility of handling them as raw materials. However, there is room to open different scenarios. As Europe is facing a problem of finite resources available, the introduction of added-value by-products as new ingredients (products with high functionality) in the food sector is advisable in the next future. It should also be considered primary importance to reduce food waste. The project highlights the approach's scalability at the EU level to other production realities and value chains.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

This appendix aims to collect research and case studies to validate and verify the schemes of the two supply chains shown in Figures 6 and 7. The literature search has been carried out in the Scopus database, and therefore may not consider different indexing.

Specifically, the research carried out skimming of the phenomenon by investigating the keywords 'circular economy' connected first to 'rice' and then to 'wine'. Among titles, abstracts, and keywords, the extractions counted 462 and 161 publications, respectively. These were then further filtered with new keywords such as 'waste' (421 results), 'husk' (165 results), 'hull' (41 results) for the database concerning the rice supply chain, and 'waste' (142 results), 'wastewater' (45 results), 'lees' (83 results), 'pomace' (43 results), 'marc' (12 results), 'stalks' (10 results), for the wine supply chain.

Further manual research has evidenced a small number of publications compared to those extracted from the system, which addresses chain waste reuse in new applications. The research highlights how often attention is not paid to the single product, but rather to the whole output set. Moreover, difficulties emerge in differentiating between hull and husk, often confused in terminology. The two tables below summarize the main results of interest.

Table A1. Application of by-products from wine production.

By-Product	Application
Lees and pomace	Improving the quality of fish feeds in terms of organoleptic characteristics and health benefits [110]
Pomace/marc	Valorization of grape agro-waste to produce bioactive molecules and new polymeric materials [100]. Extraction of molecules, fractions and biologically active biomolecules with a possible use in the nutraceutical and cosmeceutical industry from vinery marcs [97,98]. Production of compost from marc [96]. Improving animal fleshes with different pomace powder preparations [99]. Production of tannin-based adhesives for wood industry, tannin-based materials such as biocomposites and rigid foams [101]. Production of textile dye from grape pomace [102–105]
Seeds	Extraction of bioactive compounds with high added value before using biomass for energy purposes (e.g., in food, cosmetics, and pharmaceuticals sectors, biopolymers and energy sector to produce biohydrogen and biomethane [106].
Wastewater	Analysis of water consumption in wine production to identify wastewater treatment and management improvements towards water reuse [120].
Winery waste	Biorefinery opportunities from winery waste (biomass production) [121]. Employing winery waste to re-balance soil fertility; valorization of these in the agricultural sector or different industrial chains (e.g., cosmetics, nutraceuticals, etc.) [122,123].
	Production of compost and biofertilizer from viticulture waste [124].

Table A2. Application of by-products from rice production.

By-Product	Application
Straw	Natural fertilizer is used to remove phosphorus loading in water [72]. Extraction of water-soluble phenolic compounds to incorporate into bioactive starch-based films, producing bioactive food packaging [74]. Creation of innovative cloths from straw rice [75]. Transformation of rice straw in glucose for bio-carburant production [73].
Husk	Rice husk to purify colored wastewater [81]. Production of jet fuel through fluidized-bed fast pyrolysis, hydro-processing and hydro-cracking/isomerization [125]. Utilization of rice husk for a potential waste-water treatment due to their adsorption potential across a variety of common drinking water contaminants [82,85]. Production of energy and fertilizer by using rice waste [77].
Husk ash	Production of sustainable plastic composites from ashes (including rice husk ash) [78]. Production of eco-friendly concretes from rice husk ash [79].
Husk and straw	Rice husks and rice straw used as substrates for solid-state fermentation with dikaryotic and monokaryotic strains of Pleurotus sapidus [126]. Production of insulating materials for green building from rice straw mixed with waste wool. Production of biofillers from husk for polymer composites, mono- and di-glyceride mixtures. Extraction of high-added-value molecules for the food industry from bran [80].
Husk and bran (hull)	Development of a novel bio-fertilizer using rice bran and husks [127,128].
Straw, husk and bran (hull)	Development of new products as biofuels, enzymes, biodegradable material food contact, single cell protein, bio-adsorbent, nanoparticles, bio alcohol, bioactive compounds like fibers, phytochemicals, minerals, so on [76].
Bran (hull)	Oil extraction from defatted rice bran for bioethanol, lactic acid, and biobutanol production [129]. Extraction of fatty acid profile and bioactive compounds such as phenolics, flavonoids, gamma-oryzanols, and tocopherols, from bran rice [85].
Broken rice	Development of gluten-free products that require pre-gelatinized starch, such as pasta, from broken rice flour [84].

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