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INDUSTRIAL SYMBIOSIS POTENTIAL ON SPECIFIC AGRI-FOOD AND METALLURGICAL VALUE CHAINS IN LOMBARDY REGION

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Abstract

This paper focuses on the project activities carried out by ENEA on Industrial Symbiosis (IS) as part of the CREIAMO project, funded by CARIPLO Foundation, aimed at identifying and promoting new destinations and economic opportunities for by-products and waste deriving from the olive and wine sectors, under a circular economy perspective. Due to the pandemic, the ENEA's methodology for promoting and implementing IS has been adapted in order to perform from remote all the activities with the companies involved. An engagement campaign was carried out in the territory of Brescia with the support of several local associations. The IS – Operative Meeting (OM) with enterprises was held remotely on 19 February 2021. About 100 potential synergistic actions have been identified, mainly involving material resources. Following an initial processing of data, summary reports were prepared, one for each company. Significant resource flows were selected according to the quantities involved and to their economic value. As an output of this work, two technical handbooks have been drawn up for companies that are willing to transform synergies from theory to practice.

Key words: eco-innovation, industrial symbiosis methodology, residues, resource valorizations, synergies

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1. Introduction

By 2050, it is expected that the world will have a minimum of 9 billion habitants and our common desire is to ensure a comparatively high level of prosperity and welfare for all. This goal is not achievable using the present linear mode of economy, because the natural resources of the Earth are already being depleted. A profound shake-up is required and a whole re-thinking of the Western industrial system and economy needs to happen (Sacchi et al, 2021).

Circular economy aims to replace the linear economy concept, where the value of products and materials is maintained as long as possible (Korhonen et al. 2018). It is not just a question of eliminating or minimizing the production of waste, but of radically changing the conflicting vision between economic and environmental interests, traditionally considered in antithesis, with a new and broader concept of well-being, which includes both. The circular economy represents a radical paradigm shift, within which to develop new sustainable business models, able to increase the potential closure of production cycles and the efficient use of local resources.

As part of the strategies and tools for closing resource cycles, there is an increasing interest in IS, which aims at transferring and sharing of resources (raw materials, water, waste, energy waste, services,

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skills, tools etc.) between companies and / or other operators present in nearby areas (CWA 17354, 2018). This approach constitutes not only a potential competitiveness factor for industrial activities, but also an enrichment factor for the area, which sees all of its resources valued locally and not dispersed, delegated or given away to third parties.

The European Commission has attributed a strategic role to industrial symbiosis (IS) for the efficient use of resources, clearly identified in various programming and funding documents (e.g., European Resource Efficiency Platform, COM 571, 2011; COM 398, 2014; COM 614, 2015). Interest in IS was also registered in Italy, with the development of several projects dedicated to the closure of resource cycles and with the inclusion of IS in some regional planning tools (Notarnicola, 2016; Simboli, 2014, 2015).

ENEA is responsible for implementing and promoting IS using a validated methodology as result of decades of experience on this issue. In 2011 ENEA started the development and the implementation of an IS network model thanks to three projects in three Italian regions: the “Eco-Innovation Sicily” project (Cutaia et al., 2014a, 2015; Luciano et al., 2016); the "Green Project - Industrial Symbiosis" in Emilia-Romagna (Cutaia et al., 2016; 2014b); and the "Industrial Park of Rieti-Cittaducale" project in Lazio (La Monica, 2016).

The CREIAMO project, financed by CARIPLO Foundation, has as its partner the University of Brescia in the role of coordinating the activities, the University of Milano Bicocca and ENEA, which dealt with aspects relating to the circular economy, the IS, and the promotion of intersectoral synergies in particular.

This article, as part of the aforementioned project, illustrates the activity carried out by ENEA to identify and promote new destinations and economic opportunities for by-products and waste deriving from olive and wine supply chains, under a circular economy perspective. By achieving this objective, the competitiveness of companies operating in the Lombardy Region, and in Brescia province specifically, will consequently be increased, also thanks to the creation of new business models. The project adopted a system eco-innovation strategy through the creation of a network of IS in Lombardy, through which enterprises will be able to achieve economic, environmental and social benefits.

Moreover, the project represents the first structured attempt to implement IS in the region and involved various productive sectors in addition to the one directly involved in the project (olive and wine supply chain). Two different supply chains have been studied in the project: the agri-food industry, with a focus on the production of oil and wine, and the metallurgical industry, with a focus on steel production from Electric Arc Furnace (EAF).

Waste resources coming from these two sectors, respectively organic (olive and grape marc, Olive Mill Wastewater - OMWW) and inorganic resources (EAF slag), were considered for the implementation of specific valorization strategies. The choice of synergies to be implemented was guided by the characteristics and quantities of the resources made available by the companies involved in the project.

2. The potential of circular economy in agri-food chain and other industries in Lombardy

The agri-food chain includes the primary sectors of agriculture, animal husbandry and fishing, the food industry that deals with the transformation of raw materials and the production of beverages, the industry for the enhancement of by-products and waste, the distribution and commercial phase. In the Communication of the European Commission "Roadmap to a Resource Efficient Europe", the waste produced along the agri-food chain is mentioned as one of those on which to intervene primarily (European Commission, 2011).

The circular economy model aims to overcome the limits of the current system, increasing production performance and simultaneously generating an improvement in the quality of the soil, water and air. This is achieved by exploiting the reuse of agricultural residues, finding the right application for each type of residue, through a series of sequential processes. The companies must identify the actual potential of all substances that do not constitute the final product, identifying them as a source of income and not as a cost that must be incurred for their disposal. In this context, an important role is played by technological and process innovation, through the adoption of new technologies applicable to residues for their enhancement. The creation of cooperatives or districts of IS can further favour the reuse of resources in new processes. Therefore, the involvement of all stakeholders, such as research and development institutes, industry associations and government bodies, as well as companies, is primary to create favourable conditions for the development of new business ideas.

2.1. Circularity in the olive oil and wine processing sectors

Lombardy constitutes the most important agricultural region in Italy. In absolute values, the Lombard agricultural sector involves 41,116 companies, with an extension of the Utilised Agricultural Area (UAA) equal to 958,378 ha. Overall, there are 56,000 production facilities operating in the agri-food sector (agricultural production, related activities and food processing), which involve about 200,000 workers, of whom 143,000 are permanently employed, equal to 3% of the Lombard total (Data in ISMEA 2020).

With a sales volume of 3 billion euros (ISTAT data in ISMEA 2018), the olive oil supply chain represents 2% of the total turnover of the agri-food industry. Italy ranks second among the olive oil producing countries in the world.

Olive pomace (exhausted pulp, stone and seeds) and OMWW are significant by-products in Lombardy with a high environmental impact when not properly treated. However, at the same time these by-products are also rich in high-value compounds, which can be used directly after extraction, or enhanced as ingredients for other industrial sectors: food industry, feed industry, the nutraceutical and cosmetic sectors. Grapes represent one of the largest fruit productions globally, an amount of 60-70 million tons are produced every year; 60% of the grapes produced are used as “pressed grapes”, for the production of wine or grape juice (Gómez-Brandón et al., 2019; Muhlack et al., 2018). In particular, the European Union is the largest wine producer, accounting for 65% of global production; in 2018 in Italy more than 8.6 tons of grapes were harvested, and in Lombardy alone in 2019 wine production reached 130 million litres (Chebbi et al., 2021). During the wine production process, the pressing of the grapes generates solid residues (pomace), consisting of stalks, skins, seeds and water, which represent about 25% of the grape mass; for the production of 6L of wine is estimated to produce about 1 kg of pomace leftover, for a total of 10.5-13.1 million tons of pomace per year (Gómez-Brandón et al., 2019; Muhlack et al., 2018). Given the high quantities of pomace produced annually by wineries, the sector is under pressure to implement plans for an adequate and sustainable disposal of this biomass: the pomace, in fact, is characterized by high COD and BOD (Chemical/ Biochemical Oxygen) values, which makes disposal an important and costly environmental problem (Campanella et al., 2017).

There are multiple possibilities for valorizing residues and processing by-products of these two production chains, some of which are traditional and consolidated practices, others more innovative and under development. The current principal valorization processes for olive pomace, OMWW and grape marc are shown in Table 1.

Table 1. Strengths and limitations of olive oil and wine processing chain residues valorizing methods

Resource	***Technology***	***Strengths***	***Limitations***	***Reference***
Olive pomace	Pyrolysis	The valorizations of organic wastes through fast pyrolysis appears to be a highly promising option for decreasing pollutants and reducing consumption of natural resources	Developing a novel cost-effective and environment-friendly process	Dorado et al., 2021
	Bioconversion	Exhausted olive pomace (EOP) represents a potential candidate stream to be utilized in biotechnological processes	EOP composition includes significant amounts of extractives and pectin, which are both usually discarded and are not utilized in the valorization process	Paz et al., 2020
	Anaerobic digestion			Elalami et al., 2020
	Bioremediation			Flores-Céspedes et al., 2020
	Animal feed	Reduce adverse environmental effects of this by-product and to enhance the quality of products of animal origin	Maintenance of the products quality	Chiofalo et al., 2020
Olive mill wastewater (OMWW)	Purification through membranes	High content of molecules was isolated		Tundis et al., 2020
	Hydrothermal carbonization	Promising technique for wastes conversion into carbon rich materials		Azzaz et al., 2020
	Animal feed	Reduce adverse environmental effects of this by-product and to enhance the quality of products of animal origin		Branciari et al., 2020
	Bioconversion	The process was successfully validated on an industrial scale		Ramires et al., 2020
Grape marcs	Extraction of useful molecules	The technology already exists	Seasonality of raw materials	Brazinha et al., 2014
	Pyrolysis	Process applied as pre-treatment step for grape marc within energy generation	A crucial first step in developing a novel cost-effective and environment-friendly process	Marculescu and Ciuta, 2013
	Bioconversion	High by-product valorisation process	Technology improvement	Campanella et al., 2017
	Animal feed		The nutritive value of grape pomace varies depending on the proportion of seeds and pulp	Guerra-Rivas et al., 2017
	Bio remediation			Chebbi et al., 2021

2.2. The potential of circular economy in metallurgical industry

The metallurgical sector, known also as metal industry, plays an important role in Lombardy's regional industry. The number of industries in this sector is 1446 of which 406 located in the province of Brescia as the focus area (ISTAT, 2019). Meanwhile this sector is one of the main producers of industrial waste in the region with the total production of 8,290,853 tons in 2018, which formed 34.6 % of the total production industrial waste in the manufacturing sector in Lombardy region. From this number a quantity equal to 1.704.058,6 tons were produced only in the province of Brescia (ARPA Lombardia, 2019). Almost 45% of the industrial waste produced by the metal industry in Lombardy region comes from EAF slag, which corresponds to 72% of the total production of EAF slags at the national territory (Lombardy Region, 2021). As a non-hazardous waste it can be treated by the companies specialized in treating waste (ATECO code 38.21).

In addition, the companies specialized in manufacture of other non-metallic mineral products (ATECO code 23) can recover these wastes in a symbiotic way as a raw material in their production processes. The number of these types of firms is 2400 in the Lombardy region from which 420 companies are located in the province of Brescia (ISTAT, 2019). Therefore, a considerable potential exists for avoiding the disposal of this material, which made it necessary for searching new IS pathways.

2.3. Circularity in steel industry: EAF slag valorization

Steel sector is regarded as an energy intensive sector. Meanwhile, it also possesses a productive cycle with a high amount of wasted material compared to the unit of final product. Considering the different technologies for steel production, Italy is the first rank among EU (27 countries) for EAF steel production (Piemonti et al., 2021). In Italy, about 80% of the steel comes from the EAF. The steel production plants in the province of Brescia are almost exclusively equipped with EAFs, accompanied by second metallurgy processes in ladle furnaces. The main residues derived from steel production by EAF are listed in the Table 2 (Remus et al., 2013).

A high percentage of the total waste generated in steel mills belong to slags. Based on the estimations provided by the local steelmakers in Lombardy region, the total generation of slags may be reach up to 20 % of the total weight of the final steel products (Comune di Brescia, 2021; Feralpi Group, 2018). From this amount, almost one-third belongs to white slag. The generated slags stand for almost 70 % of the total waste generated in each steel company. The rest consists of less than 20 % hazardous wastes and almost 10 % non-hazardous wastes. At present, the management of white slag (LF) and black slag (EAF slag) are considerably different. Most of the white slags are also sent to landfill, even if many research initiatives have been already initiated about the possible solutions for their valorisation.

One of the most promising options is the usage of white slag as an alternative material for cement in construction application (Aponte et al., 2020; Santamaría et al., 2020). On the other hand, the situation for black slag is more complex (Piemonti et al., 2021). At this moment, different pathways are being followed by the local enterprises for their reuse. Recycling is one of the options, in which the companies send their slags as waste to other plants which have the authorization of transforming the slags to new inert products to be used in civil engineering works and as a primer for road paving.

However, some of the companies have initiated recently to take a further step in the hierarchy by developing specific plants inside their own establishment for transforming the black slag to a by-product. This type of material sometimes known as synthetic aggregate or synthetic stone is no longer considered as waste and therefore from the legislative point of view requires less sensitivity in transportation and it can be sold in the market as a new product of the company. The strength and limitations of recycling the EAF slag for innovative applications could be summarized as per presented in Table 3.

Table 2. Kind and specific quantity of solid wastes/by-products from EAF steelmaking (source: Remus et al., 2013)

Solid waste/by-product		***Specific quantity (range) (kg/t LS)***
Slags from carbon steel/low alloyed steel production:	Slag from EAF	100 – 150 10 – 30
	Slag from ladle	
Slags from high alloyed steel production:	Slag from EAF	100 – 135
	Slag from ladle	30 – 40
	AOD slag	Approximately 160
Dusts from carbon steel/low alloyed/high alloyed steel production		10 – 46
Refractory material		2 – 25
NB: LS = Liquid steel. AOD = Argon Oxygen Decarburization		

Table 3. Strengths and limitations of the incorporation of EAF slag for different applications

Application	***Strengths***	***Limitations***	***References***
Internal reuse as alloying agent in the metallurgical process	Slag can be valorised for partial replacement of lime, alloying agents and slag formers in the melt shop Potential recovery of valuable metals from slugs	Degradation of the material properties over time and efficiency loss in the steel making process. Long term monitoring and characterization of slags content are needed.	De Colle et al., 2019 Menad et al., 2021
Production of rubber and other polymeric	Slag as a filler increases the composites' hardness and elastic modulus at the expense of toughness	The leaching of hazardous elements out of the polymeric matrix The mechanical performance of the product is less than other conventional fillers	Gobetti et al., 2021
Production of stone wool thermal insulation	The production process results in a higher value-added product and also minor amount of iron as by-product	EAF slag can only partially substitute raw material The process needs energy consumption and further emissions	Paroc, 2019
Aggregates for construction industry	Concrete with EAF slag has 11% higher attenuation coefficient Bitumen mixture with EAF slag aggregates is more durable Resilient modulus and dynamic creep modulus values of EAF slag can be increased through aging process Compressive strength and elastic modulus of concrete with EAF slag aggregates are comparable to the commercially available concrete, but is cheaper to produce	Concrete with EAF slag has volume instability and durability issues under extreme conditions and is vulnerable to repeated cycles of wetting and drying EAF slag is generally more porous and have higher water absorption than conventional road pavement materials	EUROSLAG and EUROFER, 2012; Teo et al., 2020
Filter or adsorbent in wastewater treatment plant	EAF slag can: - effectively remove phosphorus from effluent - be processed to improve its adsorption capacity - be used to reduce the acidity of wastewater	EAF slag has limited adsorption capacity for long term usage Using EAF slag to treat acidic wastewater may produce unwanted precipitates that need to be disposed of separately	Teo et al., 2020
Fertiliser for agriculture industry	EAF slag: - contains Fe, K, Mn, and P that could sustain plant growth - can be processed into higher added value phosphorus fertiliser - have the potential to reduce toxic elements uptakes of agricultural plants	EAF slag also contains low amount of harmful elements such as Cd and Pb Remediation procedures might be needed to reduce harmful elements	Teo et al., 2020
Partial replacement for cement	The reuse as partial replacement of the cement is possible if combined, for example, with small percentages of gypsum or steel sludge	Increase in setting times Less initial strength development Slightly greater autogenous shrinkage compared to the standard concrete	Piemonti et al., 2021
Raw material for ceramic building materials	In terms of chemical composition, slag is similar to raw materials used for the production of ceramic tiles. Leaching test revealed that the concentrations of the heavy metals leached in both tap water and rainwater conditions were low	Optimal EAF slag wt.% varies based on its composition from different sources Monitoring of the risk from harmful elements that emits from the products are within safe level	Teo et al., 2014 Teo et al., 2016

3. Materials and methods

The methodology, developed by ENEA, is the result of consolidated experience on IS (Cutaia et al., 2015). It is based on three basic pillars:

1) Language of symbiosis: a shared language that is expressed in the formats for collecting information (personal data and relating to input and output resources);

2) Communication with companies: continuous throughout the whole symbiosis implementation process;

3) Knowledge and experience: this aspect concerns the knowledge base that allows ENEA to support collaboration between enterprises and resources exchange as prerequisite for the implementation of IS paths (Fig. 1). According to the methodology, activities related to the implementation of IS followed

these operational phases:

Step 1_ Identification of stakeholders in the Lombardy region: preparation of company's database, selection of enterprises to be involved including business associations and local authorities;

Step 2_Preparatory activity for the OM: Invitation of companies; registration; preliminary data collection;

Step 3_OM with companies: sharing of resources, finding synergies and help companies identify matches;

Step 4_Identification of significant resource flows and potential synergies: data analysis of shared resources, in-depth study of the potential synergies that emerged during the OM and identification of new potential synergies, summary report elaboration;

Step 5_ Study of synergies in collaboration with companies: study of technical feasibility and environmental aspects through LCA, assessment of economic impacts, study of legislation and technical standards;

Step 6_ Drafting of the technical handbooks;

For the CREIAMO project, the ENEA methodology has been adapted to be carried out in telematics mode, due to the pandemic situation. Therefore, both OM and information exchanges with the enterprises and stakeholder involved took place remotely.

At first, ENEA drew up a specific online form that companies filled out before the OM. These forms contain company details and shared or requested resources data (type, quantity, availability, characteristics etc.). This anonymous database (the company name has been replaced by a unique code) was used as a base of information during the online operating session.

Participants anonymously expressed their preferences on the use or willingness to share involved resources, allowing an initial match identification. The IS OM was held on February 19, 2021, aimed at enterprises in the province of Brescia and neighboring provinces.

4. Results and discussion

There were 22 firms participating in the OM and they belong to very different production sectors, as it can be seen from the graph (Fig. 2). During the meeting 96 resources were shared, mostly material resources. Of these, 24 were input resources (required by companies), and 72 output resources (offered for sharing) composed of waste, by-products or surpluses (Table 4).

Overall, 102 synergies were identified, 77 synergies on output resources and 25 on input resources. To these must be added the synergies identified by ENEA downstream of the workshops, which envisaged intermediate treatments of the resources made available (Table 5).

Following the OM activity, thanks to the contribution of Confindustria Brescia, the resources database was integrated with information on companies that were registered to the event, but were unable to participate. The identification of new potential synergies and the drafting of a summary report for each company followed this phase.

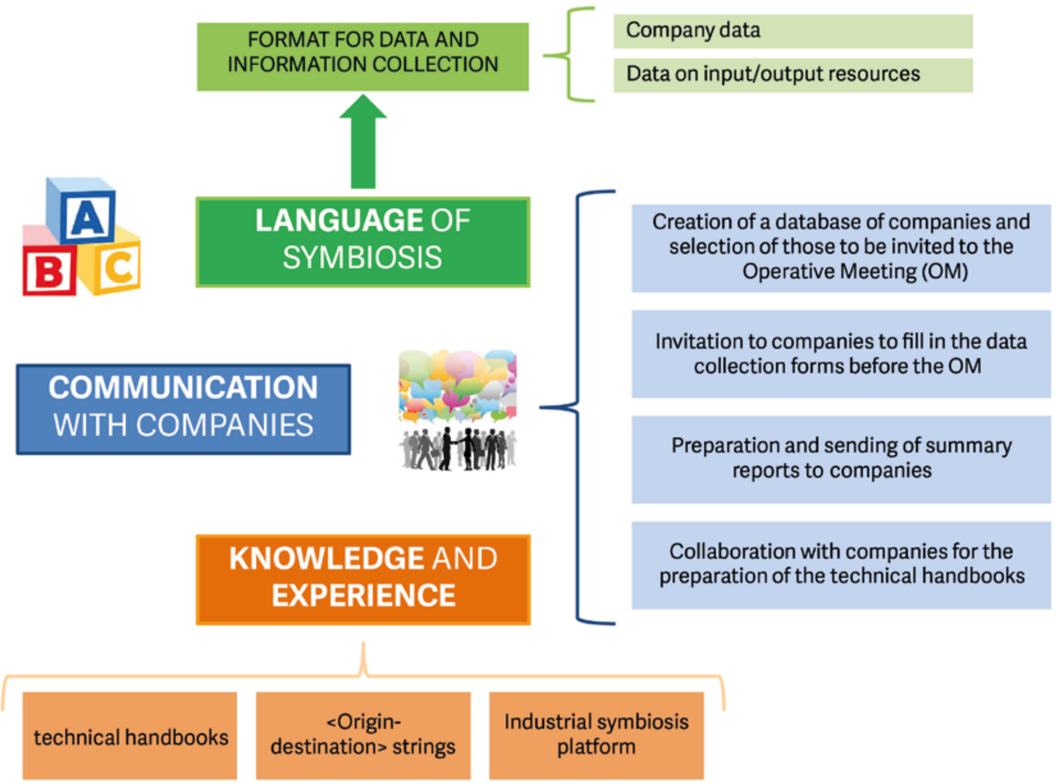

Fig. 1. The three pillars of the ENEA methodology

The document contains a summary of the shared and requested resources and a description of the potential synergies identified (Fig. 3). A further phase of investigation led to the identification of the most significant resource flows both from a quantitative and qualitative point of view. The valorizations solutions for these flows were studied in-depth in two technical handbooks: Technical handbook on the synergies identified for organic resources, i.e., waste from olive oil and wine productive process, in particular olive and grape marc and OMWW. In this handbook, three flows of organic resources have been studied starting from waste from the companies involved:

- Olive pomace, produced by three different farms with the possibility of being valorized:
  - Through the extraction of compounds with higher added value such as polyphenols or antioxidants, in turn addressed to the fishing, cosmetic or nutraceutical industry;
  - For the production of bio-oils used for combustion;
  - For the production of natural bio-surfactants.
- OMWW, produced by three different farms with the possibility of being valorized:
  - Through the extraction of compounds with higher added value such as polyphenols or antioxidants, in turn addressed to the fishing, cosmetic or nutraceutical industry;
  - For the production of natural bio-surfactants.
- Grape marc, output classified as by-products from two different farms with the possibility of being valorized:
  - Through the extraction of compounds with higher added value such as polyphenols or antioxidants, in turn addressed to the fishing, cosmetic or nutraceutical industry;
  - For the production of bio-oils used for combustion;
  - For the production of natural bio-surfactants.
  - Technical handbook on the synergies identified for inorganic resources, which investigates the potential synergies for the resources deriving from the steel sector and from industrial and post-consumer waste plastic materials. In this handbook, three streams of inorganic resources have been studied in particular, starting from waste from companies involved;

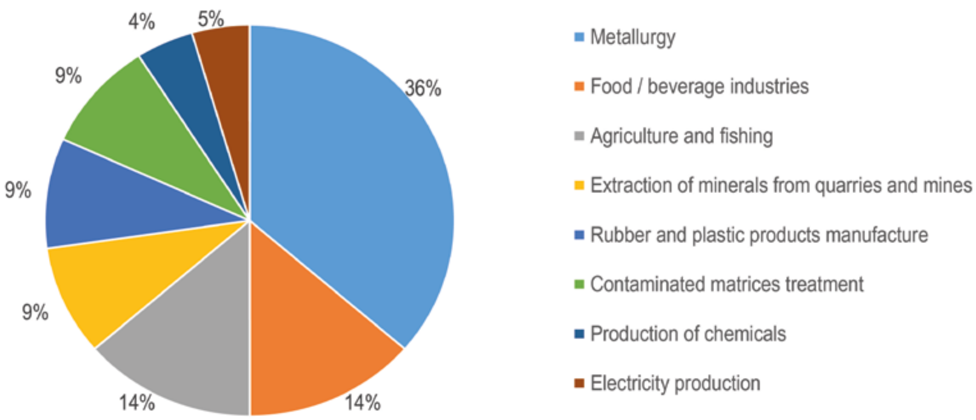

Fig. 2. Production sectors of the 22 companies that participated at the IS OM

Table 4. Shared resources during the IS OM

Resources category	*Input resources*	*Output resources*	*Total*
Material	21	64	85
Water	1	2	3
Energy	1	1	2
Competence	1	2	3
Other	0	3	3
	24	**72**	**96**

Table 5. Synergies emerged during the IS OM

	Synergies on output resources	*Synergies on input resources*	*Total*
Material	68	24	92
Energy	7	0	7
Competence	2	1	3
	77	**25**	**102**

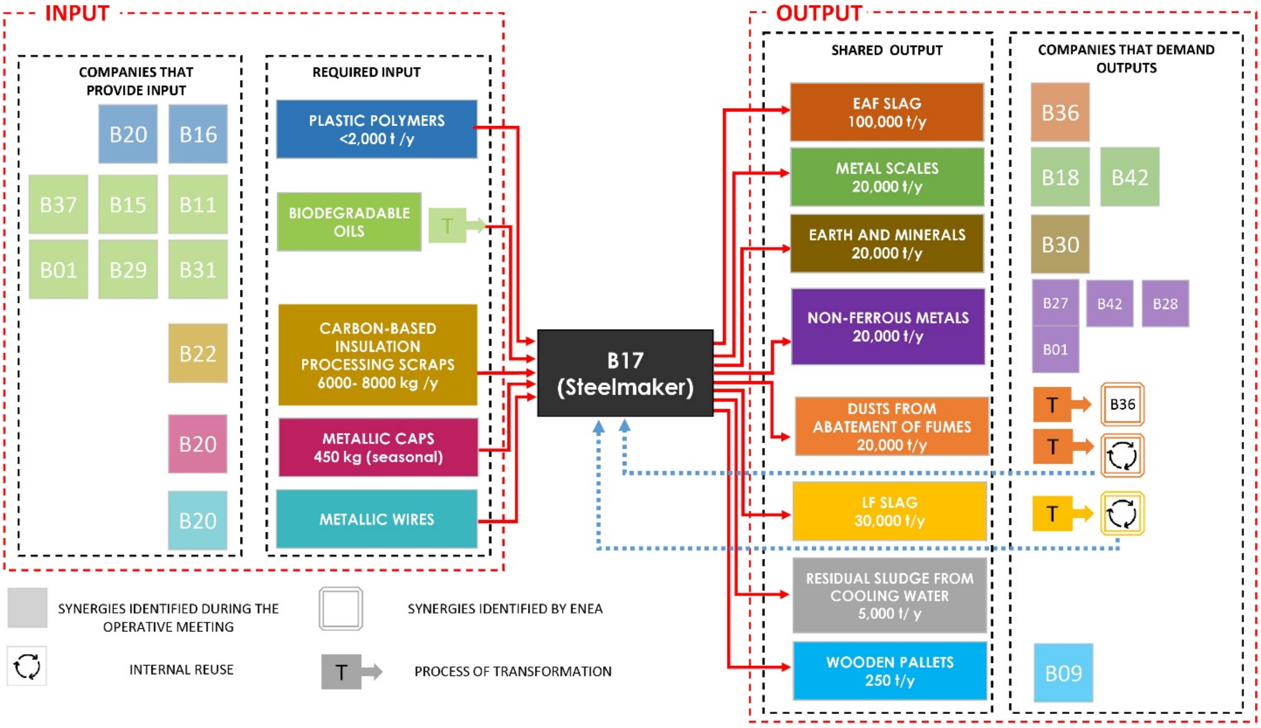

Fig. 3. Example of a summary scheme of the synergies identified as reported in the summary report

- Black slag from EAF, treated as a by-product or waste by two companies in the steel industry and intended for reuse in a company that produces cement and bituminous conglomerates;
- Plastic waste in the form of flakes and powders from a food packaging production company and intended for steel companies such as Secondary Reducing Agent (SRA) for use in blast furnaces as a reducing agent in the oxidation reactions of ferrous minerals to replace Coke.
- Post-consumer plastic waste for use in the steel industry for the same purposes.

4.1. Scenario for the enhancement of wine and olive oil waste: Extraction of high added value molecules

Biomasses are renewable energy sources that are distinguished from other renewable sources (such as wind, solar, geothermal) as the available energy is stored in the chemical bonds present in the various molecules that compose it. This means that they are a source of energy, but also of basic chemical compounds or high added value and biomaterials (Torres et al., 2020). The extraction of chemical compounds with high added value from biomass already represents an important market in the pharmaceutical (chitosan), cosmetics (chitosan and extracts polyphenols), nutraceutical (dyes derived from biomass, texture modifiers and food supplements) and agricultural (pyrethrum-based insecticides); so the extraction processes can be defined as sustainable, it is important to use technologies with high energy efficiency and which are based on low environmental impact solvents obtained preferably from renewable sources (Herrero and Ibañez 2018).

Olive pomace, OMWW and grape marc represent a very varied source of bioactive compounds that could have potential applications in various markets as mentioned before. Real cases have been identified during the OM (Fig. 4). Among the companies involved, two of them (indicated with the code B03, B16) requested as input molecules with high added value such as antioxidants and polyphenols, intended for the fishing industry, to increase the quality of feed, or for the creation of plastics for food packaging, to increase the freshness and shelf life of packaged foods. Among the companies present none was able to share directly these types of molecules but five of them (B11, B15, B37, B29, B31) shared olive pomace, OMWW and grape marc for a total of 1040 m^3/y, 1300 m^3/y e 100 tons/y respectively. In literature there is much research aimed at extracting these products from pomace, OMWW and pomace as they are present at high titers (Table 1). The extraction of these high added value molecules is now carried out on an industrial scale starting from edible plants and crops.

Therefore, a possible strategy to valorise these by-products could be the implementation of these extraction processes, which already exist, using the resources examined in this work as starting biomass. Fig. 4 shows, more in detail, the case study developed by ENEA; the green and purple arrows highlight the distance of olive pomace, OMWW and grape marc respectively from the companies that supply these outputs to the different processing firms identified by ENEA in the Lombardy region. Furthermore, the grey arrows highlight the distances between the processing companies identified and the ones that require polyphenols and antioxidants as input.

In the arrows (Fig. 4) a range of distances is shown from the smallest to the largest between the various companies taken in consideration. These values can therefore undergo changes since the intermediate extraction process, which must be done on the resources, is carried out on site by the companies in question or by third-part companies. The distances between firms are one of the factors that has the greatest impact on economic costs but also on the environmental impact. For this reason, one of the foundations of IS is the closeness between companies and for this reason in this work the distances between them have been analyzed in detail. In general, it has been observed that the distances between the companies that provide resources (B11, B15, B37, B29, B31) and those that receive them for treatment (A, B, C, D, E) lie in a range of distance that goes from 13 to 191 km, while between the "T" companies and those that use the final resource (B03, B16) they are found in a range that goes from 29 to 100 km. It is possible to observe in detail the specific ranges for each company in the synergy diagram (Fig. 4).

4.2. Scenario for the enhancement of steel mill waste: the use of black slag as an artificial inert

The diagram (Fig. 5) outlines the synergy between three steel companies and a firm that produces cement and bituminous conglomerates using black steel mill slag as an artificial aggregate for alloyed and unalloyed uses (alloyed uses refers to the use for cements, concretes or bituminous conglomerates; unalloyed uses refer to the use for the construction of embankments and road foundations, landfill "capping" etc.).

Among the enterprises involved, three of them belonging to the steel sector (indicated with the code B26, B17, B04) indicated the black slag from an electric furnace steel mill (EAF) as a resource to be shared. Only two (B17 and B04) made by-products available, while only one (B26) shared the resource as waste, preliminarily subjected to a process of separation and recovery of steel fragments. The total quantity of black slag amounts to 270,000 tons per year, of which 200,000 are certified by-products according to the UNI EN 13242 (2013) standard, used as fillings in civil engineering works, as drainage layers for covering or layers of capillary rupture for landfills. The remaining quantity (70,000 t / year) is waste and is sent to authorized and specialized platforms for reuse in road foundations and in cement and bituminous conglomerates. The transport phase of the aforementioned resources from the company that supplies them and the one that uses them takes place for an average distance of about 25 km.

5. Conclusions

The IS activities carried out in the CREIAMO project have aroused interest among the companies who actively participated in synergies implementation, confirming environmental, social and economic advantages deriving from resources exchange between enterprises.

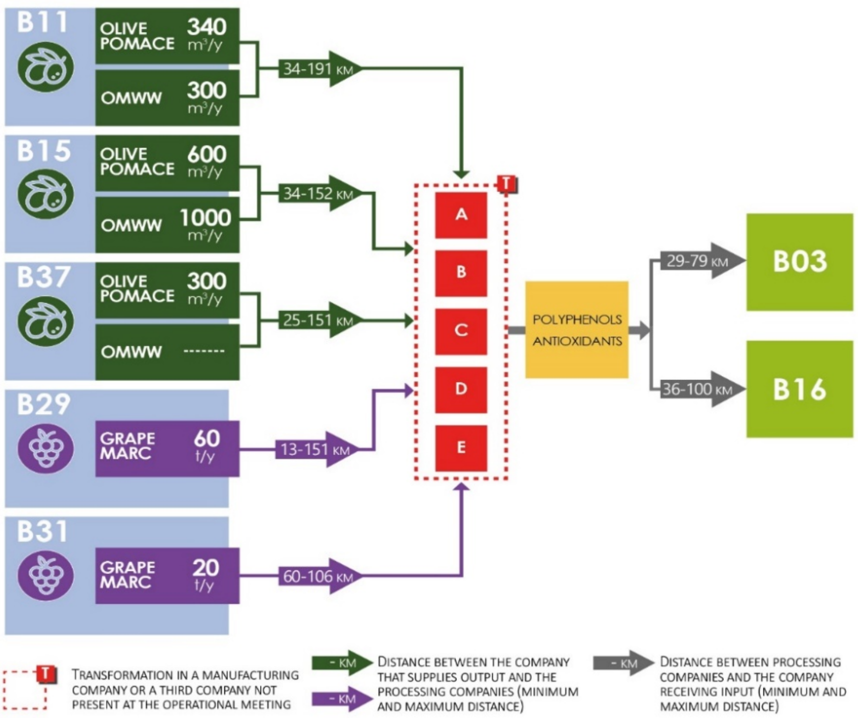

Fig. 4. Enhancement scenario of olive pomace, grape marc and OMWW for the extraction of high added value molecules

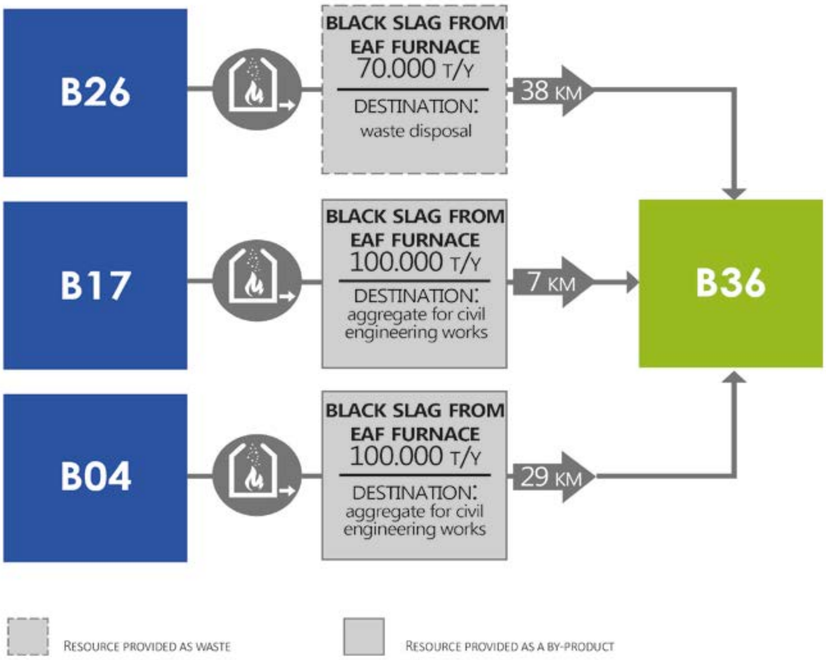

Fig. 5. Synergy diagram for black slag from EAF

In fact, the development paths outlined, such as the extraction of high added value molecules from oil and wine production waste and the use of black slag as an artificial inert from steel mill waste, can be taken as a pilot case for the development of analogous synergies in territories where there is a productive fabric that produces the same kind of resources.

The feedback effects mainly materialize in economic and environmental advantages, as in the case of the production of antioxidants and polyphenols, where the use of agro-industrial by products determines a reduction in production costs, an increase in value chains and a closure of production cycles with the relative reduction of environmental impacts. Analogous effects affect the valorisation of EAF slag with both purely environmental advantages (reduction of the exploitation of natural resources, reduction of the impact on the landscape, reduction of soil consumption etc.), but also involve characteristic aspects of the circular economy (use of otherwise destined for landfill), as well as technical performance.

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