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The contribution and potential of Industrial Symbiosis for the ecological transition

October 27th 2021

Edited by Tiziana Beltrani and Marco La Monica

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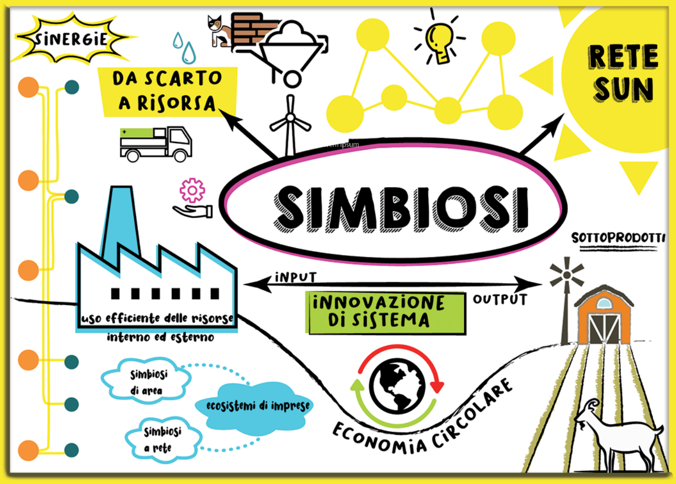

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ECOMONDO
Il contributo ed il potenziale della Simbiosi Industriale per la transizione ecologica

INTRODUZIONE

La simbiosi industriale si sta sempre più affermando in Italia come strumento operativo dell'economia circolare per l'implementazione della transizione ecologica.

In tale direzione, il Piano Nazionale di Ripresa e Resilienza (PNRR), approvato nell'aprile del 2021, nella Missione 2 *"Rivoluzione Verde e Transizione ecologica"* prevede di definire una nuova strategia nazionale per l'economia circolare, includendo anche misure concrete per l'applicazione della simbiosi industriale attraverso appositi strumenti normativi e finanziari. La revisione e l'aggiornamento della strategia esistente si concluderà a giugno 2022. É importante, però, evidenziare che già nella prima bozza di Strategia di Economia Circolare messa in consultazione pubblica, la simbiosi industriale viene individuata come un'area di intervento cruciale per la transizione verso l'economia circolare in Italia. Il documento, riprendendo anche una proposta già avanzata dalla Piattaforma Italiana degli attori per l'Economia Circolare - ICESP - nel 2020 nonchè da ENEA, fa riferimento all'istituzione di "*un Programma nazionale per le imprese allo scopo di sostenere la creazione di processi di simbiosi industriale e la riconversione eco-industriale delle aree produttive del Paese integrato con una serie di incentivi (e disincentivi) fiscali che possano favorire questi percorsi"*.

Per favorire la realizzazione del PNRR, per quanto riguarda la componente C1 *"Agricoltura sostenibile ed Economia circolare"* della Missione 2, nell'ottobre 2021 il Ministero della Transizione Ecologica ha pubblicato degli avvisi per finanziare sia progetti per la realizzazione di nuovi impianti di gestione dei rifiuti e l'ammodernamento di impianti esistenti (Avviso M2C.1.1 I 1.1, risorse finanziare per un miliardo e mezzo di euro), sia progetti *"faro"* di economia circolare finalizzati a promuovere l'utilizzo di tecnologie e processi ad alto contenuto innovativo nei settori produttivi legati alle filiere di carta e cartone, plastiche, RAEE, tessili (Avviso M2C.1.1 I 1.2, risorse finanziarie per 600 milioni di euro). In particolare, in quest'ultima linea di investimento, saranno valutate positivamente le proposte progettuali da parte delle imprese che favoriranno scelte tecnologiche finalizzate *"all'incremento dell'utilizzo di materia riciclata o di materia prima seconda nel processo industriale, anche attraverso pratiche di simbiosi industriale"*.

In linea con le finalità riprese anche dal PNRR, già da qualche anno il Ministero dello Sviluppo Economico ha introdotto una serie di misure per sostenere la riconversione produttiva del Paese per un migliore e più efficiente utilizzo delle risorse.

In tale direzione si ricorda, in particolare, l'intervento del Fondo per la crescita sostenibile per i progetti di ricerca e sviluppo nell'ambito dell'economia circolare, attivato con D.M. 11/06/2020, finalizzato a sostenere la ricerca, lo sviluppo e la sperimentazione di soluzioni innovative per l'utilizzo efficiente e sostenibile delle risorse, con la finalità di promuovere la riconversione delle attività produttive verso un modello di economia circolare in cui il valore dei prodotti, dei materiali e delle risorse è mantenuto quanto più a lungo possibile, e la produzione di rifiuti è ridotta al minimo. A tal fine è individuata un'apposita linea di intervento per le imprese finalizzata ad agevolare la *"progettazione e sperimentazione prototipale di modelli tecnologici integrati finalizzati al rafforzamento dei percorsi di simbiosi industriale"* (risorse finanziarie per 220 milioni di euro circa). Tale misura è attualmente ancora in vigore e può, sinergicamente con quella attuata dal MiTE, rafforzare la diffusione dell'innovazione tecnologica e di sistema legata alla simbiosi industriale all'interno del tessuto produttivo nazionale.

Vista, dunque, la crescente rilevanza della tematica, su iniziativa di SUN, del CTS di Ecomondo e di ENEA, il 27 ottobre 2021 si è svolto in modalità mista - presenza e on-line - ad Ecomondo, la quinta edizione della conferenza della Rete Italiana di Simbiosi Industriale SUN – Symbiosis Users Network dal titolo *"Il contributo ed il potenziale della Simbiosi Industriale per la transizione ecologica"*.

L'evento ha rappresentato una occasione di confronto su casi concreti di simbiosi industriale, sugli standard tecnici e/o operativi e sugli strumenti a supporto sia della implementazione sia degli investimenti per la simbiosi industriale.

Molti dei contributi esposti dalla comunità scientifica e imprenditoriale in quella giornata, sono raccolti in questi atti.

Ing. Laura Cutaia

Presidente SUN, ENEA - Responsabile del "Laboratorio di valorizzazione delle Risorse" (RISE) nel Dipartimento "Sostenibilità dei Sistemi Produttivi e Territoriali"

Dott. Giacomo Vigna

Divisione Economia circolare e politiche per lo sviluppo ecosostenibile, della Direzione Generale per le politiche industriali del Ministero dello Sviluppo Economico.

INTRODUCTION

Industrial symbiosis is increasingly becoming an operational tool of the circular economy for the implementation of the ecological transition in Italy.

In this direction, the National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza - PNRR), adopted in April 2021, in Mission 2 "Green Revolution and Ecological Transition" plans to define a new national strategy for the circular economy, also including measures to implement industrial symbiosis through specific regulatory and economic instruments. The review and update of the existing strategy will end in June 2022. However, it is important to highlight that even the first draft of the Circular Economy National Strategy, submitted to public consultation, identifies industrial symbiosis as a crucial area of action for transitioning to the circular economy in Italy. Also receiving what proposed by the Italian Circular Economy Stakeholder Platform - ICESP - in 2020 as well as by ENEA, this document seeks to establish a national program for companies in order to support industrial symbiosis and the eco-industrial reconversion of the national production areas, integrated with a series of tax incentives (and disincentives) that can favor these paths.

To encourage the implementation of the PNRR, in October 2021 the Italian Ministry of Ecological Transition published calls for one and a half billion euros to finance projects to both build new waste management plants and revamp existing ones (call M2C.1.1 I 1.1, C1 component "Sustainable Agriculture and Circular Economy" of Mission 2). Moreover, also "flagship" circular economy projects will be funded for 600 million euros, aiming at promoting the use of highly innovative technologies and processes in production sectors linked to the paper and cardboard, plastics, WEEE, textile chains (call M2C.1.1 I 1.2); the use of recycled or secondary raw materials in the industrial process will be positively evaluated, also through industrial symbiosis approaches.

In line with the aims of the PNRR, the Italian Ministry of Economic Development has already introduced a series of measures to support the national productive reconversion towards better and more efficient use of resources.

For example, the Fund for sustainable growth for research and development projects in the context of the circular economy (Ministerial Decree 11/06/2020) aimed at supporting the research, development and testing of innovative solutions for the efficient and sustainable use of resources and at promoting the reconversion of production activities towards a circular economy model in which the value of products, materials and resources is kept for as long as possible, and waste generation is minimized. To this end, a specific line of action is identified for companies to facilitate the design and prototype testing of integrated technological models to strengthen the industrial symbiosis pathways (financial resources of approximately 220 million euros). This measure is currently still in force and canstrengthen the spread of technological and system innovation linked to industrial symbiosis, synergistically with what implemented by the Italian Ministry of Ecological Transition.

Therefore, given the growing relevance of the issue the Italian Network of Industrial Symbiosis (SUN - Symbiosis Users Network, the CTS of Ecomondo and ENEA organized the fifth edition of the conference of the entitled "The contribution and potential of Industrial Symbiosis for the ecological transition". The conference was held on 27 October 2021. This event represented an opportunity for discussion on concrete cases of industrial symbiosis, on technical and/or operational standards and on tools to support both implementation and investments for industrial symbiosis.

Many of the contributions presented by the scientific and business community on that day are collected in these proceedings.

Eng. Laura Cutaia

President of SUN, ENEA - Responsible of the "Laboratory for Resources Valorization" (RISE) in the Department for "Sustainability"

Mr. Giacomo Vigna

Circular Economy and Ecosustainable Development Policies Division, Italian Ministry of Economic Development.

ANALYSIS OF THE SYNERGIES OF INDUSTRIAL SYMBIOSIS CONCERNING THE STEEL WASTE IN INDUSTRIAL AREAS

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ABSTRACT

The main by-product of the steel industry is slag whose production is functional to that of the steel itself. This work aims to analyze the cases of industrial symbiosis implemented in various countries with particular attention to the exchange of slag which, from steel mill waste, becomes a secondary raw material for other industrial sectors. In all, 12 cases of scientific literature relating to industrial areas were analyzed, and classified in function of the type of slag (deriving from different production processes). The final application of the slags is studied in terms of receiving sector and the barriers to the implementation of industrial symbiosis. It was found that the cement and road constructions industries are the main symbiotic receiving partners. In the scientific literature the reuse of slag is extensively studied in cases of integrated cycle steel production, while the case studies involving electric furnace slag are much more limited.

Keywords: *BF-BOF slag, EAF slag, industrial symbiosis, steelmaking, waste reuse*

Introduction

The attention of manufacturing industries in recent years has increasingly focused on the implementation of systems aimed at improving the recycling rate of by-products and the valorization of waste as an environmentally and economically advantageous alternative to the ever-increasing disposal costs. This is due to the increasing sensitivity towards the preservation of natural resources and the big problem of waste disposal that led the EU commission to issue Directive 2008/98 [1] and the ambitious goal of "zero waste". The production of cast iron and steel derives from two main paths: production based on iron ore (integrated process by the blast furnace-basic oxygen furnace (BF-BOF) route) and production of based on ferrous scrap (by the electric arc furnace (EAF) route). More than 70% of the world's steel is produced using the integral cycle, based on the blast furnace (BF), where iron ore is reduced to cast iron, which is subsequently converted to steel in the basic oxygen furnace (BOF). The remaining 30% follows the second route, where the ferrous scrap is melted by the electric arc furnace (EAF) and refined in ladle furnace (LD). For this reason, the emphasis is mainly placed on case studies involving integrated steel mills. Slag is the by-product produced in greater quantity. The slag is functional to the production of the metal itself as it has the task of removing the impurities present in the iron ore, steel scrap and other added components, protecting the liquid metal from oxygen and maintaining the temperature inside the furnace. With a view to circular economy, it should be emphasized that the enhancement of by-products does not aim only at their use in the production of conventional products but also at the study and development of new products. Through a new destination of secondary materials, on the one hand, large quantities will be saved from landfills and, on the other, savings will be made in the extraction of new raw materials.

Methods

It was from the literature by selecting several key words such as "industrial symbiosis in the steel sector", "slag reuse", "steel sector by-product reuse", "steel sector waste reuse" and "circular economy in the steel sector". The search engines used included databases such as Web of Science and Scopus, and freely accessible search engines, such as ResearchGate and Google Scholar.

Due to the small number of cases of industrial symbiosis involving electric arc furnace slag, a more targeted research was carried out in this regard. Therefore, two real cases of the enhancement of EAF slag in Italy have been added: Alfa Acciai (Brescia, Italy) and Global Blue (ABS) (Udine, Italy). They are not reported in the scientific literature and are not classifiable as cases of industrial symbiosis, nevertheless the authors considers them not negligible in relation to the purpose of this study.

Results

1. **Taranto, Italy** [2]

Steel production process: Integrated cycle; Industrial symbiosis model: Bottom-Up

Industrial symbiosis description: Within a complex network of symbiosis, BF slag and mill scale are sold as a substitute raw material to the cement plant.

Barriers: Long-term economic return. Lack of information and communication (need for a mediator). Corporate core business focused exclusively on the product. Poor trust in partners. Unclear legislation.

Benefits: Reduction of waste in landfills. Less exploitation of natural resources.

2. **Styria, Austria** [3, 4]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: BF sand and slag are sold to the cement and construction industry.

Barriers: Poor trust in partners. Slow bureaucracy.

Benefits: Reuse of 200,000 tons of Steel mill slag, 85,000 tons of blast furnace slag.

3. **Kwinana, Australia** [3, 5, 6]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down
Industrial symbiosis description: Within a complex network of symbiosis, BF slag is sold to the cement industry.
Barriers: Availability of (reliable) recovery/recycling technologies. Relatively low price for utility resources. Confidentiality regarding commercial matters. Intensive approval procedure for the reuse of by-products. Logistic distance between companies. Core business focus on the product.
Benefits: Avoided 260,000 tons of materials from being landfilled annually.

4. **Jinan, Cina** [7]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down
Industrial symbiosis description: Within a complex network of symbiosis, the BF slag is sold to the cement and road construction industries.
Barriers: Not described.
Benefits: Revenues from sales to the cement industry 10 M USD/year. Avoided cost of disposal 5 M USD/year. Avoided slag landfilling 180 Mt/year.

5. **Liuzhou, Cina** [8, 9]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down
Industrial symbiosis description: BF slag and steel mill dust are reused in the cement and construction industry. The by-products of the desulphurization process are used to produce fertilizers.
Barriers: Absence of specific waste treatment sites.
Benefits: Saving of about 2.4 M tons of raw materials. Reduction of about 3.4 M tons of solid waste.

6. **Lin-Hai, Taiwan** [10, 11]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down
Industrial symbiosis description: BF and BOF slag is used in the cement and construction industry, while desulfurization slag is also sold as fertilizer.
Barriers: Laws governing intellectual property rights often make it difficult to share information between industries. Slow burocracy, Unclear legislations.
Benefits: Reduction of energy costs and waste disposal.

7. **Kawasaki, Giappone** [11, 12]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down
Industrial symbiosis description: The use of BF slag as a substitute for clinker for the production of cement accounts for 56% of the material exchanges.

Barriers: Wet granulation of slag requires large amounts of water. Lack of a standardized system for waste management.

Benefits: 565 000 tonnes of waste avoided from incineration and landfill (whole symbiosis network).

8. Puhang, Corea del sud [13, 14]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: The BF slag is supplied to an adjacent cement plant as a substitute for clinker. The non-ferrous fraction of the recycled steel slag is used in cement (fine particles) and construction (coarse particles).

Barriers: Low demand for recycled products. Lack of standards dedicated to recycled products.

Benefits: -40% atmospheric emissions and 98.3% recycling of by-products (whole symbiosis network).

9. Texas, USA [15]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: EAF slag is used in the cement plant adiacent to the still mill.

Barriers: Not described

Benefits: Reuse of 130,000 tons of steel slag.

10. Avesta Svezia [11, 16]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: The steel mill sells 77% of the slag to an infrastructure company that markets it as recycled aggregate.

Barriers: Not described

Benefits: Cost of secondary raw materials compared to traditional aggregates. Cost of disposal avoided.

11. Unknown, Brasile [17]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: The steel mill donates the slag to an outsourced company that sells it to secondary markets after treatment, mainly for the conservation of local roads.

Barriers: Transportation costs. Lack of research.

Benefits: Avoid landfill of 144,000 tons/year of waste.

12. Ferriere Nord, Udine, Italia [18]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: The steel mill sends the EAF slag to treatment plants for reuse in the asphalt. The LF slag is treated to be used as a substitute for lime and reintroduced into the cycle.
Barriers: Not described.
Benefits: Reuse of EAF slag 200ktons/year as Basalt and porphyry replacement. Reuse of 30ktons/year LF slag and refractories as Lime replacement.

13. Alfa Acciai, Brescia, Italia [19]

The slag produced during the melting of the scrap in the electric furnace constitutes the raw material of the ALFA-Sinstone® granulate, usable for civil engineering works and road construction. This material is a valid substitute for the non-renewable natural raw material.

14. Global Blue (ABS), Udine, Italia [20]

The slag produced in the steel mill ABS constitutes Ecogravel® products that are mainly used for the construction of roads. Ecogravel contributes to the reduction of waste to be sent to landfills and CO_2 emissions and allows less exploitation of natural resources.

Discussion and Conclusion

In this work, 12 cases of industrial symbiosis in the steel industry in Asia, America, Australia and Europe are analysed. Most of the cases analysed consist in the production of integral cycle steel. In order to investigate the reuse of EAF waste, especially in the Italian territory, two cases (indicated as +2) were analysed that do not consist of real cases of symbiosis. The cases of Brescia and Udine provide for the treatment of EAF and LF slag for the production of aggregates with their own CE marking which bring economic and environmental advantages but which are nevertheless more a valorisation of the waste transformed into a finished product to be marketed (Ecogravel and Alfa Sinstone) than a symbiotic activity. Also in the case of Avesta and Osoppo the slag is transformed into finished products (OKTO-products and Granella respectively) but in these cases the marketing is carried out by an infrastructure companies which, by combining traditional products, offers a sustainable alternative. In addition, other symbiotic exchanges were also highlighted. While all industrial symbiosis activities at Asian sites (except Lin-Hai) have been induced by government initiatives via China's Five-Year Development Plan, Japan's Eco-Town Program, or South Korean EIP Initiative, the symbiotic connections documented in the rest of the world (EU, USA, AUS) have spontaneously formed from the motivation of cost reduction. In most of the industrial symbiosis activities defined in the analysed case studies, the cement and building materials industry is involved as a receiving symbiotic partner. The most frequent synergistic exchange is the use of BF slag and steel slag as a substitute for clinker for the production of cement.

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Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Symbiosis Users Network

AN ITALIAN DATABASE OF COMPANY'S BY-PRODUCTS, AIMING TO SUPPORT THE INDUSTRIAL SYMBIOSIS APPROACH

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ABSTRACT

This work, carried out as part of the activities of the LE2C (Lombardy Energy Cleantech) cluster, proposes a database of companies indicating the by-products that could also be recovered from other companies that work in differentiated sectors. The goal is to provide tools aimed at promoting not only the circular economy, but also an industrial symbiosis approach. The database also contains information about the region and province of company's origin, allowing to provide a preliminary analysis at local and national levels. The database, and the collected data, with some preliminary analysis, are presented for the first time at this conference. As an example, the assessment of biomass feedstock availability (in the present case the cereal straw) is shown, with the aim to make companies able to provide bio-energy planning (that may be very interesting in the current situation of ecological transition).

Keywords: *Industrial symbiosis, Circular economy, waste, by-product, cluster analysis*

Introduction

The European Commission's Circular Economy Action Plan is addressed to increase Europe's economic competitiveness, sustainability, resources efficiency, and security. Industrial symbiosis (IS) is considered as a quite new waste management strategy, aiming to directly valorise wastes or by-products deriving from an industrial process, by their use as raw materials by another company. This strategy is considered an additional opportunity for the creation of a circular economy (CE). In addition, IS can be a suitable approach to contribute to the reduction of greenhouse gas (GHG) emissions. Literature reports about 1300 articles referring to IS. Figure 1 shows the co-occurrence map, based on bibliographic data, considering SCOPUS publications containing "industrial symbiosis" in the title, abstract, and as a keyword. The data were updated on September 17, 2021. Data analysis was performed by "VOSviewer version 1.6.16," 2020. Based on the results of the proposed analysis the papers can be grouped in five clusters.

Cluster 1 (represented by red bubbles – 163 items) is mainly devoted to SI approaches and tools, also involving the regulation. Cluster 2 (highlighted by green bubbles – 148 items) concerns the application fields of SI, as for example biofuel, biomass, food waste, carbon capture, and concrete. Cluster 3 (represented by blue bubbles – 52 items) is related to urban IS, also considering social implications. Cluster 4 (highlighted by yellow bubbles – 35 items) is most addressed to SI strategies and modelling. Finally, cluster 5 (represented by violet bubbles – only 11 items) concerns industrial symbiosis projects. It can be concluded that, despite the important literature production (about 1300 papers in SCOPUS), the available industrial example of IS are quite limited. It is evident that actions addressed to meet the companies needs and promote their collaborations are mandatory.

For this aim, in the frame of the LE2C activities (that are devoted to support companies to accelerate innovation), a database reporting the available data about wastes and by-products, of Italian companies, is proposed.

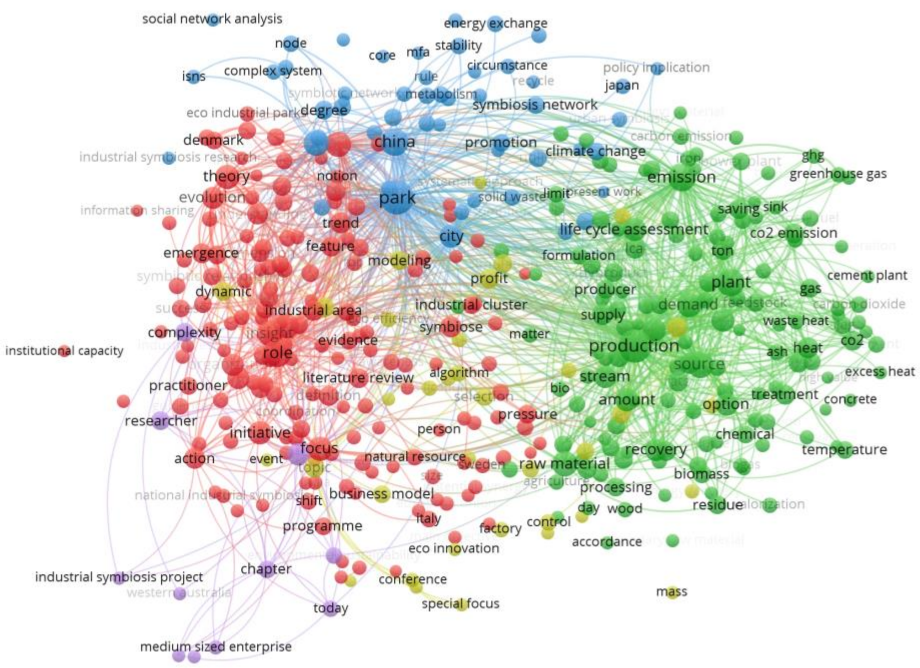

Figura 1. *The co-occurrence map, based on bibliographic data, considering SCOPUS publications containing "industrial symbiosis" in the title, abstract, and as a keyword. The data were updated on September 17, 2021. Data analysis was performed by "VOSviewer version 1.6.16," 2020.*

Methods

The database was realised by considering and managing all the public data available at: https://www.elencosottoprodotti.it. This website contains all the mandatory information for the database realisation. However, it is important to highlight that all the data refer to 2019 and concern exclusively registered companies.

The database allows to select the company and waste (and/or by-product) origin. By-products are classified on the basis of economic activity through codes called ATECO.

The database allows also to identify companies that need to use specific by-products (User) and/or companies that have by-product to discharge (Producer).

The information that can be extracted are the following:

- ✓ the "registration number". It corresponds to the company identification. This information allows also to identify if the company is a manufacturer or a user of a by-product;
- ✓ the name of the registered companies;
- ✓ The "Producers/Users" information, to select the company role;
- ✓ The "Address" that shows the company's registered address;
- ✓ The "Province" and "Region" columns;
- ✓ The "Economic activity", that is a typical classification adopted by the Italian national statistical institute (ISTAT) for economic statistical surveys (the ATECO 2007 version is currently in use);
- ✓ The "Production cycle of origin", that reports the waste origin;
- ✓ The column "Name" (or Type of Waste) giving the specific waste typology.

Results and discussion

The database allows to catalogue more than 1000 users and producers of industrial by-products. A first database inspection allows to highlight that about 65% of the companies are Producers and the other are Users. Then it is evident that mainly the companies which originate by-products are interested in the possibility to find a suitable way to reuse them. Table 1 reports the companies showing their regional location.

Table 1. *Users and Producers' companies (in the database) with their Region of origin*

	Producers in all Italian regions	Users in the Italian regions	Overall
LOMBARDIA	66	58	124
PIEMONTE	83	114	197
VALLE D'AOSTA	6	0	6
VENETO	47	23	70
TRENTINO ALTO ADIGE	3	0	3
FRIULI VENEZIA GIULIA	24	3	27
EMILIA ROMAGNA	99	24	123
LIGURIA	0	0	0
UMBRIA	5	5	10
TOSCANA	55	31	86
MARCHE	29	5	34
ABRUZZO	11	9	20
MOLISE	5	2	7
LAZIO	37	3	40
BASILICATA	23	2	25
CAMPANIA	14	15	29
SARDEGNA	11	9	20
SICILIA	18	15	33
CALABRIA	17	10	27
PUGLIA	107	30	137
Overall	660	358	1018

Conclusion

The proposed database allows also to group the wastes with attention to the possibility to reuse some of them, in the frame of the industrial symbiosis strategy. As an example, it is possible to select a waste from a specific origin to verify its availability on specific area, making them available to interested users. The database allows to extract information about each single Producer, that may be directly contacted by the potential User. For example, the proposed database contains several data about biomass generated as by-products. This information may be of particular interest for companies, operating in the frame of ecological transition policy.

Indeed, it is fundamental to highlight that a fundamental research area about biomass management consists of studies aiming to verify the amount of biomass feedstock that is potentially available. However, there are no data and/or statistics about the produced quantities, the prices, or the supply methods for second generation feedstock, for several biomass wastes [2]. As an example, we have considered straw. It is an agricultural crop by-product, deriving from dry stalks of cereals and legumes after removal of the grain and chaff. Generally, straw is about half of the crop yield, making this residue one of the most abundant agricultural by-product.

Figure 2 reports the straw Producers number as evaluated from the database, considering the Italian regions.

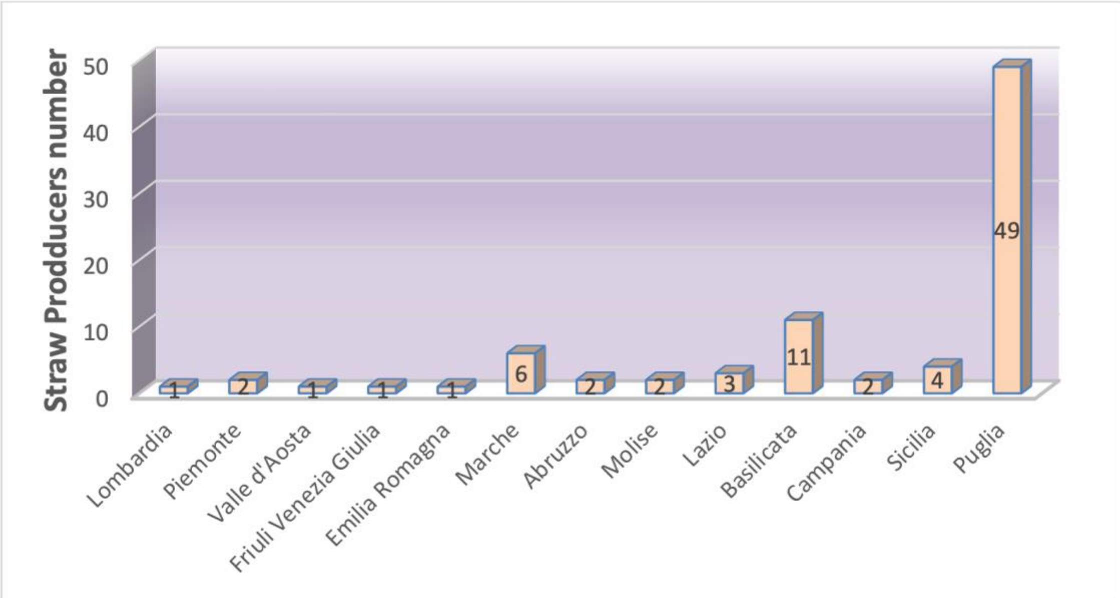

Figure 2. Straw Producers in all the Italy regions

Figure 2 highlights that straw is highly available in Puglia, where it is possible to find the largest Producer companies' number in Italy (49). This is a very interesting result, because it allows to conclude that in Puglia the interest in straw management is very high, if compared to other regions. Then Puglia is the first Italian region that may be involved in the biomass valorization strategies concerning straw.

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HYDROGEN FOR THE TRANSITION OF THE PROCESS INDUSTRY

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ABSTRACT

The main objective of the IPCEI proposal is the construction of a large-scale green hydrogen production plant through innovative technologies based on integrated solar and oxyhydrogen systems. The initiative is part of the roadmap for decarbonisation, towards a complete transition to renewable energy sources, where this initiative could represent an interesting pilot among European regions. The "Hydrogen" project aims to install 3 plants for the production of green hydrogen by contextualizing the technology in various industrial applications: the "Taranto Hydrogen Project" which will be developed to serve the former ILVA steel plant with the aim of industrial and environmental redevelopment of the area, the "Brindisi Hydrogen Project" which will be applied in the Site of National Interest for soil remediation and the "Sardinia Hydrogen Project" focused on verifying the autonomy of energy supply. In addition, the project provides for the distribution of hydrogen also in the transport and civil sectors, after requalification of the networks.

Keywords: *Green hydrogen; decarbonisation; IPCEI, transition; climate change*

Introduction

The European Hydrogen Strategy can be achieved through two integrated actions, the first aimed at stimulating the production of energy through integrated sources of green hydrogen, the second aimed at triggering the related virtuous demand process.

The first action involves the involvement of industrial sectors that support the production of green hydrogen systems based on cutting-edge research while the second action can be achieved through the involvement of identifiable "end users" in the industry (large combustion plants), transport and other key sectors. The Puglia Region with its provinces of Brindisi and Taranto has been playing a strategic role for years in the field of national energy policies, as well as in the production of steel.

Another sector of fundamental importance is that of transport where it is possible to use hydrogen in direct (oxy-hydrogen) or accumulation terms. In fact, in the last

20 years, about a third of the entire Italian coal-fired electricity capacity has been concentrated in Puglia, leading this region to produce up to 210% of its electricity needs to meet its internal consumption, which constitutes about 15 % of all Italian electricity and becoming the first region for electricity export for key economic sectors and the first for wind capacity (25%). Brindisi is the city with the highest concentration of power plants fueled by fossil sources followed by Taranto which, due to the high industrial pressure, has been declared a high environmental risk by the Italian government.

The project is an integral part of the roadmap towards decarbonisation and environmental sustainability of the entire proposing industrial chain which intends to demonstrate the efficiency of a plant for the production of green hydrogen within degraded areas where relevant industrial activities are carried out that can become the end users of the hydrogen produced.

The project idea is focused on the installation of a plant for the generation of green hydrogen from renewable sources (photovoltaic integration with alkaline and wind electrolysis), supported by various stakeholders present in the value chain at a national level with the strong collaboration of high professional skills at the border and international level.

Methods

The methodology used for the realization of the prototype is based on technical, environmental, social and economic criteria that also concern the study of the life cycle of the integrated offshore system. Therefore the project will provide demonstrative efficiency in a pilot site which aims to show the technical feasibility in a nearby operational environment that can be used for the construction of a "Plant for the production of hydrogen and oxygen from the electrolysis of water fed by renewable sources solar sources. ”The plant will be obtained by assembling various existing and tested technologies:

- Photovoltaic / wind power plant: produces all the electricity necessary for the operation of the "user" production plant; the use of energy is mainly in "self-consumption", but, to prevent the operation of all machinery only during the hours of morning and afternoon sun exposure, the presence of accumulation or withdrawal from the national electricity grid is not recommended, even if foreseen, or the differentiation of energy sources;

- Filtration and Ultrafiltration plant: filters the quantity of water arriving at the plant;
- Reverse Osmosis Plant: further refines the quantity of water treated upstream from the Filtration and Ultrafiltration Plant;
- Electrolysers: through the physical principle of water electrolysis, they produce a total volume of 222,469,410 H_2 m^3/year of hydrogen which, given the hydrogen density of 0.0899 kg/m3, can also be expressed as weight of tons / year of production, a volume of 111.234.705 m^3/year of oxygen O_2 which, considering the hydrogen density of 1.429 kg/m^3, can also be expressed in weight equal to tons/year of production.
- Pipes for water collection: pipes and collectors with which the electrolysis system is fed;
- Oxygen supply pipe: pipes and manifolds with which it is possible to convey the production of pure oxygen to interested third parties;
- Hydrogen supply line: the entire hydrogen production will be fed into a methane pipeline and transported to its destination in order to allow the end user to release less harmful and polluting emissions into the atmosphere.

Renewable and unconventional energy sources, such as solar and wind energy, even if they will remain available for an infinite period, due to their intermittent recourses, require solutions to store any excess energy produced, then storage or a solid chain of users. final, in order to be used during times of high energy demand [1, 2]. Different solutions are developed to store the excess energy produced (at full capacity or in experimental mode) such as the accumulation of compressed air energy, batteries, accumulation of flywheel energy (mechanical inertia), hydroelectric energy (accumulation of energy at pumped water), accumulation of superconducting magnetic energy, the storage of thermal energy and also the production of hydrogen and therefore the storage or injection into the natural gas network (power to gas) [3].

The concept behind the Hydrogen Project is to demonstrate in operational terms that the production and use of H_2, applied to industries with a high emission impact (steel, refineries, large combustion plants, transport), combined with the possibility of investment in innovative technologies, leads to a substantial improvement in environmental impacts.

Therefore, the hydrogen cycle integrated with solar and electrolysis from water seems to be an optimal solution since it intercepts all the "key aspects" of the Decarbonization Process (Figure 1 Project idea).

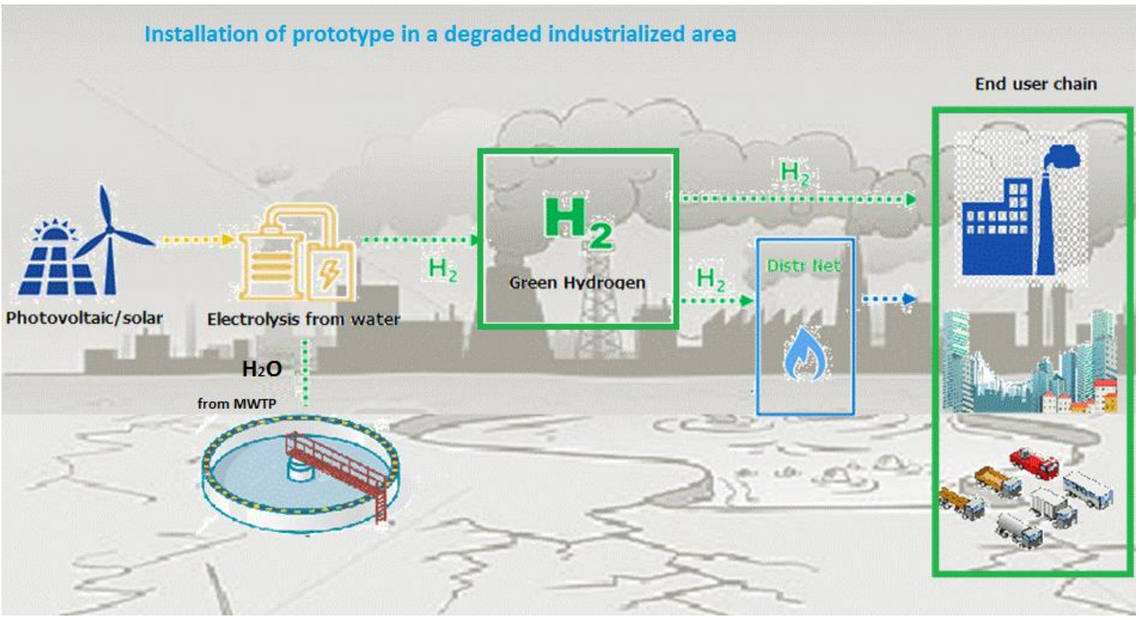

Figure 1. *Project idea*

Results

The implementation of the various green hydrogen supply chains, from supply to demand, industrialization and installation of the necessary technologies (fuel cells, electrolysers and related infrastructures) presuppose positive impacts in terms of research and development and industrial prospects, in terms of lower environmental impact, including job opportunities.

The feasibility of creating a production of "Hydrogen Valley" would give new breath to the areas of Brindisi and Taranto, which have long been classified as having a "high risk of environmental crisis" and would represent a great opportunity for growth for the area.

An environmental sustainability analysis will be carried out with the aim of evaluating and identifying opportunities to improve the environmental behavior of the green hydrogen solution on a large scale for industrial purposes, considering selected environmental indicators, which best describe the overall performance of all processes within of the value chain.

To this end, in the first place, a multi-criteria approach will be adopted for the selection of environmental indicators, adequately matching the relevant objectives that should be improved by the technologies implemented in the Hydrogen project. Particular attention will be paid to indicators such as the carbon footprint (equivalent of CO_2), acidification (equivalent of kg of SO_2), depletion of fossil resources (equivalent of kg of oil) or depletion of ozone (equivalent of kg of CFC). Secondly, an inventory analysis from a life cycle perspective (LCI) will be developed for the two valuation case studies (i.e., baseline and future scenario after project implementation) considering all the stages of the value chain, including upstream and downstream processes related to the industrial demo scenario. All partners will contribute to the collection of information for LCI, as well as reliable literature sources, industry average lifecycle data from lifecycle inventory databases, industry association reports, government statistics, or similar. Finally, the development of the impact assessment will be carried out to provide conclusions and recommendations based on the results obtained through the set of indicators and impact categories selected in an LCA perspective.

The collaboration between ENEA, Polytechnic of Bari and other public and private research bodies, will lead to the operational development of technologies in the advanced energy sector to be used in the process industry located in the territories of Brindisi and Taranto. All the results will be analyzed, described and mapped, in terms of improvement of the emission frameworks, in relation to the performance of industry and production and functional improvement in the fight against climate change.

Discussion and conclusion

The transition to a new hydrogen market is facing significant risks with regard to the overall technical and scientific knowledge of this rather new field. The project is a development phase in a period in which the current scenario of the hydrogen market is still in its infancy and the project can be considered a pioneer of the new renewable energy source. Several obstacles and risks can be defined as follows.

Economic barriers can be considered as those barriers that interfere with market penetration due to their negative impact on economic growth due to the high investment costs (CAPEX), operating costs (OPEX) and final cost of hydrogen production, which includes the generation, storage and transport of hydrogen. The absence of adequate incentive strategies and the application of tax breaks, subsidies or sanctions on conventional alternatives to encourage market uptake are of utmost importance for further relevant economic growth in the green hydrogen market. Furthermore, the enormous uncertainty caused by the lack of general information on hydrogen technology is the main barrier to accessing the financial market and the consequent implementation of financial instruments. Technical barriers are those risks related to each component and / or the process as a whole that limit the efficiency, effectiveness, reliability and safety of hydrogen. their problems are the limits to the injection of hydrogen into natural gas networks. The current permitted percentage of hydrogen blending in the natural gas network can vary from 1% to 6% in different European countries. In addition, very strict requirements must be met in terms of safety, fuel quality control and possible negative impacts on existing network components, such as turbines, compressors or end-user equipment.

Regulatory and operational barriers are those barriers resulting from an inadequate legislative and regulatory framework or lack of it that prevents, seriously hinders or extends the duration of the implementation of hydrogen projects such as classification and authorization procedures. In fact, administrative simplification is needed, in terms of minimizing regulatory and authorization uncertainty, of the energy framework to push stakeholder investments, maturing a clear responsibility for the implementation of energy solutions. Social barriers are considered to be risks related to the lack of awareness, familiarity and general acceptance of hydrogen by citizens and end users. However, many aspects have evolved in recent years, but policies and public support are still needed to strengthen hydrogen development, including dedicated strategies to ensure social acceptance by end users.

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THE INDUSTRIAL SYMBIOSIS ACTIVITIES WITHIN THE CREIAMO PROJECT. PRELIMINARY RESULTS

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ABSTRACT

The CREIAMO project aims to boost the creation of new destinations for residues originated by olive oil and wine production, new options for their economic valorization and new business models to increase the competitiveness of companies operating in the Lombardy Region. To achieve these objectives, the project operated on different eco-innovation strategies: process and product eco-innovation and systemic eco-innovation through industrial symbiosis (IS). This paper is focused on the project activities related to industrial symbiosis. Due to the pandemic, the ENEA's methodology was adapted in order to perform remotely all the activities with companies. An engagement campaign was carried out in the province of Brescia with the support of several local associations. The industrial symbiosis-working table with companies was held remotely on 19 February 2021. About 100 potential synergies 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 from the economic point of view. For these synergies, two operating manuals have been drawn up for companies that want to transform synergies from theory to practice.

Keywords: *Oil and wine residues; eco-innovation; synergies; industrial symbiosis methodology; Lombardy.*

Introduction

This article illustrates the activity carried out by ENEA (Italian Agency for New Technologies, Energy and Sustainable Economic Development) within the CREIAMO project "Circular economy in the oil and wine sectors. Valorization of by-products and residues through processes innovative and new business models ".

The CREIAMO project, funded by the Cariplo Foundation, aims to identify and promote new destinations and opportunities for economic enhancement for the by-products and waste from olive and wine supply chains, with a view to circular economy. By achieving this objective, the competitiveness of companies operating in the Lombardy Region will consequently be increased, also thanks to the creation of new business models (e.g. industrial symbiosis).

The project adopted different eco-innovation strategies:

- process and product eco-innovation. The production residues will be used for the production of bio surfactants, which, once extracted, will be used for the treatment of contaminated soils;
- system eco-innovation through the creation of a network of industrial symbiosis in Lombardy, through which companies will be able to achieve economic, environmental and social benefits.

Moreover, the project represents the first structured attempt to implement industrial symbiosis in the Lombardy region.

ENEA is responsible for implementing and promoting industrial symbiosis 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 [1;2;3]; the "Green Project - Industrial Symbiosis" in Emilia-Romagna [4;5]; and the "Industrial Park of Rieti-Cittaducale" project in Lazio [6].

The ENEA methodology used in all these projects to support companies in the realization of IS matches was adapted for the CREIAMO project to be applied in telematics mode.

Methods

The goal is to launch a structured action in the Lombardy region, with particular reference to the province of Brescia, on industrial symbiosis through the methodology developed by ENEA because of consolidated experience on industrial symbiosis issues.

The methodology includes:

- The involvement of companies from different production sectors. Production sectors heterogeneity is one of the fundamental requirements for intercepting potential synergies, even unprecedented ones;
- The organization of working groups between the companies involved as fundamental moments of comparison, knowledge and exchange of information and data. It is important to underline that ENEA had to readjust this phase, which normally involved face-to-face discussions with companies, in light of the pandemic situation, transforming face-to-face meetings into virtual work sessions.
- A phase of elaboration and systematization of the collected data in which the potential exchanges emerged during the round tables and identified ex post on the basis of the information provided are identified;
- Preparation of Operating Manuals, documents for in-depth analysis of the synergies of industrial symbiosis that analyze and describe in detail the significant synergies

that emerged during the work table and provide technical and regulatory indications for the replicability of the synergies.

- Operational meetings with companies for an in-depth study of some aspects and issues related to resources and processes.

Results

The industrial symbiosis-working table was held on February 19, 2021 in telematic mode, 22 companies attended the meeting from different production sectors (**Error! Reference source not found.**) in addition to the one directly involved in the project.
96 resources were shared, of these 24 are input resources or resources required by companies, and instead 72 are output resources that are offered for sharing, they are waste, by-products or surpluses (**Error! Reference source not found.**).
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 working groups, which envisaged intermediate treatments of the resources made available (**Error! Reference source not found.**).

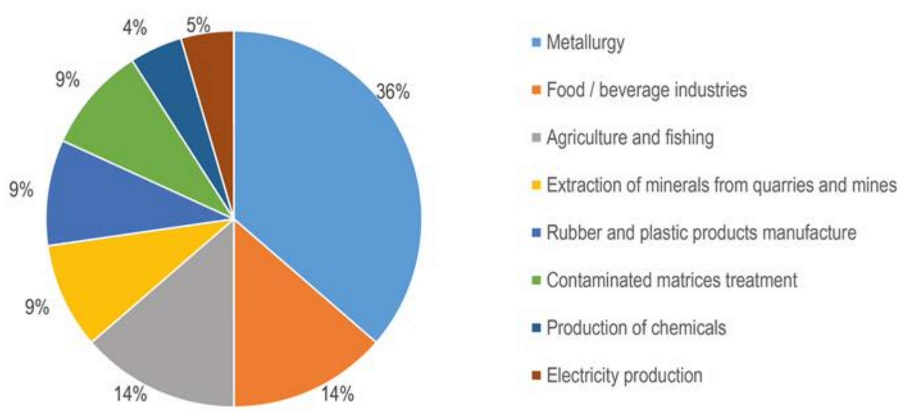

Figure 1. *Production sectors of the 22 companies that participated at the industrial symbiosis-working table. (ENEA elaboration)*

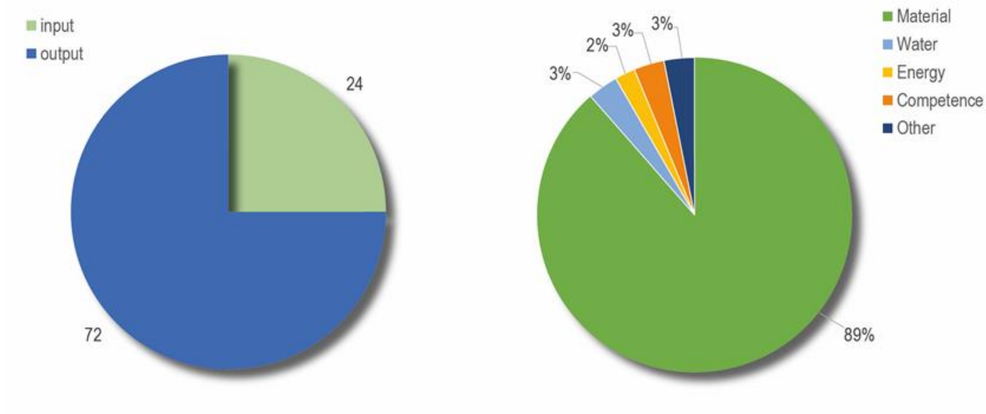

Figure 2. *Shared resources (ENEA elaboration)*

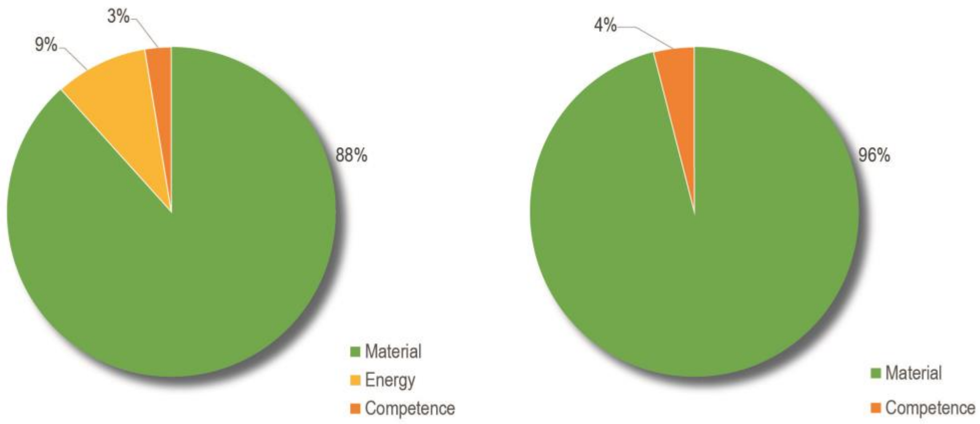

Figure 3. *Synergies emerged during the work table (ENEA elaboration)*

Following the work table activity, thanks to the contribution of Confindustria Brescia, the resources database was integrated with information on companies that were unable to participate. The identification of new potential synergies and the drafting of an Individual Report for each company followed this phase. The document contains a summary of the shared and requested resources and a description of the potential synergies identified.

A further phase of investigation led to the identification of the most significant resource flows both from a quantitative and qualitative point of view. These flows have been described and detailed in two Operating Manuals:

- Operating Manual on the synergies identified for organic resources, i.e. waste from olive oil and wine productive process, in particular olive and grape pomace and vegetation waters (**Error! Reference source not found.**). In this manual, three flows of organic resources have been studied starting from waste from the companies involved:

1. Olive pomace, produced by three different farms with the possibility of being enhanced:
    - 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.
2. Oil vegetation waters, 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.
3. Grape pomace, output classified as by-products from two different farms with the possibility of being valorised:
    - 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.

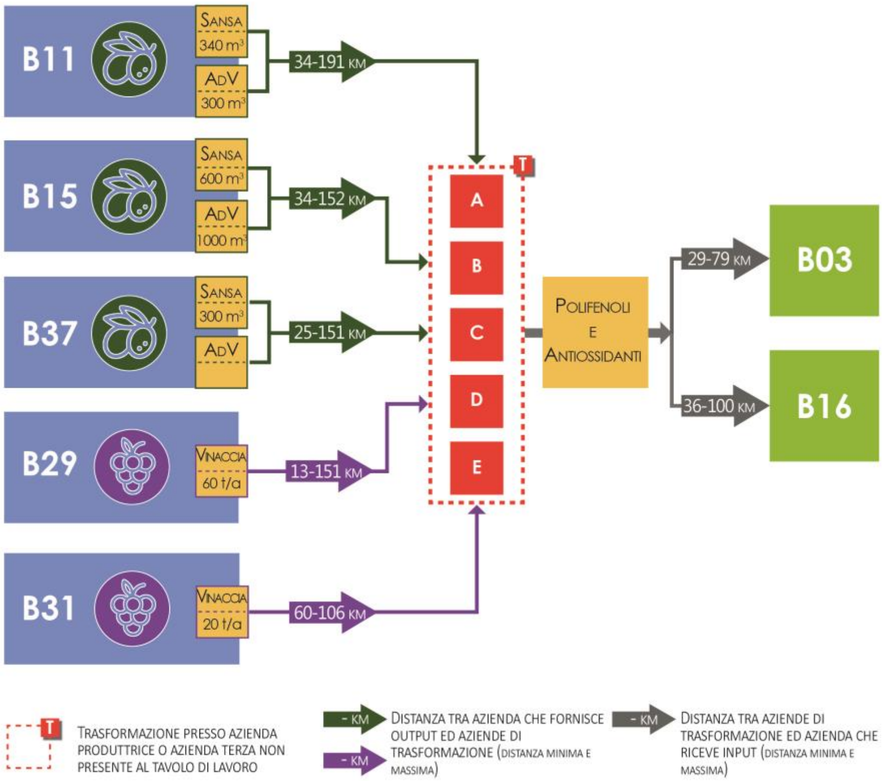

Figure 4. *Example of a synergy diagram (layout) for the enhancement of organic resources (ENEA elaboration)*

- Operating Manual 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 (**Error! Reference source not found.**). In this manual, two streams of inorganic resources have been studied in particular, starting from waste from the companies involved:
    1. 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;
    2. Plastic waste in the form of flakes and powders from a food packaging production company and intended for steel companies such as S.R.A. (Secondary Reducing Agent) for use in blast furnaces as a reducing agent in the oxidation reactions of ferrous minerals to replace Coke.
    3. Post-consumer plastic waste for use in the steel industry for the same purposes.

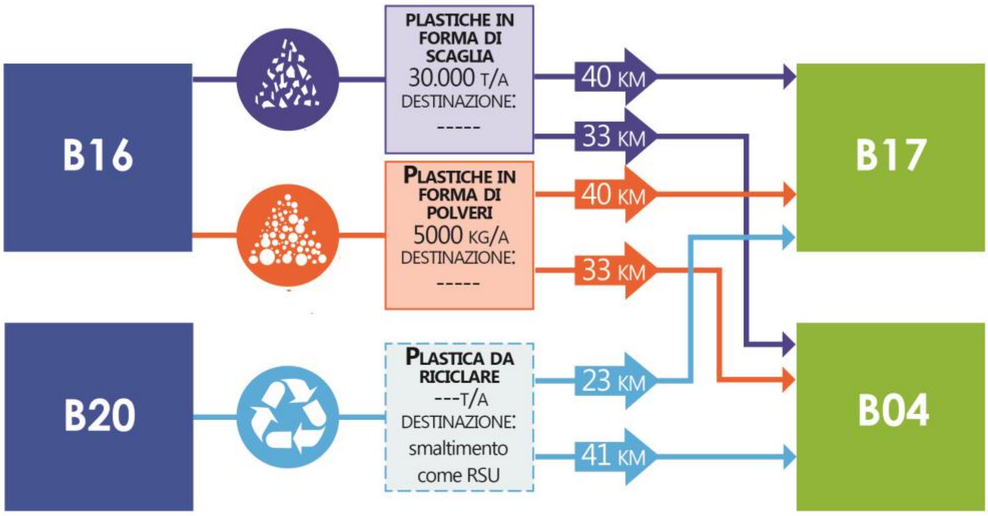

Figure 5. *Example of synergy diagram (layout) for the enhancement of inorganic resources (ENEA elaboration)*

Operating Manuals are documents in which all the technical and regulatory information relating to the synergies under consideration converge. Are composed of two parts:

- The first part shows the scheme of synergies that emerged from the analysis of the data shared at the working table and from the subsequent in-depth study of the data (**Error! Reference source not found.** and **Error! Reference source not found.**). This part briefly summarizes the path of the synergy identified through a layout, a geographical classification of the companies involved (**Error! Reference source not found.**) with the relative mutual distances and a synoptic framework for each resource (**Error! Reference source not found.**), accompanied by a table that lists the specific aspects to be taken into consideration for each phase of the path. : Regulations; Technical standards; Logistic aspects; Economic aspects; other relevant aspects;
- The second part of the manual (technical file) deals in detail with regulations, technical standards and the characteristics of waste and production processes for their enhancement.

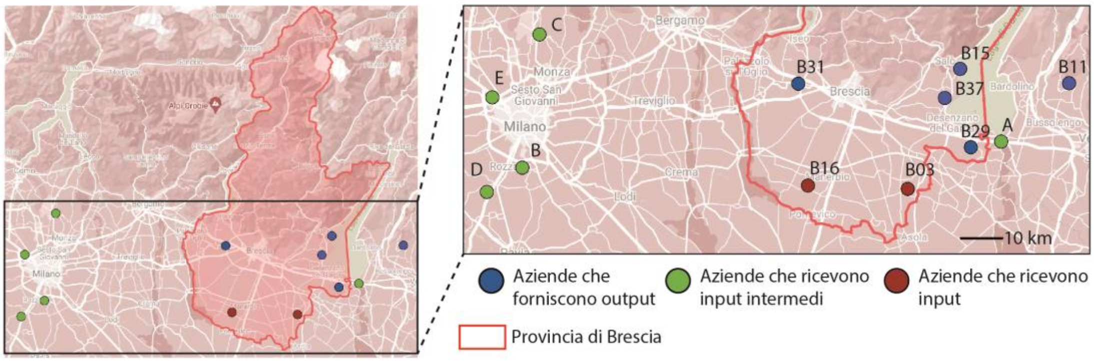

Figure 6. *Example of geolocation of the industries involved in the synergies (ENEA elaboration)*

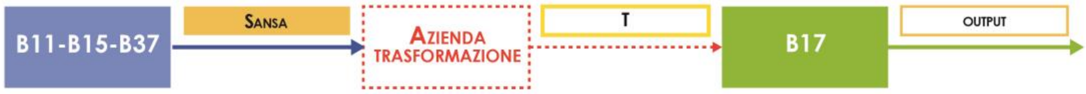

Figure 7. *Example of a synoptic diagram relating to each process of enhancement of the resources considered (ENEA elaboration)*

Discussion and conclusion

Activities related to industrial symbiosis are currently underway as part of the Creiamo project. In this phase, the companies are actively involved in sharing information relating to the potential synergies identified by ENEA in the operating manuals. In particular, ENEA is collaborating with interested companies and potential stakeholders in order to validate the solutions outlined for the enhancement of the resources involved. This in order to assess the real feasibility of the synergies identified and the potential barriers that could hinder their implementation.

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Industry 4.0 and Industrial Symbiosis: An Overview

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ABSTRACT

The article, through a literature review, aims to investigate the current areas of interaction between the studies concerning Industrial Symbiosis and the Industry 4.0 technologies in order to highlight opportunities, criticalities and potential developments.

Keywords**:** *Industrial Symbiosis; Industry 4.0; Automation; Automatic control; Blockchain*

Introduction

Nowadays, in Industrial Symbiosis (IS) studies [1], the availability of data quality and information is increasingly recognized for the methodological and application development of these approaches, a quality that is strictly connected to the characteristics of the data themselves (e.g. reliability, accuracy, availability, timeliness). Therefore, the use of information technologies for the detection, collection and analysis of data finds more and more space in order to propose increasingly effective solutions, in the different application contexts, from micro (products, processes, single companies), to meso (supply chains, cluster, network) and macro ones (territorial systems, regions). Industry 4.0 was born as a framework characterized by the widespread application of new production technologies (automation and computerization) to improve plants productivity and, above all, to increase the level of interaction and integration among the various parts of the production system. In the framework of Industry 4.0, the concept of sustainability plays an important role. It is understood in the three typical dimensions, namely environmental, economic and social, and it can be reached thanks to a synergy among them. In the context of IS, the enabling technologies of Industry 4.0, in addition to the undeniable benefits connected to the collection and sharing of data (made possible, for example, through input-output analysis, or matching tools) are studied in relation to the environmental effects of advanced forms of interaction (collaborative data sharing, social networking) up to holonic-virtual systems.

Methods

The method used in the present research consists of two phases. The first is represented by a bibliographic analysis conducted in a time range from 2000 to 2021, chosen to verify the industrial developments of the new millennium, using Discovery [2], JStore [3], ResearchGate [4] and Scopus [5], as databases for scientific articles. The research was aimed at identifying a link between the concept of IS and some areas related to the Industry 4.0 framework, summarized by the following keywords: *Agent Based Modelling (ABS); Algorithms; Artificial Intelligence; Association-Rule Mining; Automatic Control; Automation; Big Data; Blockchain; Computer Networking; Enabling Technologies; ICT; Industry 4.0; Input-Output Data; Java Application; Machine Learning; Online Platform; Programming; Software; Urban-Industrial Symbiosis; Web Service.* From this search, 143 articles were obtained. In a second phase, following a selection and refinement operation through titles, abstracts and keywords, it was decided to investigate those articles that highlighted a link between IS and, respectively, Industry 4.0, Automation, Automatic Control and Blockchain to understand what are the links existing among the areas defined by the selected keywords and the development of IS solutions (if any).

Results

A total of 12 articles emerged from the literature overview (published in a period ranging from 2016 to 2021), revealing the existence of a relationship between the general field of Industry 4.0 and IS. In the article by Germani et al. (2020) [6], it is clear that, in an industrial context, it is necessary to optimize and stimulate the collaboration between internal and external resources such as material, energy and human ones, according to the paradigm of Industry 4.0, whilst respecting the constraints of sustainability pillars. The best answer is identified in the implementation of IS approaches, as these can operate as a primary engine and driver for the development of Circular Economy in an Industry 4.0 perspective. The sharing of resources among different companies and the integration of information along the entire value chain - from supplier to consumer- are, indeed, considered the pillars for the development of Industry 4.0 [7]. In the contribution of Naderi et al. (2019) [8], a sustainability and economic efficiency index for a production line or process is presented, which allows small and medium-sized enterprises (SMEs) and other companies to make decisions that can improve economic efficiency, reduce environmental impacts and increase the positive social return of some production strategies. The use of this index aims to facilitate changes in the structure of production systems in order to implement the paradigms of Industry 4.0 through facilitating technologies such as simulation and virtual reality, applied to studies of economic, social and environmental impacts in the organization, promoting strategies and alternatives in the production chains able to minimize and/or mitigate environmental and occupational risks, and to encourage IS solutions or the birth of eco-industry networks to increase eco-efficiency and the positive social return linked to the functioning of production systems. A further result of the analysis carried out highlighted the existence of a production line simulation software named Norlean Analyzer Operation (NOA) [9], which offers the user a virtual replica of a factory, a machine or of a process starting from the analysis of a large amount of production data that are converted into statistical models. The algorithms that define the production model are then built, linked to the income statement, and the complete business model of an industrial company is created. The goal is to convert Big Data into intelligent data capable of providing useful information for the decision-making process, in order to obtain a reliable forecast of the functioning of a Sustainable Manufacturing System (SMS) and its social return (SR).

In addition, other sub-fields, within Industry 4.0 framework, highlighted potential interactions with IS studies:

Automation - Among the articles collected, 15 highlight a link between the keyword IS and Automation. A positive example of the use of automated solutions capable of contributing to improve the environmental performance of companies is the MAESTRI Total Efficiency Framework (MTEF) [10]. As part of a EU-funded collaborative project, currently under development, its objective is the sustainable improvement of the environmental and economic performance of industrial companies by providing a holistic platform as a management system that allows an overall performance assessment of environmental efficiency performance (related to material and energy resources), of value and costs through a life cycle perspective. MTEF uses a middleware platform that facilitates automation in the transfer of data from machines, systems and sensors present in industrial sites, to tools and software applications of the end user. It allows to seamlessly interconnect heterogeneous devices, systems and subsystems in order to achieve a higher degree of interactions among the company, management systems and end users. The MTEF is based on four pillars: 1) an effective management system aimed at the continuous improvement of processes; 2) efficiency evaluation tools to support improvements, optimization strategies and support to decision-makers, clearly evaluating the use of resources and energy of all the elementary flows of the process and eco-efficiency performance; 3) the IS paradigm for obtaining value from waste and energy exchange; 4) an Internet of Things (IoT) and automated infrastructure to support easy integration and better data exchange between business systems and tools. This tool will be able to support and assist companies wishing to commit to implementing IS in their business.

Automatic Control - In the case of the relationship between IS and Automatic Control, the research conducted produced a single result, that is the contribution of Gao et al. (2018) [11]. In this article, the concept of Automatic Control allows for further consideration in the implementation of IS solutions, and takes on the role of "regulator". The authors propose a methodology to evaluate the "disturbance" effects (external factors, for example related to collaborative relationships, technological factors, etc.) on the vulnerability of Eco-Industrial Parks (EIP) and, specifically, it is based on the theory of the Automatic Control applied to the case study of Guigang EIP (China), through the simulation performed by using Simulink software [12]. The results of the simulation provide information to support the design and decision-makers, in the planning choices of the IS: firstly, the company in the front-end (key enterprise) of the ecological industrial chain is the most important, because it is the one that mostly influences the stability of the system, using and transporting the most of the material and energy flows inside the EIP. This result leads the authors to affirm the need to build the EIP around key companies, so as to improve the stability of the system. It emerges that if the "disturbance" is located outside the system and close to the "key company", the impacts is more relevant; the disturbances applied in the central position had a less significant impact at the level of the whole EIP. Furthermore, when the disturbance persists at the end of an ecological industrial chain, the impact on the vulnerability of the entire system is lower.

Blockchain - Research evidenced two articles that highlight the potential role of Blockchain in the development of IS solutions. Blockchain (core technology for cryptocurrency) is capable of transforming supply chains in a variety of industries, has the potential to be applied in product and component labeling to enable waste collection, sorting, management and reuse after use. It provides an automatically updated public record of all transactions that have occurred among the parties. The technology, if applied to IS solutions, aims to address issues of trust and transparency among the parties, favoring the dissemination of information in order to define: i) which flows are involved; ii) what is the chemical composition of these flows and whether this composition is compatible with current production processes; iii) what are the transportation needs and potential costs. However, the information that answers these questions is confidential and access to data in the value chain is limited: this represents the main obstacle to the connection among companies. In this direction, interesting is the example of Bext360 [13], a start-up that uses Blockchain, Artificial Intelligence and IoT to digitalize global commodity supply chains, disseminate sustainable practices for communities, consumers and the environment, and simplify buying and selling operations of coffee in wholesale markets and make the coffee supply chain fair and transparent. Coffee farmers harvest the beans which are placed in a BextMachin, which uses Artificial Intelligence and sensors to analyze and classify them according to quality standards. The Blockchain instantly tracks and monitors which farm and which farmer should be paid and how much, via a mobile application. Transactions recorded on Blockchain provide the data to solve supply chain inefficiencies, increase compensation to farmers and enable consumers to understand where their products come from. The use of Blockchain technology increases transparency, reduces transaction costs for verification and certification, guarantees more reliable contracts and fair payments along the value chain. Another example is a Flemish government agency [14] which has developed a digital matchmaking platform in which different actors offer/receive waste or by-products streams, thanks to which companies are able to identify information on products, on their chemical composition, on the quantities offered and on the continuity of waste flows (one-off or continuous). The platform offers a gradual privacy setting, whereby companies can decide which information to make visible and at what levels.

Conclusions

The reduction of waste emissions and the use of primary resources in material-intensive industries is considered as one of the most critical and promising paths to accelerate Sustainable Development. The European Union recognizes the IS as one of the main tools to achieve this goal, as it is able to stimulate different companies to collaborate in an environmental sustainability and Circular Economy perspective. The research conducted has highlighted how IS solutions can be favored in highly digitized and automated contexts. The current challenge for companies is linked to overcoming the barriers related to communication and collaboration through the sharing of information and resources, capable of fostering integration, at the same time, favoring the development of IS solutions. In a context of high technological development such as that represented by Industry 4.0, operators are driven to specialize in new and different functions compared to the past, to "dialogue" with machines and complex systems, and to collaborate with them. Therefore, only through an effective and integrated management of these aspects, it will be possible to guarantee the maximum productivity of the factory and the quality of the finished products, and to ensure productivity, efficiency and sustainability in a context of Industry 4.0 and Circular Economy.

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WHAT HAMPERS THE IMPLEMENTATION OF INDUSTRIAL SYMBIOSIS ON A LARGE SCALE IN ITALY?

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ABSTRACT

This paper is aimed at highlighting the main barriers that hamper Italian small and medium enterprises from implementing the industrial symbiosis practice. Semi-structured interviews have been conducted with top managers of 10 Italian small and medium enterprises. The barriers mentioned by managers have been categorized according to the three IS phases, i.e., willingness, assessment, and implementation. Based on the results, several implications and policy actions are suggested.

Keywords*: Industrial symbiosis; barriers; semi-structured interview; small and medium enterprise.*

Introduction

Although industrial symbiosis (IS) is widely claimed to potentially enhance the efficiency of production systems [1], creating economic [2] and environmental [3] benefits simultaneously – supported by several success cases around the world [4,5] – the number of companies known to adopt such practice is still too low [6]. The literature has conducted several studies aimed at highlighting the barriers hindering the implementation of IS [7,8] and at suggesting policy actions to overcome them [9,10]. Nevertheless, there are no studies specific to the Italian case.

This paper is aimed at filling this gap by highlighting what hampers the implementation of IS on a large scale in Italy, with a particular focus on small and medium enterprises (SMEs), which are currently more than 50% of companies in Italy. The paper is organized as follows: Section 2 presents the methodology, Section 3 addresses the results, and Section 4 is devoted to discussion and conclusions.

Methods

The research considered a sample of 10 companies, selected because they are known to adopt circular economy practices, mentioned by the "100 Italian Circular Economy Stories" report [11]. Companies have been selected so that all the three main geographic areas of the country (i.e., Northern, Center, and Southern Italy) are represented. For each company, a semi-structured interview has been conducted with a top manager, aimed at collecting information on the following topics: (1) the business model adopted by the company; (2) the extent to which the main concepts of IS are known inside the company; (3) past projects, even failed, aimed at implementing IS; and (4) which barriers to IS implementation have been encountered (in case the company had already conducted at least one IS project) or are perceived to exist (in case the company did not already conduct IS projects). All the interviews have been recorded and transcribed.

Results

Figure 1 displays the results coming from the interviews. Barriers have been categorized according to the three phases of IS, i.e., the willingness to adopt such practice, the assessment of potential benefits, and the implementation of the IS project. In the following subsections, the barriers found are presented.

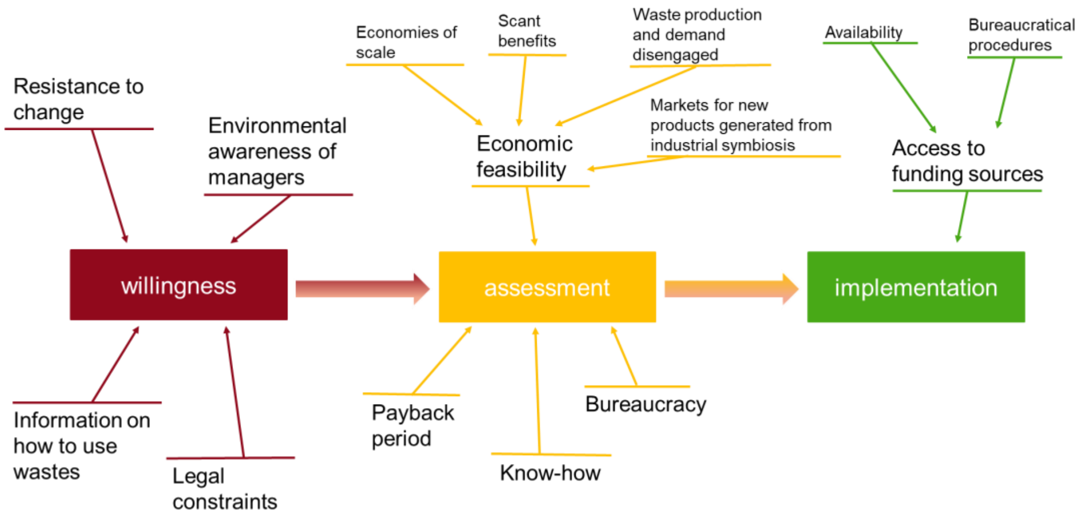

Figure 1. *Barriers hampering the industrial symbiosis phases (willingness, assessment, implementation).*

Willingness to explore industrial symbiosis

Several barriers were found to hamper the willingness of companies to explore IS.

A first barrier concerns the resistance to change. Introducing IS into the company business model usually requires the introduction of new routines and practices, and potentially even the update of the existing ones. In this regard, companies with high resistance to change are usually less willing to explore IS opportunities. Another important factor that impacts on the willingness to implement IS is the environmental awareness of managers. Although the literature highlights that the main driver towards IS is the chance to gain economic benefits from the symbiotic practice [12], managers with low awareness of the environmental problems seem to be less prone to explore IS. From the technical perspective, the lack of information about how to use wastes makes IS opportunities unknown to companies. Finally, there are some constraints, from the legal perspective, that affect the willingness of companies towards IS. IS relationships might require specific authorizations to be implemented, which might be long and expensive for companies to obtain.

Assessment of industrial symbiosis opportunities

According to the results from the interviews, the economic feasibility is the most important barrier in the assessment phase of IS, obstructing the shift to the implementation phase. Accordingly, some IS projects are unfeasible from the economic perspective or the economic benefits are considered not enough by companies. The low economic feasibility (or even the economic unfeasibility) is due, in turn, to several issues. First, one-to-one IS relationships might involve low quantities of wastes, which are not enough to fully exploit the economies of scale. Accordingly, the additional costs required to treat wastes before they can be used as inputs, as well as the logistic costs, are not minimized and these costs erode the potential economic benefits for companies. One issue that contributes to exacerbating this problem is the decoupling between waste production and waste demand, which is a problem largely discussed in the literature [13,14]. Indeed, such a decoupling further reduces the quantity of wastes that can be exchanged in IS relationships, thus hindering the optimization of the operations required for IS. An additional barrier arises for those companies which generate new products through IS – readers interested to deepen such an IS business model are referred to Albino and Fraccascia [15]: the market could be not ready enough for these products, which therefore register a low market demand.

Unfortunately, the economic feasibility is not the only barrier arising from the assessment of IS. In this regard, results from the interviews highlighted that the investments required to start IS projects might be characterized by high payback periods, which play an important role in discouraging the companies. Indeed, companies might want to prefer investing in other projects, characterized by lower payback periods. This issue is of key importance for SMEs, which might have limited capital to invest. A further barrier towards IS is the access to the know-how required to implement and manage IS projects, from both the technical and operational points of view. SMEs might not have such know-how internally, thus being forced to achieve it outside the company, which requires additional costs – that, in turn, erode the potential economic benefits from IS. Finally, the bureaucracy (i.e., the procedures required to activate and operate the IS relationships) is again perceived as a strong barrier.

Implementation of industrial symbiosis projects

Concerning the implementation of IS projects, almost all the companies mentioned the access to funding sources as a strong barrier. The access to funding sources can be obstructed by two issues: (1) the limited availability of funding sources, due to a scant number of competitive bidding processes or a limited amount of money destined to each of them; and (2) the difficulty to take part in the competitive bidding process, due to the bureaucratical procedures required for the access.

Discussion and conclusions

This research was aimed at highlighting the main barriers perceived and experienced by Italian SMEs concerning the adoption of the IS practice. These barriers hinder the phases of willingness, assessment, and implementation of IS. Several elements for discussion can be highlighted here.

First, the lack of information about the potential usage of wastes could be overcome by making ad-hoc databases available to companies, created by reviewing the IS projects described in the literature, as well as all the other success cases of IS. The problems related to the economic feasibility could be mitigated by encouraging the transition from one-to-one IS relationships to IS networks, where the high number and heterogeneity of the involved companies might favor higher quantities of wastes available to be exchanged, as well as can mitigate the negative effects due to the disengagement between demand and supply of wastes. Concerning the new products made through IS, further studies are required in order to investigate the consumers' acceptance of these new products, as well as to highlight the determinants impacting on the willingness to buy them. Finally, several policy measures can be suggested to highlight the above-mentioned barriers, such as providing financial and bureaucratical support to companies that (explore to) implement IS and make easier the bureaucratical procedures required to implement IS and take part in competitive bidding processes.

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BLOCKCHAIN TECHNOLOGY TO DRIVE INDUSTRIAL SYMBIOSIS WITHIN CIRCULAR SUPPLY CHAIN MANAGEMENT

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ABSTRACT

Over the past few years, digital technologies created new opportunities to tackle sustainability challenges. The strategic management of supply chains is essential to close the loop among production, consumption and waste valorization echelons. This requires a strong correlation, integration and collaboration among the involved entities. Blockchain technology could have the potential to spread Circular Economy (CE) principles within green supply chain, allowing to track tangible and intangible assets within a peer-to-peer network. In particular, this working paper explores whether a blockchain platform can be implemented into an Industrial Symbiosis (IS) context. A methodological framework is presented including all the synergies that the blockchain technology can boost for a consistent data flow along the supply chain. Preliminary discussions from the field are proposed, also, together with existing constraints and a roadmap for the future steps.

keywords: *Industrial symbiosis; blockchain; circular supply chain; sustainable economy; waste valorization.*

Introduction

In the last decades, digital technologies are creating new opportunities to tackle sustainability issues, encouraging companies and final users to move towards Circular Economy (CE). In this context, it is essential to find solutions that allow reducing the negative consequences on the environment without jeopardizing economic aspects [1]. Industrial Symbiosis (IS) rises as an emerging paradigm and suitable option [2]. To pursue the goal of redirecting waste and by-products of a company as inputs for other businesses, a key issue to face is the matching of resources of all the entities taking part to the supply chain network, the managing of relationships among stakeholders and the mapping of material flows along the system [3]. Advanced solutions to manage the flow of information is essential to guarantee a smooth interconnection among the supply chain entities. Blockchain is a viable enabling technology to manage distributed and complex informative systems with multiple origins and destinations of the data flow. A blockchain is a distributed ledger where data are shared on a peer-to-peer network. Once a new transaction is recorded on the system, it builds a block that is linked to the others, creating a chain. Blockchain technology became popular after the 2008 financial crisis and through the development of cryptocurrency and Bitcoins [4]. Although the primary application was in the financial sector, the features of blockchain inspired several sectors, including supply chain management [5]. Blockchain provides several improvements regarding the traceability and transparency of data. This is a crucial issue for both IS and supply chain management. Since it uses a distributed public general ledger, blockchain is a useful way to manage supply chain informative flows. This technology is helpful because it decreases human errors, reduces information asymmetries, eliminates fraudulent activities, improves reliability throughout the chain, tracks products and related information and increases consumer and supplier trust [6].

This working paper aims at establishing whether and how blockchain technology can support IS to strengthen circular supply chains. The goal is to provide an updated review of both IS and the blockchain technology as a starting point to preliminary set a two-step methodological framework, i.e. conceptual and operative, including all the entities and win-win synergies that the blockchain technology can enhance for a consistent data flow.

The paper is organized as follows: Section 2 presents the aforementioned two-step methodological framework, Section 3 raises preliminary discussions about the state-of-the-art, while the last Section 4 concludes this working paper outlining the next research steps.

A two-step methodological framework

This section proposes a methodological framework made of two steps supporting the decision of integrating a blockchain platform into IS networks. The first step deals with a conceptual scheme including five branches, i.e. technological, economic, social, environmental, and legislative, to offer a logical pattern guiding practitioners in applying blockchain technology in CE networks. The second step starts from the outputs of step one presenting a more operative approach and a potential “to-be scenario” in case of blockchain will be effectively implemented within IS networks.

First step: conceptual framework

The conceptual framework considers the abovementioned five branches of assessment. Each branch has different factors to consider and related tools, KPIs and benchmarks for evaluating the feasibility to introduce blockchain technology into an IS network.

Alongside qualitative aspects, few quantitative techniques have been included for a holistic problem evaluation. The diagram in Figure 1 represents the main elements to consider. In the middle of the chart, a hypothetical network of firms, i.e. the IS system connected by blockchain technology, is exemplified to represent its compliance to technological, economic, social, environmental and legislative branches.

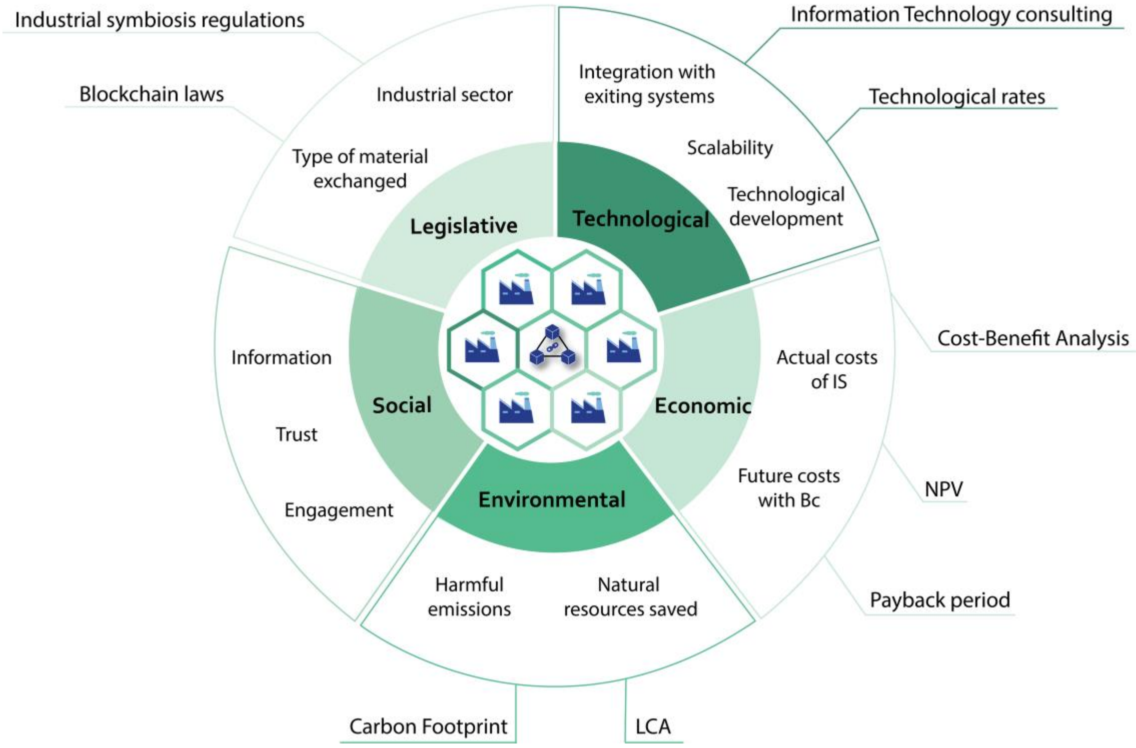

Figure 1. *Conceptual framework for a feasibility study to introduce blockchain technology into IS networks*

Second step: operative framework

Following the conceptual scheme, after collecting outputs from the feasibility study, an operative layout is suggested to link an IS network and a blockchain system, presenting a possible reference configuration. To develop the framework, the analogies between IS and blockchain technology are highlighted. They can both be considered as networks, ecosystems and platforms. Blockchain is a distributed peer-to-peer network where data are stored and shared among participants, while IS is a network of companies where resources can be traded through the support of a digital platform, following CE principles. They are both characterized by the presence of actors which collaborate for the development of an ecosystem and for the creation of synergies. The following framework assumes that blockchain technology can be beneficial as a link between supply chains, by endorsing the end-of-line of one company and the beginning of another (Figure 2). Two manufacturing companies can share data about their input needs and waste or by-products that they want to dismiss through a blockchain platform. Waste generated from an end-of-line of a company is delivered to another company, which utilizes it as an input. Smart contracts are an essential tool to mediating relationships between different organizations and their execution can simplify the approval from multiple actors of the digital agreements. Another element introduced within the new system is an incentivization mechanism through digital tokens. When business waste is transmitted to another company instead of a landfill, a token is awarded to both supply and demand sides. This tool is fundamental for incentivizing parties to create synergies with the available resources and enhancing their engagement into the IS network.

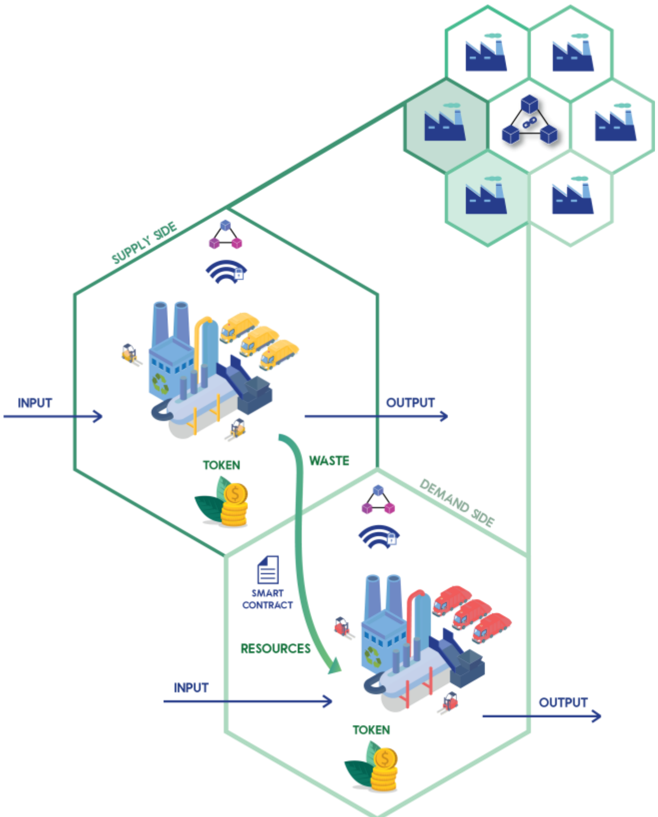

Figure 2. *Operative framework for a blockchain-based IS network.*

Discussion

The literature is starting to investigate the use of blockchains in IS contexts. Several issues are still open [7], e.g. the most of digital platforms are not available to public, the lack of information infrastructures, the insufficiency of functional support, procedural and technical difficulties in heterogeneous data collection and storage, the lack of willingness, trust and cooperation among companies, difficulties in customizing digital solutions to case studies, etc. In this context, the introduction of the blockchain technology could be a chance to overcome IS coordination problems rising when the number of firms is high and it helps to automate tasks that are currently performed by human operators, subject to errors. Blockchain allows information exchange and transparency reinforcing trust among individuals who participate to the IS network. Several research efforts highlight the potential of blockchain technology in greening supply chain CE models, but the existing literature refers, only, few actual real cases that link blockchain technology to IS. The gap between the wide range of academic literature dedicated to blockchain technology and the few studies about practical applications is an urgent lack to cover, especially regarding blockchain and sustainability. The need of experimental evidences about sustainable advantages that blockchain technology offers, the optimization of CE networks through digital technologies and studies regarding methodologies for integrating IS and blockchains are good examples of research needs that deserve immediate attention [8].

Conclusions

Blockchain is a potential and powerful technology to strengthen Industrial Symbiosis (IS) in the modern hyper-connected and real-time industrial context. Its potential is discussed in this working paper and integrated into a two-step methodological framework supporting decision makers and institutions in the design and management of circular supply chains. The conceptual framework stresses five branches of assessment, i.e. technological, economic, social, environmental and legislative, while the next operative framework encourages the goal of setting up synergies among the supply chain nodes in the direction of Circular Economy (CE), waste and by-product valorization. Despite good basis for the wide acceptance of the IS concept already exists at the institutional level, lot of steps are required to create commitment among the operative actors to push them into the concept and to stress the benefit they can gain. These challenges, together with quantitative methods and multi-target approaches to quantify opportunities for all the stakeholders are among the expected next steps of this work.

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A PRELIMINARY BI-OBJECTIVE MODEL TO ENHANCE INDUSTRIAL SYMBIOSIS AT THE LOCAL SCALE

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ABSTRACT

Industrial Symbiosis (IS) sets networks of entities where by-products and waste from one entity, or company, are redirected to other industrial processes becoming secondary raw resources, from a Circular Economy (CE) perspective. Resources are not only materials, but also energy, services and expertise. In this way, economic, environmental and social benefits become possible. The literature lacks of analytic models addressing this topic, finding potential synergies among input and output companies, coordinating the network and mapping the physical and informative flows. This working paper introduces a preliminary bi-objective model to enhance IS networks at the local scale by minimising costs and environmental impacts.

Keywords*: Industrial symbiosis; bi-objective optimisation; waste valorisation; by-products.*

Introduction

The increasing awareness to environmental issues encourages companies and individuals to move towards green economy, as a reference model that aims not only to economic benefits but also to the environmental sustainability [1]. In this context, Industrial Symbiosis (IS) gains value towards Circular Economy (CE) goals. IS has been defined as the engagement of distinct entities in a system where materials, energy, water, service and by-products are exchanged among the participants of the network, reducing waste and extending the life cycle of each product [2]. In this way, by-products and outputs of an entity become potential inputs and secondary raw materials for another industrial process. By linking companies and creating relationships, economic, environmental and social benefits are achieved, avoiding the waste disposal and the consumption of new primary resources. High challenges and barriers exist when starting implementing IS, regarding legislative, technical, economic and social aspects. The role of the enablers, as the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) for the Italian context, is crucial to find synergies among local companies matching their input-output resources [3]. Additionally, the support of reference models and operative tools to predict the IS impact is useful for the effective implementation of new IS paths at the local scale. The goal of this working paper is to present a preliminary bi-objective model to enhance local IS networks, looking for those synergies that minimise costs and environmental impacts. The paper is organised as follows: Section 2 focuses on the model formulation, Section 3 describes the model debugging, while the last Section 4 outlines conclusions and future research steps.

Bi-objective model formulation

Linear programming is behind the proposed model formulation. Two objective functions are to be minimised: the former involves IS network costs, the latter deals with the environmental impacts. The following notations are introduced.

- **Indices**

i	input companies receiving resources, $i = 1, \dots, m$
k	resources and by-products, $k = 1, \dots, l$
o	output companies sharing resources, $o = 1, \dots, n$

Figure 1: *Indices*

- **Parameters**

Table 1. *Parameters*

$\boldsymbol{C^k}$	**vehicle capacity for resource k $[unit/travel]$**	$\boldsymbol{H_P^k}$	**water intensity to produce resource k $[m^3/unit]$**
C_A^k	purchase cost of resource k $[€/unit]$	H_S^k	water intensity to dispose resource k $[m^3/unit]$
C_D^k	transportation cost of resource k $[€/km]$	H_T^k	water intensity to transform resource k $[m^3/unit]$
C_S^k	disposal cost of resource k $[€/unit]$	M	big M
C_T^k	transformation cost of resource k $[€/unit]$	m_{oi}^k	1 if company o can exchange with company i resource k; 0 otherwise
D_i^k	demand of resource k by company i $[unit/year]$	M_P^k	carbon footprint to produce resource k $[kg\ CO_2\ eq./unit]$
D_{oi}	distance between companies o and i $[km/travel]$	M_S^k	carbon footprint to dispose resource k $[kg\ CO_2\ eq./unit]$
E_P^k	energy intensity to produce resource k $[kWh/unit]$	M_T^k	carbon footprint to transform resource k $[kg\ CO_2\ eq./unit]$
E_S^k	energy intensity to dispose resource k $[kWh/unit]$	P_o^k	annual production of resource k by company o $[unit/year]$
E_T^k	energy intensity to transform resource k $[kWh/unit]$	w_E	energy carbon footprint $[kg\ CO_2\ eq./kWh]$

C^k	**vehicle capacity for resource k** $[unit/travel]$	H_P^k	**water intensity to produce resource k** $[m^3/unit]$
F_{oi}^k	fix cost for IS path between companies o and i for k $[€/year]$	w_H	water carbon footprint $[kg\ CO_2\ eq./m^3]$

- **Decisional variables**

q_{oi}^k	amount of resource k exchanged between companies o and i $[unit/year]$
y_{oi}^k	1 if the IS path between companies o and i to exchange the resource k is chosen; 0 otherwise

- **Objective functions**

$$min\ \{\varphi^C, \varphi^S\} \qquad (1)$$

$$\varphi^C = \sum_{k=1}^{l}\sum_{o=1}^{n}\sum_{i=1}^{m} y_{oi}^k \cdot F_{oi}^k + \frac{q_{oi}^k}{C^k} \cdot D_{oi} \cdot C_D^k + q_{oi}^k \cdot C_T^k \qquad (2.1)$$

$$+ \sum_{k=1}^{l}\sum_{i=1}^{m}(D_i^k - \sum_{o=1}^{n} q_{oi}^k) \cdot C_A^k \qquad (2.2)$$

$$+ \sum_{k=1}^{l}\sum_{o=1}^{n}(P_o^k - \sum_{i=1}^{m} q_{oi}^k) \cdot C_S^k \qquad (2.3)$$

$$\varphi^S = \sum_{k=1}^{l}\sum_{o=1}^{n}\sum_{i=1}^{m} q_{oi}^k \cdot (E_T^k \cdot w_E + M_T^k + H_T^k \cdot w_H) \qquad (3.1)$$

$$+ \sum_{k=1}^{l}\sum_{i=1}^{m}(D_i^k - \sum_{o=1}^{n} q_{oi}^k) \cdot (E_P^k \cdot w_E + M_P^k + H_P^k \cdot w_H) \qquad (3.2)$$

$$+ \sum_{k=1}^{l}\sum_{o=1}^{m}(P_o^k - \sum_{i=1}^{m} q_{oi}^k) \cdot (E_S^k \cdot w_E + M_S^k + H_S^k \cdot w_H) \qquad (3.3)$$

where (1) minimises the two objective functions, (2.1) computes the fix costs of the IS network, the logistic costs for transporting resources from the output to the input companies and the transformation process costs for the exchanged resources, (2.2) considers costs for purchasing a resource in case the demand is not met by the IS material flows and (2.3) adds the disposal costs of a resource in case of excess. The environmental impact are in φ^S, where (3.1) represents the $kg\ CO_2\ eq.$ emissions for the transformation process of the exchanged resources within the IS network, (3.2) adds the $kg\ CO_2\ eq.$ emissions for producing the additional units of each resource, while (3.3) includes the $kg\ CO_2\ eq.$ emissions to dispose the excess of resources.

- **Feasibility constraints**

The following feasibility constraints complete the model formulation:

$\sum_{o=1}^{n} q_{oi}^{k} \leq D_{i}^{k}$	$\forall\, i, k$	(4)
$\sum_{i=1}^{n} q_{oi}^{k} \leq P_{o}^{k}$	$\forall\, k, o$	(5)
$y_{oi}^{k} \leq m_{oi}^{k}$	$\forall\, i, k, o$	(6)
$q_{oi}^{k} \leq y_{oi}^{k} \cdot M$	$\forall\, i, k, o$	(7)
$q_{oi}^{k} \geq y_{oi}^{k}/M$	$\forall\, i, k, o$	(8)
$y_{oi}^{k}\ binary$	$\forall\, i, k, o$	(9)
$q_{oi}^{k} \geq 0$	$\forall\, i, k, o$	(10)

(4) ensures that each input company does not receive more than its resource request, (5) limits the output quantity of each resource for each output company to its annual production, (6) limits the resource flow between input and output companies to entities that may share each resource, (7) admits resource exchange between input and output companies if the correspondent path is chosen, (8) forces to have a resource flow in case a path between input and output companies is chosen. Finally, (9) and (10) give consistence to the decisional variables.

The complexity of the problem can be estimated considering the number of decisional variables and feasibility constraints. The model includes $2 \cdot l \cdot n \cdot m$ variables and $l \cdot (n + m + 3 \cdot n \cdot m)$ constraints except on those giving consistence to the decisional variables.

Model debugging

At this stage of the research, the model was preliminary debugged to check its consistency against a preliminary basic test instance. The chosen coding language is AMPL using an urban small-scale instance of about 17 m^2 with three resources, i.e. timber, rubber and aluminium, and four input/output companies. The total resource request is of about 71 tons/year, while the availability of by-products is of about 60 tons/year. Consequently, at least 11 tons/year of resources must come from new primary resources. After a solving time of about 5 seconds, the single objective cost optimum is of 91’256 €/year, while the single objective environmental impact optimum is of 225’251 kg CO_2 eq./year. The best balancing between the two objective functions is among the next research steps.

Conclusions

Industrial Symbiosis (IS) allows implementing Circular Economy (CE) principles encouraging the exchange of secondary resources among entities and companies of different industrial sectors. Its effective implementation presents barriers, so the support of analytical models and operative tools is crucial to explore synergies among local companies. This working paper discusses a preliminary bi-objective model that has the potential to enhance IS at the local scale defining the best network configuration from a cost and environmental perspective. After the model formulation and its preliminary debugging, future developments foresee the inclusion of technical and legislative constraints and new environmental impact categories, as well as the full implementation to real case best balancing the two objective functions through bi-objective optimisation techniques.

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PHOENIX – P2G: PLATFORM FOR BIOMETHANATION RESEARCH

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ABSTRACT
Power to Gas technology can be used to produce biomethane. The particular aspect is that the plant can utilize the CO_2 removed by gaseous waste through an upgrading process.

Keywords: *Power to Gas; biomethane; CO_2, H_2, anaerobic granular sludge*

Introduction
The present work investigates the application of Power to Gas technology which can be used to produce biomethane through the Sabatier's reaction, that combines hydrogen with carbon dioxide. The particular aspect is that the plant could use the CO_2 removed by gaseous waste through an upgrading process.

Moreover, to increase and speed up the production of biomethane, ultrasound technology is used. The project was carried out through the collaboration among 4 companies and a research center: Giammarco Vetrocoke Srl, the leader of the aggregation, Veritas Spa, RCV Vania Impianti Srl, Unitech Srl and Ca 'Foscari University, precisely the DAIS (Environmental Sciences, Informatics and Statistics) with Ca' Foscari Foundation.

The goal of this project is to develop a pilot plant that, using innovative technologies such as ultrasounds, is able to reuse the CO_2, extracted from gaseous wastewater through an upgrading process, for the production of biomethane.

Methods
This technology could be applied to increase the solubilization of CO_2 (recovered from the exhaust gas of a combustion or a digestion process) into a liquid solution; this solution could subsequently be used in a Power to Gas (P2G) process or eventually used as feed flow for microalgae biomass growth. In this project hydrogen (H_2) and carbon dioxide (CO_2) are mixed with water to create a gas-liquid mixture; the mixture will be then sent to an ultrasonic reactor, which works at high intensity and low frequency (kHz) to improve mixing efficiency.

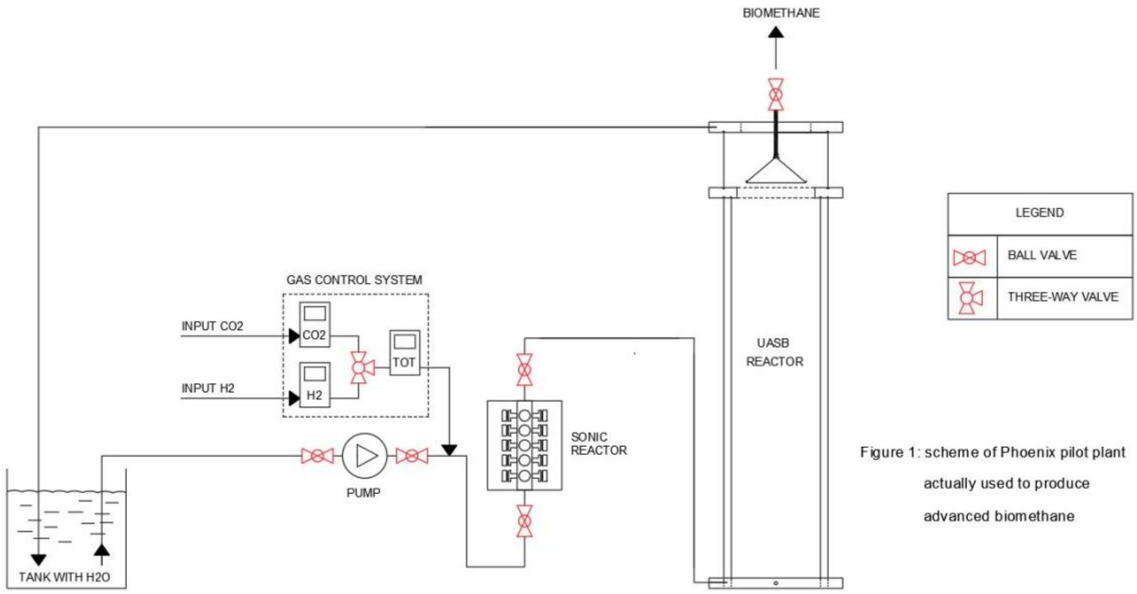

Figure 1. *Power to Gas plant*

Transducers, arranged around a cylindrical tube, are used to create a real ultrasonic reactor. The transducers give rise to acoustic waves which act on the liquid-gaseous mixture that passes through the reactor. In this way, inside the cylindrical tube, micro bubbles are formed which will subsequently implode. By exploiting this phenomenon, known as cavitation, it is possible to increase the concentration of gas in the liquid-gaseous mixture.

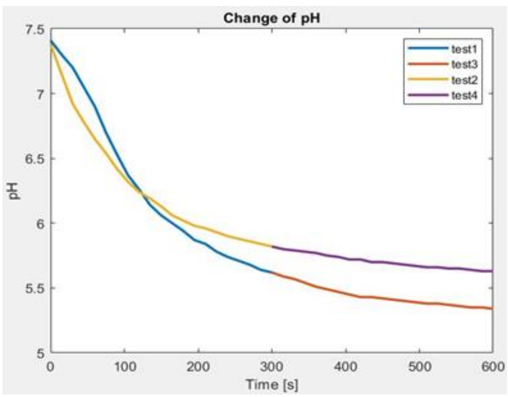

Figure 2. *Solubilization of CO_2 into H_2O during various tests*

Once the mixture is optimized, it will be sent to an up-flow anaerobic sludge blanket (UASB) type reactor filled with anaerobic granular sludge; the hydrogenotrophic bacteria of the granules will biologically carry out the reaction among CO_2 and H_2 into methane (CH_4), that can be used for mobility or cogeneration. The overall project idea is reported in Figure 1.

Figure 3. *Power to gas plant installed*

Results

The Phoenix - P2G project could open a new horizon in the scenario based on the creation of a dedicated process capable of optimizing some basic elements of the biomethanation process, that will guarantee all partners an upgrade in terms of acquired know-how and competitiveness on their own market segment. In particular the elements that compose the final system are: capture system by chemical bonding of the CO_2 present in industrial fumes, the ultrasonic cavitation system that optimizes the reversible enrichment of "biomethanizing" gases of a circulating solution, the granular fluidized bed bioreactor with his relative controls, moreover a prototype system of catalytic methanation.

The Phoenix integrated prototype represents, in a "circular energy" scenario, a platform for testing ex-situ CO_2 treatment processes and the CO_2 conversion into a useful type of energy through the combination with hydrogen, produced by integrated photovoltaic processes and energy storage systems already present, for example, in the Veritas Green Propulsion Laboratory in Marghera (Venice).

Discussion and Conclusion

It is confirmed that the experimentation activity carried out on the PHOENIX - P2G pilot could lead to the construction of full-scale CO_2 energy conversion plants which, in combination with the production of H_2 via RES, allow, in-situ or ex-situ, the production of biomethane, from biological and catalytic processes. The biomethane produced in these ways, unlike the biogas obtained from traditional anaerobic digestion plants, does not have spurious components such as CO_2, SO_2 etc and is therefore readily usable for automotive and / or injection into the grid.
The industrial research activity that has been carried out has led to encouraging results regarding the development of hybrid biotechnological processes aimed at GHG reduction and production of advanced biofuels as well as the experimentation of new processes based on sonochemistry, which could open new development scenarios in the bioenergy and green chemistry sectors, especially in the areas undergoing eco-sustainable industrial conversion.

POPLYHOUSE. POPLAR PLYWOOD CONSTRUCTIONS

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ABSTRACT

This article presents the first case study resulting from the collaboration between the company E.Vigolungo Sp.A. and the Lorena Alessio Architetti studio. The cooperation involves the design and construction of a building with the supporting structure in poplar, as well as the prefabrication of infill modules composed by poplar panels and natural insulating fibers. PoplyHouse brand was born out of this experience. The PoplyHouse proposal is part of a system of circular economy, which begins with the cultivation of poplar and ends with the possibility of reusing the construction material and / or recycling it. In Italy, poplar cultivation, understood as the art of growing poplars, is one of the few cases of integration between industrial and agricultural activity. The plywood is now made with advanced technologies and with very low formaldehyde content or natural glues. The production cycle is also sustainable, with the use of all production waste.

Keywords: *Poplar Plywood; Prefabrication; architectural modules*

Introduction

In recent years, interest in the use of wood in the building sector has grown considerably, helping to reduce the environmental impact of new buildings and providing new solutions for the built environment. Currently, its return to the building sector has led to a renewed interest in the design of prefabricated and drywall structures which guarantee practicality of installation and speed of assembly and disassembly of the structures.

This essay is intended as an account of the architectural experimentation, the result of the collaboration between the Lorena Alessio Architetti studio and the company E. Vigolungo S.p.A, which led to the birth of PoplyHouse: a new construction system for prefabricated dry structures, made of poplar plywood.

Poplar wood is commonly considered a material that is not very resistant and unsuitable for structural roles, but it is now being rediscovered and enhanced. PoplyHouse intends to contribute not only to the identification of environmentally sustainable solutions in the construction world, but also to the protection and support of the local poplar wood supply chain, an Italian excellence for over a century.

Methods

The advantages of poplar cultivation and poplar plywood

In Italy poplar cultivation is one of the few cases of integration between industrial and agro-forestry activities: poplar is considered an agricultural crop and not a forestry one and its cultivation is carried out according to sustainable methods.
In environmental terms, its advantages make it a potential driver of the green economy: the rapid absorption of carbon present in the atmosphere, the carbon stock property, i.e. the retention of CO_2 within the derived products (panels, plywood and chipboard), the bio-filtering action of soil water, the phyto-remediation and phyto-restoration action are just some of the considerable advantages.
Its transformation into plywood is the main use of poplar wood: the advantages that make this transformation suitable are mainly enclosed in the characteristics of lightness, clarity, homogeneity, versatility of use, ease of processing and cost-effectiveness compared to other types of wood with higher performance.

The birth of PoplyHouse

PoplyHouse was born from the Japanese-inspired design of the architect Lorena Alessio and technical experimentation with poplar plywood by the company E.Vigolungo S.p.A.: it is a research project that led to the design of a structural joint and a new system of prefabrication with dry wooden portals.
Figure 1 shows the numbers of the first experimental project: a showroom located in Canale, next to the industrial plant of the Vigolungo company, of 160 sqm, for which 452 plywood panels were used, or 160 poplars.

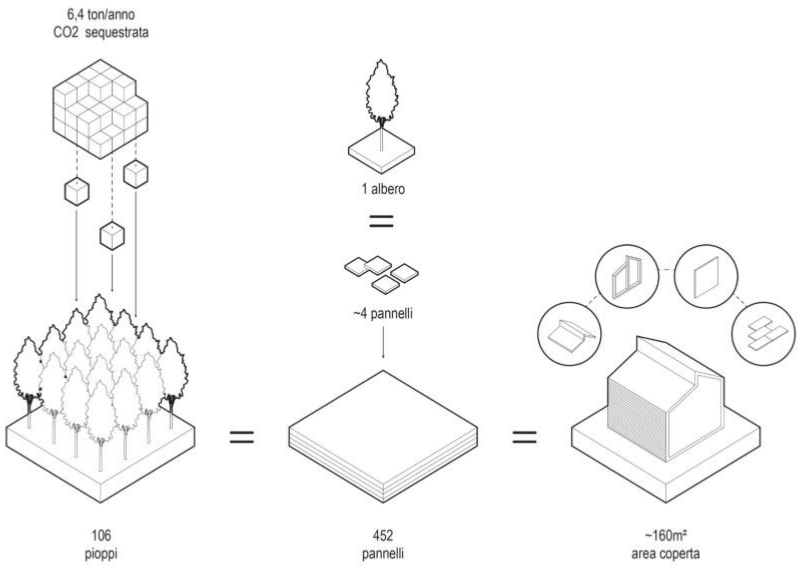

Figure 1: From trees to PoplyHouse structures

The technological limitation of the standard maximum dimensions of plywood sheets (panel widths between 125 and 185 mm, lengths between 185 and 254 mm and thicknesses between 12 and 25 mm) has played an important role in the engineering of large load-bearing structures, making the use of continuity joints necessary. By looking at the classic "dovetail joints" and the tradition of the Japanese craftsmen, a new type of high-strength, dry-assembled joint was developed.

The portal structures used in the PoplyHouse projects are of the "closed frame" type, arranged in parallel, according to the maximum dimensions allowed by the materials used for the secondary structures. The planned load-bearing frames have been designed in such a way as to limit as far as possible the stresses at the points of least resistance.

Therefore, during the experimentation phase it was necessary to carry out various load tests before engineering the portal: the load test cycles were carried out using caissons filled with water and concrete blocks, until a test weight of 3200 kg was reached on the entire 4.50 m span beam. These load tests made it possible to identify the elastic and plastic deflections undergone by the structures and to optimise the geometries, tolerances and thicknesses necessary to obtain a high-performance frame under the design loads required by the standards.

Results

The new portal system, combined with the use of the new joint, represents an innovative connection system in poplar plywood that responds to the current trend in the building sector to favour the use of drywall structures in order to ensure ease of installation and speed of assembly and disassembly of structures.

One of the main advantages is the mono-materiality: unlike other drywall joints currently in use, the new PoplyHouse joint does not require additional components (such as plates, bars, screws, bolts).
All the components of the new construction system are laser-cut by CNC machines and joined by the new joint without the use of glue, resin or metal elements. The innovation also lies in the great flexibility that allows the connection system to be adapted to the desired spans, guaranteeing excellent results in terms of load resistance. This flexibility is determined by the comb shape of the joint, which improves resistance by acting simultaneously on two levels: on the vertical level, it wedges the joint elements to the pre-assembled structure of the portal; on the horizontal level, it acts as a fastener for the PoplyHouse joint, increasing its resistance to bending.

Figure 2. PoplyHouse – Showroom of E.Vigolungo S.p.A. – Photo by Tino Gerbaldo

PoplyHouse prototype – the E-Vigolungo S.p.A. showroom is the winner of the 2021 Sustainability Award of the Agency for Energy and Sustainable Development - AESS.

Conclusion

PoplyHouse is an alternative solution in the building world; it is a modular system for prefabricated structures made of poplar plywood, ethical, sustainable.

New trends in living, new lifestyles, exacerbated by Covid-19, have led people to adopt new habits; spaces have had to respond to more pronounced needs. The transition from indoors to outdoors has become more fluid; indoor, intermediate and outdoor spaces have been filled with new meanings; there is a need to have space for more functions at different times of the day.

PoplyHouse wants to respond to these needs; it wants to be versatile, adaptable, modular.

Outside, inside or beside represent three different configurations that the system can assume: it adds, connects, assembles spaces usable for different uses. The main areas of use, on which the group is currently working, are residential, tertiary (offices, showrooms, hotels) and interior/furniture.

The simplification of the components and the ease of construction of the PoplyHouse system create a new relationship between man and the built environment, favouring the connection with the natural element of wood, which has a positive effect on man's wellbeing.

The ultimate goal of the project is a simple accessibility of the system: the offer of a tailor-made service, customised, easy to build and adaptable to the context.

To the already well-known environmental advantages of poplar, the new PoplyHouse building system adds the advantages of prefabrication, offering a product: single-material, quick to build, modular, with low atmospheric and acoustic pollution, which supports the Italian poplar wood industry. In addition to this, the company E.Vigolungo S.p.A must be credited with an intense and continuous focus on the poplar supply chain, making it possible to apply the principles of the circular economy to PoplyHouse structures.

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EEPA – ECOLOGICALLY EQUIPPED PRODUCTIVE AREA – "CARTONECO"

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ABSTRACT

The setting up of a network of enterprises for the start-up of an EEPA – Ecologically Equipped Productive Area- is based on the exchange of by-products, identified as production residues which overcome the restrictions of article 184 bis of legislative decree 152/2006. In the experimental phase, the cardboard by-product was identified as an industrial residue from the production process of a company promoting the EEPA, which can be exchanged among the other participants. The project envisages the exchange "as is" and as cardboard straw, as immediately practicable and unifying elements for use in packaging. For the reuse of the cardboard by-product, the participating companies have signed up to an action and investment programme for the production of edge protection, boxes, scenic elements, easy-to-make pop-up invitations and two R&D projects for biofabrication and additive manufacturing. After the experimental phase, the exchange programme intends to work on other available industrial residues such as PE, ABS, MDF panels, PMMA, etc.

Keywords: *Circular economy, Industrial symbiosis, By-product, Recycling, Reuse*

Introduction

The "Cartoneco" EEPA business network was set up to shape an ecosystem that exchanges by-products, innovative services and technological capabilities, with the aim of increasing its resilience and readiness with respect to sudden changes and critical shifts from the external market.

Furthermore, the EEPA wants the continuous exchange of information to produce the involvement of companies on the topics of sustainable growth and circular economy and strengthen industrial symbiosis with a view to increasingly stronger collaboration, which goes beyond mere business competition.

The "Cartoneco" EEPA business network, which has officially requested regional recognition, envisages the exchange of technological services for the experimentation of innovative production techniques, with the possibility of sharing production processes and machinery, to determine the possibility of creating new, more efficient, innovative products or new production processes.

In the experimental phase, the eight participating companies began to exchange the cardboard by-product, certified as such and corresponding to the regulations in force by the validation declaration issued by the Environmental Verifier (1), a production residue of the company Arken Spa, which becomes the raw material for exchange and creative recovery for the companies participating in the EEPA.
The project started with a study of applicable legislation, in particular an analysis of article 184 bis of Legislative Decree 152/2006, which defines the restrictions which exist as regards the qualification of an industrial residue as a by-product.
The implementation of the first project "Cardboard by-product exchange" -by the companies participating in the EEPA- involved an initial investment in an operating machine that transforms the cardboard by-product into cardboard straw and strips - articles that are exchanged with the participating companies and used for the packaging of products as protection and/or filling elements.
For the other projects, pre-prototypes were developed for corner protection, pop-up boxes and invitations, scenic elements, boxes and displays, cardboard shelves for "Record" display units, mannequins, busts and interlocking cardboard accessories. In addition, two R&D projects have been envisaged concerning bio-fabrication and the use of cardboard pulp possibly integrated with resins and/or biopolymers for the manufacture of 3D-printed products.

Methods

The methodology used in the first year -and in the following years for the envisaged projects- follows the guidelines of the UN Global Compact sustainability document and the circularity of processes, from the assessment of opportunities and risks to the definition of the strategy and objectives, the subsequent implementation of the strategy and objectives within the company, up to the control and measurement of the results achieved and communicated, with the commitment of the leadership to return to point one. All with a view to continuous improvement.
The opportunities and risks involved in the cardboard by-product conversion project were assessed through numerous surveys, statistics and perspectives compiled by COMIECO[1], in particular the report updated in July 2020 on changing market demands and - at the same time - changes in consumer behaviour.
Targets have been scheduled and individual projects submitted to all companies for approval. For 2024, the year by which we expect to be fully operational, an ambitious process has been planned which envisages the use of advanced technologies and the creation of new materials, which are often referred to as 'emerging materials' and -

in this specific case Advanced Growing- (3) i.e. all those materials resulting from the controlled cultivation of microorganisms (bacteria, yeasts, algae, mycelium, etc.) which are directly grown and/or produced in their final form, function and performance, by exploiting the natural growth behaviour of the deposited organisms - in our case - on a bed of cardboard by-product.

Shown below are the per annum objectives of the distribution of the cardboard by-product and its transformation into products with higher added value than just cardboard straw.

Table 1. *Distribution of the exchange of the cardboard by-product – year 2021*

By-product		Cardboard straw		Cardboard by-product		Total	
1500 kg		Percentage	Weight (kg)	Percentage	Weight (kg)	Percentage	Weight (kg)
1	Arken SpA	60,1	901,5	0	0	60,1	901,5
2	Glasvetrina Srl	11,1	166	0	0	11,1	166
3	Arkengraf Srl	11,1	166	0	0	11,1	166
4	Rinnovative Srl	5	76	3	54	8	121
5	Paolo De Giusti	5	76	2	30	7	106
6	Bene Comune	1,6	24	0	0	1,6	24
7	Il Colore del Grano	1	15,5	0	0	1	15,5
8	CRF	0	0	0	0	0	0
9	Transfer to paper mill	0	0	0	0	0	0
10	Market	0	0	0	0	0	0
	CHECK TOTAL	95	1425	5	75	100	1500

Table 2. *Distribution of cardboard by-product and revenue table – year 2022*

2022								
Annual by-product (kg)	Projects	% of distribution for individual projects	Total weight (kg)	Unit weight (kg)	Number of pieces	Market unit price (kg/piece)	Revenue (€)	Market unit price (kg)
3000	Cardboard straw	74,5 %	2235			4,92	10.991,80 €	4,92 €
	Pop up box	7,5 %	225	0,6	375	40	15.000,00 €	66,67 €
	Corner bumper	7,5 %	225	0,2	1125	0,3	337,50 €	1,50 €
	Scenographic elements	2,5 %	75	12,0	6,25	180	1.125,00 €	15,00 €

2022								
	Custom box and display stand	2,5 %	75	0,5	150	5	750,00 €	10,00 €
	Pop up card	2,5 %	75	0,1	750	5	3.750,00 €	50,00 €
	Record stand	2,0 %	60	4	15	20	300,00 €	5,00 €
	Mannequins, busts and interlocking cardboard accessories	0,5 %	15					
	Additive manufacturing	0,5 %	15					
	Transfer to paper mill							
CHECK TOTAL		100,00 %	3000,00		2421,25		**32.254,30 €**	**10,75 €**

Table 3. *Distribution of cardboard by-product and revenue table – year 2023*

2023								
Annual by-product (kg)	Projects	% of distribution for individual projects	Total weight (kg)	Unit weight (kg)	Number of pieces	Market unit price (kg/piece)	Revenue (€)	Market unit price (kg)
3450	Cardboard straw	39,0 %	1345,5			4,92	6.617,21 €	4,92 €
	Pop up box	22,0 %	759	0,6	1265	40	50.600,00 €	66,67 €
	Corner bumper	12,0 %	414	0,2	2070	0,3	621,00 €	1,50 €
	Scenographic elements	8,0 %	276	12,0	23	180	4.140,00 €	15,00 €
	Custom box and display stand	6,0 %	207	0,5	414	5	2.070,00 €	10,00 €
	Pop up card	5,0 %	172,5	0,1	1725	5	8.625,00 €	50,00 €
	Record stand	5,0 %	172,5	4	43,125	20	862,50 €	5,00 €
	Mannequins, busts and interlocking cardboard accessories	1,5 %	51,75	0,3	173	18	3.105,00 €	60,00 €
	Additive manufacturing	1,5 %	51,75					
	Transfer to paper mill							
CHECK TOTAL		100,00 %	3450,00		5712,63		**76.640,71 €**	**22,21 €**

Table 4. *Distribution of cardboard by-product and revenue table – year 2024*

2024								
Annual by-product (kg)	Projects	% of distribution for individual projects	Total weight (kg)	Unit weight (kg)	Number of pieces	Market unit price (kg/piece)	Revenue (€)	Market unit price (kg)
3650	Cardboard straw	16,0 %	584			4,92	2.872,13 €	4,92 €
	Pop up box	27,0 %	985,5	0,6	1642,5	40	65.700,00 €	66,67 €
	Corner bumper	17,0 %	620,5	0,2	3102,5	0,3	930,75 €	1,50 €

2024								
	Scenographic elements	12,0 %	438	12,0	37	180	6.570,00 €	15,00 €
	Custom box and display stand	8,0 %	292	0,5	584	5	2.920,00 €	10,00 €
	Pop up card	8,0 %	292	0,1	2920	5	14.600,00 €	50,00 €
	Record stand	5,0 %	182,5	4	45,625	20	912,50 €	5,00 €
	Mannequins, busts and interlocking cardboard accessories	4,5 %	164,25	0,3	547,5	18	9.855,00 €	60,00 €
	Additive manufacturing	2,0 %	73					
	Biofabrication test	0,5 %	18,25					
	Transfer to paper mill							
CHECK TOTAL		100,00 %	3650,00		8878,63		**104.360,38 €**	**28,59 €**

Methods

In the first four months of 2021, around 350 kg of cardboard by-product were exchanged in the form of straw and around 50 kg as 'as is'.
Obviously, a carton shredder machine was purchased to produce cardboard straw; a "Cameo" cutting plotter to experiment with prototyping invitations and pop-up boxes; a Pantograph cutter with laser marking head for wood and cardboard for pre-prototyping boxes and the like.

Discussion and Conclusion

Already in the early months of the second half of 2021, the project has shown its validity in the exchange of the cardboard by-product, confirming the correctness of the idea of being able to embark on the path of the circular economy and - with the collaboration of all participating companies - initiate certain aspects of industrial symbiosis that underline the change in industrial culture underway.
The need to start with 'simple' by-products that can be experimented with without incurring environmental incidents is confirmed by the tranquillity of the participating companies, which have begun investing in order to initiate an ecological transition and thus move on - after acquiring the necessary experience – to other by-products generated by corporate production cycles and which can find new life through innovative products.

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LA GESTIONE DEGLI SCARTI NELLA FILIERA OLEARIA NELL'OTTICA DELL'ECONOMIA CIRCOLARE

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ABSTRACT

L' obiettivo di questo paper è quello di analizzare gli impatti ambientali derivanti dall'utilizzo degli scarti della filiera dell'olio in Sicilia quale materia prima seconda per la produzione di biocombustibili.

A tal fine viene analizzata un'azienda che coltiva e produce olio in provincia di Catania, la Agrosol, che cede gli scarti di produzione ad un'azienda produttrice di biodiesel sita in provincia di Enna, Assoro Biometano, nell'ottica della simbiosi industriale tra due Imprese Siciliane. Gli impatti ambientali vengono analizzati attraverso l'analisi LCA, secondo quanto previsto dalle norme ISO 14040, attraverso l'applicazione del software SIMAPRO. İ dati elaborati sono forniti direttamente dalle due aziende indagate.

Keywords***:*** *Simbiosi industriale; Life Cycle Assessment; scarti oleari; sostenibilità ambientale*

ABSTRACT

The objective of this paper is to analyze the environmental impacts resulting from the use of waste from the oil supply chain in Sicily as a secondary raw material for the production of biofuels. For this reason, a company that cultivates and produces oil in the province of Catania, Agrosol, is analyzed, which sells production waste to a biodiesel producer located in the province of Enna, Assoro Biometano, with a view to industrial symbiosis between two Sicilian companies. The environmental impacts are analyzed through LCA analysis, in accordance with the ISO 14040 standards, through the application of the SIMAPRO software. The processed data is provided directly by the two companies investigated.

Keywords***:*** *Biofuels; Industrial symbiosis, Life Cycle Assessment, Oil waste, Environmental sustainability*

Introduction

"La simbiosi industriale è una forma di intermediazione per facilitare una collaborazione innovativa tra le aziende, in modo tale che i rifiuti prodotti da una di esse vengano valorizzati come materie prime per un'altra. La parola 'simbiosi' è di solito associata alle relazioni che intercorrono in natura, in cui due o più specie scambiano materiali, energia, o le informazioni in un modo reciprocamente vantaggioso. Una collaborazione locale o più ampia nell'ottica della simbiosi industriale può ridurre la necessità di materie prime vergini e lo smaltimento di rifiuti chiudendo così il ciclo dei materiali." Nell'ottica della sostenibilità ambientale ed economica, per essere ancora più efficace la simbiosi industriale deve essere estesa a più realtà commerciali e la gestione dei flussi dei rifiuti deve essere applicato a diversi settori e industrie. Inoltre, vi è ancora molto da approfondire circa: gli impatti ambientali e sociali, l'armonizzazione di tecnologie, processi, metodi, l'impegno della società a creare un'economia circolare a livello europeo, le informazioni sui rifiuti come risorsa, le tecnologie di trattamento dei rifiuti, i modelli di business e di coordinamento tra i flussi e gli attori coinvolti [1].

La simbiosi descritta in questo studio avviene tra l'azienda di produzione olearia Agrosol e l'azienda di produzione di biocarburanti Assoro Biometano; tale scambio di materia nasce dall' esigenza di dare una valorizzazione più appropriata agli scarti della filiera olearia e proprio per questo motivo le due realtà imprenditoriali sostengono un continuo scambio d' informazioni in merito alla produzione dei relativi impianti in un'ottica di economia circolare [2].

In particolare, e con riferimento alle acque di vegetazione immettendo quest'ultime nel processo produttivo di Assoro Biometano si ha un impatto ambientale in misura notevolmente più ridotta rispetto allo spargimento delle stesse sul suolo agrario.

Le acque di vegetazione, benché prima ritenute un refluo agroalimentare molto inquinante, in realtà sono prive di sostanze pericolose per l'uomo e l'ambiente, come agenti patogeni, metalli pesanti, ecc. Però a causa dell'elevato carico organico e la bassa biodegradabilità, provocano qualche effetto indesiderato sulla funzionalità degli agroecosistemi interessati al loro sversamento: l'abbassamento dei valori di pH del terreno, il rallentamento dei processi di trasformazione e di biodegradazione del refluo a causa dell'azione antimicrobica dei polifenoli totali. Inoltre, dal conferimento scaturiscono anche vantaggi economici sia per il frantoio che in mancanza di terreno agricolo utile allo sversamento deve obbligatoriamente rivolgersi ad impianti di depurazione delle acque reflue con i relativi costi di smaltimento, sia per Assoro Biometano che acquisisce gli scarti utili alla propria produzione ad un prezzo simbolico di 1 euro ogni 1000 liti di acqua vegetativa [3].

Methods

Attraverso LCA viene implementato uno studio per valutare gli impatti ambientali degli scarti generati dalla filiera dell'olio. Lo studio viene effettuato attraverso lo strumento d' analisi SimaPro. Tutti i dati per l'applicazione dello strumento sono stati forniti dall'azienda SimaPro è uno strumento professionale per raccogliere, analizzare e monitorare le prestazioni ambientali di prodotti e servizi [4]. Con tale software è possibile modellare e analizzare cicli di vita complessi in modo trasparente e sistematico, seguendo le norme ISO 14040-14044. Si inizia l'analisi con la Rete Network; come illustra la figura 1 si può notare che vengono inseriti come output quelli che sono i prodottoti e sottoprodotti derivanti dall'intera filiera. Lo studio viene fatto attraverso un'allocazione su base economica.

Tabella 1: *Allocazione olio e scarti su base economica*

Output noti a tecnosfera. Prodotti e coprodotti	Quantità fisica	Unità di misura	Quantità fisica	% Allocazione	Categoria	Commento
Evo	1200	Litri	Volume	60 %	0Agrosol	8 euro
Sansa	350	Tonnellate	Massa	20 %	0Agrosol	130 euro a tonnellata
Olive oil mill waste (acqua di vegetazione)	490000	Litri	Volume	20 %	0Agrosol	1 euro ogni 1000 litri

Gli input necessari alla produzione propria per la linea di prodotti "feudo San Vito" sono i seguenti:

Input noti da natura (risorse)	Sottocompartimento	Quantità fisica	Unità di misu
Occupation, construction site		1100	m2a
(Inserisci linea qui)			
Input noti da tecnosfera (materiali/combustibili)		**Quantità fisica**	**Unità di misu**
olive		80	ton
Tap water {GLO}| market group for | APOS, S		500	ton
(Inserisci linea qui)			
Input noti da tecnosfera (elettricità/calore)		**Quantità fisica**	**Unità di misu**
Electricity, medium voltage {IT}| market for | APOS, S		50000	kWh

Figura 1. Input per la realizzazione dell'olio

Risultati e discussione

Inseriti gli output con allocazione economica e gli input al fine di aggregare i risultati ed ottenere un indicatore unico per la quantificazione dell'impatto complessivo generato dal ciclo di vita dell'olio extravergine d'oliva è stato utilizzato il metodo di valutazione CML-IA baseline; da ciò emerge la rete network che prende in considerazione gli impatti dei diversi input [5]. È possibile osservare come tra il concime organico, il trasporto ed il Tillage (aratura), il maggior impatto ambientale è dato dall'utilizzo del macchinario per l'aratura del terreno. Tutti e tre gli input portano alla produzione delle olive, che insieme all'acqua utilizzata per il lavaggio, ed all'elettricità utilizzata per il funzionamento del ciclo di produzione, permettono la produzione del prodotto finale ovvero l'olio d'oliva. L'elettricità utilizzata impatta in misura relativamente ridotta perché il frantoio utilizza energie rinnovabili come il fotovoltaico per sostenere l'energivoro impianto di produzione [6].

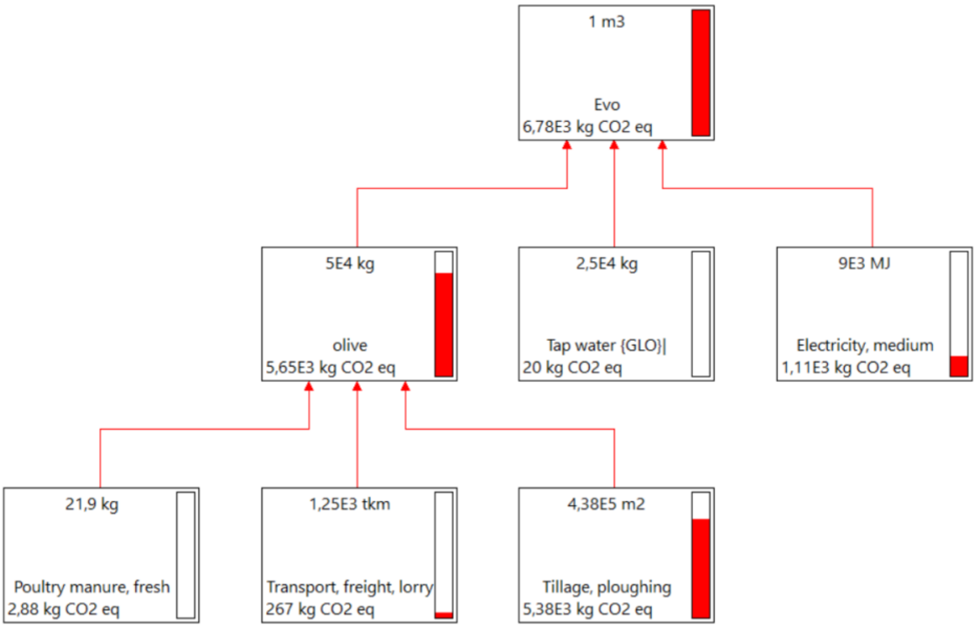

Figura 2. Rete *network*

La valutazione degli impatti ambientali derivanti dal processo di trasformazione viene effettuata praticando una suddivisione in tre aree di impatti in particolare, impatti sulla salute umana (Ozone depletion, Human toxicity), impatti sull'ecosistema (Terrestrial ecotoxicity , Marine ecotoxicity , Freshwater eutrophication, Global warm, Acidification) e impatti sulle risorse (Abiotic depletion ,Abiotic depletion fossil) [7]. Nella valutazione degli impatti si è osservato che in tutte tre le aree, tra le l'olio, le olive, l'acqua e l'energia utilizzata per la produzione, la fase di coltivazione delle olive impatta maggiormente. Questo risultato è dato dal maggior sacrificio di risorse energetiche e dal consumo del carburante derivante dall' utilizzo delle macchine agricole [8]. Da queste prime analisi si può già fare una classica degli stadi produttivi più critici in relazione agli impatti ambientali così da adoperare tutte le azioni necessarie la fine di ridurli in tali fasi.

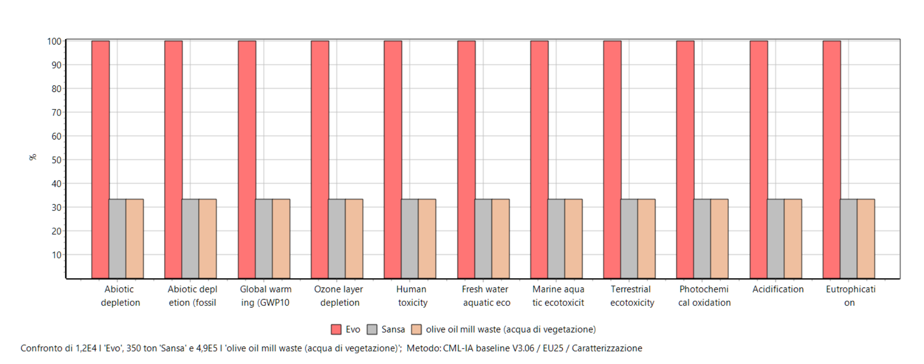

Figura 3. *Valutazione impatti ambientali*

Un'ulteriore analisi è stata fatta in riferimento al prodotto e sottoprodotti ottenuti dalla lavorazione delle olive.

L'olio, ovvero il prodotto principale ottenuto dalla lavorazione delle olive, ha un impatto maggiore rispetto a quelli che sono gli scarti, (sempre con riferimento alle 3 aree d'impatti della precedente analisi) ovvero i sottoprodotti destinati ad Assoro Biometano [9].

Questo maggiore impatto è dato, non solo dalle diverse quantità che nel caso in esame (Produzione propria) sono: olio 12000 litri; sansa 350 tonnellate; acque di vegetazione 490000 tonnellate. Ma soprattutto è dato dalla diversa allocazione su base economica. In quanto, come illustrato nella figura 3 l'olio viene commercializzato a 8€ a litro, mentre la sansa a 130€ a tonnellate, e l'acqua di vegetazione ad un costo molto irrisorio ovvero 1€ ogni 1000 litri. In fine è necessario precisare che quest' analisi in quanto basata sull' allocazione economica dell'olio e dei suoi sottoprodotti è valevole solo per la campagna olivicola oggetto dello studio cioè inerente all' anno 2020 non può essere paragonabile o confrontabile con altri anni in quanto il prezzo è variabile di anno in anno.

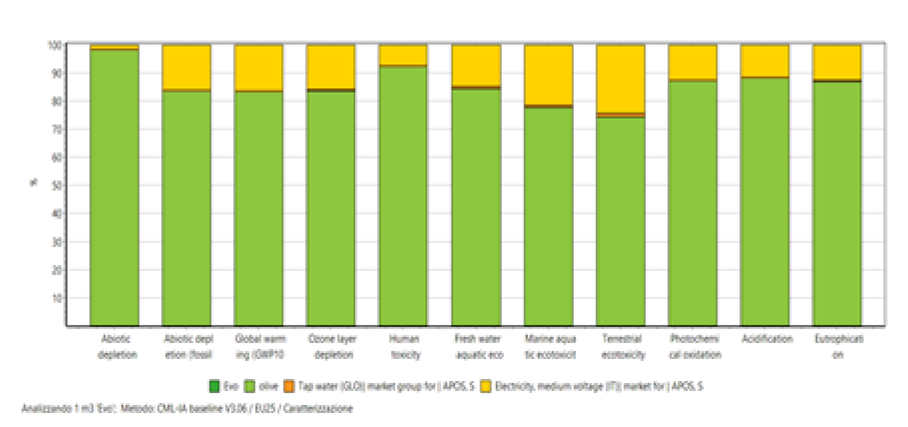

Figura 4. *Impatti ambientali tra i diversi sottoprodotti*

Numerose sono anche le variabili in gioco nel ciclo di vita dell'olio d'oliva ed in generale dei prodotti agroalimentari: differenti modalità di gestione dell'oliveto (irrigato o meno, coltivazione biologica, raccolta meccanica o manuale, etc.), varietà di olive coltivate e conseguente resa in olio (il prodotto studiato ha una elevata resa rispetto a molte altre varietà di olive), tipo di imballo utilizzato (bottiglie o latte). Particolare attenzione bisogna porre, infine, nei riguardi dei trattamenti di tipo fitosanitario, il cui impatto in termini di emissioni sul terreno va attentamente valutato [10].

Conclusioni

Sviluppare attività di ricerca industriale anche nell' ambito della simbiosi industriale consentirebbe di fornire alle imprese risposte al fine di adottare modelli di simbiosi. Un ulteriore sviluppo potrebbe quindi essere rappresentato dalla creazione di un network di simbiosi a livello regionale di cui facciano parte tutti gli enti coinvolti nei processi produttivi e di verifica. In questo modo si potrebbe lavorare, attraverso tavoli di lavoro interistituzionali e aperti alla partecipazione del mondo della ricerca e dell'impresa, mirate all'individuazione di soluzioni e alla semplificazione dei processi produttivi e autorizzativi comprendendo gli iter burocratici per la valorizzazione dei sottoprodotti, dei residui e dei rifiuti. Successivamente a questa fase si potrebbe attuare un'analisi quantitativa dell'evoluzione del network sulla base dei partecipanti coinvolti, valutando anche l'incremento di sinergie generate e soprattutto, tradotte in applicazioni pratiche.

Inoltre, grazie alle informazioni ricavate dall'analisi LCA si potrebbe realizzare un piano d'azione per minimizzare gli impatti ambientali, individuati preventivamente nelle varie fasi del processo produttivo e della filiera in modo tale da poter sempre monitorare i comportamenti "eco-sostenibili" che le imprese mettono realmente in pratica e in tal caso incentivarli e premiarli attraverso (per esempio) dei benefici fiscali [11].

Inoltre, il Recovery Plan è un'occasione unica per accelerare i processi di decarbonizzazione e rilanciare l'economia italiana, ma è necessario che la sua attuazione sia gestita da figure in grado di garantirne la continuità.

Nella fattispecie la decarbonizzazione viene inserita nei processi di digitalizzazione per cui sono stati stanziati 40,7 miliardi di euro. La trasformazione verso il digitale incorpora già in sé un elemento di decarbonizzazione più o meno ampia a seconda dei processi in cui va operare, in fine per monitorare i processi di cambiamento del modello di sviluppo, l'Agenda 2030 ha definito un sistema composto da 17 Obiettivi di Sviluppo Sostenibile (Sustainable Development Goals), 169 traguardi o sotto obiettivi e oltre 240 indicatori, sulla base dei quali verrà valutato periodicamente, in sede ONU, ciascun Paese ed essere così sottoposto al giudizio delle opinioni pubbliche nazionali ed internazionali. Gli obiettivi si articolano sulle tre dimensioni dello sviluppo sostenibile: crescita economica, inclusione sociale, tutela dell'ambiente, in un approccio integrato.

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Makingh Engines "Ready for H2"

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ABSTRACT

Because hydrogen is uniquely positioned to serve a low- and zero-carbon energy power sector, INNIO believes it will become a driver of the energy transition. As a result, INNIO has based its research and development strategy on hydrogen, launching its "Ready for Hydrogen" portfolio to meet customer demand for sustainable solutions using pipeline gas and hydrogen power generation.

Keywords**:** *Hydrogen, engin;, carbon emissions; power generation Introduction*

Introduction

Like electricity, green hydrogen is an energy carrier rather than a natural resource. It is a fuel that is carbon free and can alternatively be used as a base product for synthetic fuels that are either carbon based (synthetic gas or methanol) or carbon free (like ammonia). Methanol and ammonia are chemical products that are widely used in the chemical industry but also are considered new fuels for internal combustion engines.

When hydrogen is produced through the electrolysis of water and electricity stemming from renewable sources, it is called renewable hydrogen (green H2). When hydrogen is produced out of pipeline gas using steam methane reforming and carbon capture and storage (CCS), it is called low carbon hydrogen (or blue H2). For INNIO's Jenbacher distributed power generation solutions, the source of the hydrogen is not particularly important.

INNIO classifies hydrogen applications in three categories (Figure 1):

A - Hydrogen that is a composition in the pipeline gas

B - Hydrogen that is locally admixed to the engines' fuel or part of a synthetic gas

C - Pure hydrogen usage

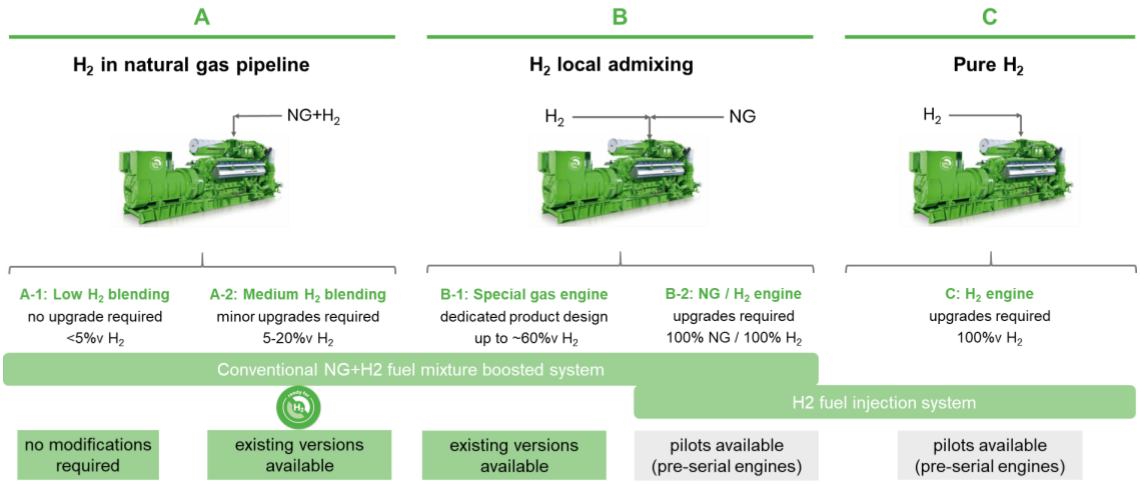

Figure 1. *Engine solutions, depending on H_2 availability (© Innio Jenbacher)*

It is important to understand hydrogen's availability. In the gas pipeline network, hydrogen can be available a few hours a year, continuously but fluctuating, or continuously with a constant amount. Admixing hydrogen locally to the engines' fuel allows control of the amount of hydrogen that is mixed with the pipeline gas, but again the hydrogen may be available a few hours per year, seasonally or continuously. The pure hydrogen engine can run only when hydrogen is available.

Methods

Hydrogen availability for engine solutions

Pipeline gas with high hydrogen content

With biogas upgraded to biomethane achieving pipeline gas quality standards—the most common renewable gas currently used for greening the gas supplied to end customers—the gas industry already is preparing for a 100% carbon-neutral/carbon-free future by 2050 [1]. However, hydrogen admixing to pipeline gas in the transmission and distribution networks is anticipated in parallel to the development of an independent hydrogen infrastructure. Particularly when hydrogen is mixed to pipeline gas in the distribution network system, many gas consumers are affected with fluctuating fuel properties as the physical composition of the gas is changing.

The aim of adding hydrogen to the pipeline gas network is to decarbonize pipeline gas and use the existing gas infrastructure for transport and storage. Studies show that up to 20% (v) of hydrogen can be added to the existing pipeline gas transmission and distribution system. Twenty percent (v) of hydrogen in the pipeline gas results in a decarbonization of only 7%, because hydrogen has a volumetric heating value of less than 30% compared to pipeline gas. With 20% (v) hydrogen, the Wobbe Index (WI) of the gas goes down by 5% to 6% and the Methane Number (MN) goes down by 10 to 15 points. If permanent, a constant switch from zero to a certain percentage of hydrogen could be done, and all end users could accordingly adjust their appliances, turbines, engines, boilers, etc. The real challenge is a very likely discontinuous hydrogen injection to the pipeline gas grid. Therefore, a continuous signal about the hydrogen content in the pipeline gas needs to be provided from the gas supplier to end consumers. The signal, which can be included in the engine's control system to allow for stable operations, makes Jenbacher engines ready for 20% (v) H_2 in pipeline gas.

Local admixing of hydrogen to pipeline gas

Admixing hydrogen locally at the engine allows control of the amount of hydrogen that is mixed with pipeline gas, and the hydrogen content is always known to the engine control system. That makes this engine configuration easier to design and operate. INNIO distinguishes between two solutions.

B-1: Premixed engines are needed for mixing locally up to ~60% (v) hydrogen to pipeline gas. This allows the use of a conventional fuel system with a single fuel-air mixing pre-turbocharger. The fuel supply system including the turbocharger design is adjusted according to the maximum amount and the availability of admixing hydrogen. The engine still can achieve full output running at 100% pipeline gas but will reduce output at higher hydrogen admixing, depending on the base gas and engine version. The engine design can be optimized for 100% pipeline gas operation or for operation with high hydrogen admixing.

B-2: A dual fuel engine is required if the engine is capable of running on 100% pipeline gas as well as 100% hydrogen. In this case, two fuel supply systems on the engine are required: a conventional fuel system with a fuel-air mixing pre-turbocharger for pipeline gas operation and a separate fuel injection system for hydrogen operation. The engine performance can be optimized for 100% pipeline gas operation or for 100% hydrogen operation.

100% hydrogen utilization

Operating a distributed generation power asset on 100% hydrogen is the long-term vision, but some engines for peaking and combined heat and power (CHP) could be installed to run on hydrogen in the near term as hydrogen clusters emerge and transfer away from fossil fuel completely. If hydrogen is the fuel of choice and no other carbon-neutral or carbon-free fuel is available for backup, the engine can be designed for 100% hydrogen operation with a single fuel system. INNIO successfully ran the first tests with a small 150 kW engine on 100% hydrogen at a demonstration plant in northern Germany 20 years ago. In 2020, 100% hydrogen operation of a 1 MW engine was demonstrated at the HanseWerk Natur customer site in Hamburg, Germany.

Retrofit options for converting pipeline engines to hydrogen engines will be available soon for dedicated products. The Jenbacher Type 4 engines already are available today as H2-engines. This requires software changes for the engine controls together with some hardware changes. When these engines are optimized for hydrogen operation, it is still important to understand the availability of hydrogen, the application and the engine's operating profile.

Results

While pipeline gas is the most commonly used fuel for engines, 6,000 Jenbacher engines already are running on renewable gas in Europe. The main renewable gas application for Jenbacher engines is raw biogas, but sewage gas, landfill gas, flare gas and a wide range of process gases also have been used for many years. Biomethane could replace pipeline gas to a certain extent while having the same physical properties. Synthetic methane produced from hydrogen (preferably green hydrogen) also is an excellent replacement for conventional pipeline gas.

Hydrogen as a fuel for engines is a promising solution. That's because the advanced engine technology is available and proven for hydrogen, along with a wide range of gaseous fuels, and there is no need for new technology invention, only modifications of some engine parts. However, to achieve high power density, high efficiency and reliable operation with hydrogen as the main fuel for engines, more experience and further development are needed (Figure 2). Similar to the development success of the Jenbacher Type 6 engine over 30 years, an H_2-engine development roadmap can be expected, with performance growth similar or better than can be found in today's engines.

CO_2 emissions decrease in a non-linear way when looking at hydrogen volume percentage content because there is a significant difference in lower heating value per Nm3 between pipeline gas and hydrogen of a factor of 3.4. Therefore, more than 75% (v) hydrogen is required to reduce carbon emissions by 50%. NO_x emissions are expected to decrease as well because of the adjustment to a leaner combustion process. However, if hydrogen is provided in an uncontrolled way and the engine is not equipped with the latest LeanoxPlus control technology, NO_x emissions will go up and quickly can exceed emission limits. To ensure safe and reliable engine operations, a signal detailing the hydrogen content is required and can be installed on the engine control system.

Particularly when the hydrogen content changes markedly, this will ensure reliable engine operations at constant or lower NO_x emissions.

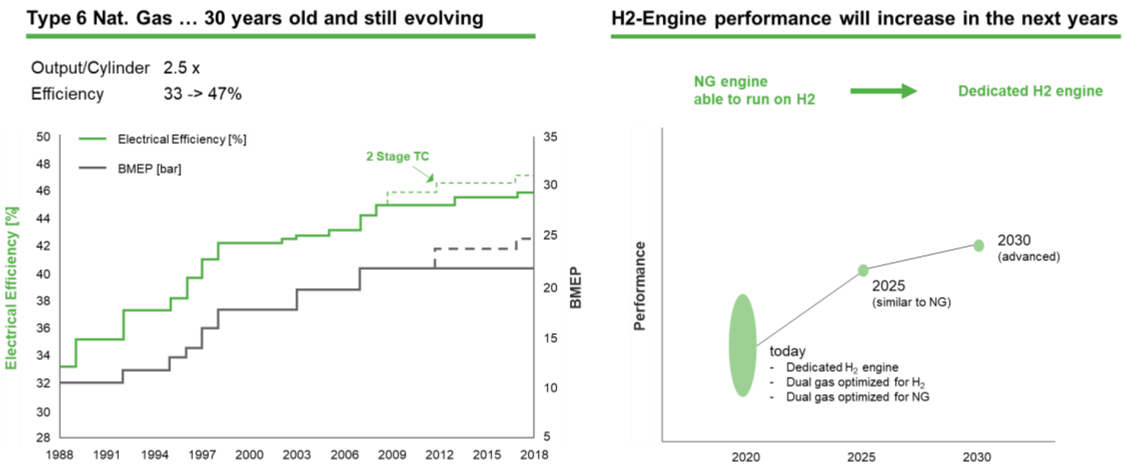

Figure 2. *The way to CO_2 free engines and CHP power plants*

Conclusion

Although the energy transition often is considered to be expensive, in many places renewable power generation from solar and wind is already the most economical power source. While in the end a more or less 100% renewable world might be very affordable, the challenge lies in the transition period. Until renewables can take over, fossil fuels must be used in parallel and phased out gradually—sometimes, but not always, with parallel infrastructure.

Renewable fuels allow for the use of established and widely available infrastructure for transport and distribution, storage and retail selling. Changes are required to switch the infrastructure from today's fossil-based fuels to renewable fuels, but these adaptations are available and already are being implemented. Current distributed power generation technologies allow a flexible transition from the use of fossil fuels to renewable fuels as they become available.

The most cost effective and fastest solution to achieving the energy transition targets and becoming carbon neutral is the utilization of existing infrastructure with required adaptations that allow for the use of different fuels. Stranded investments should be avoided as much as possible—an achievable goal with the smart design of INNIO products labeled "Ready for H2." These products allow retrofits for an easy conversion from pipeline gas to hydrogen or any other renewable gas at a later date.

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