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Circular Economy: Origins, Evolution and Role of MSW

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***Abstract* - Circular economy is presented today in opposition to linear economy. This last one was introduced at the end of the 19th, based on the terms: take, make, consume, through away. Its development was connected with the technological innovations for increasing the productivity as an absolute target. The analysis of the literature demonstrates that the first concepts of the material circularity were introduced before an official definition of waste, through the terms of Industrial Symbiosis and Industrial Ecology since the 40s. In the following decades important enhancements can be met in the criteria available for having an economy more oriented towards sustainability. A milestone can be considered the issue of the circular economy package from EU in 2015, specifically related to MSW, with the concepts of efficient and sustainable use of resources and new integrated model of production, distribution and consumption. As the EU decided to give centrality to MSW, this article analyses its role in the above-mentioned literature. CE and MSW were analysed also from another aspect: the generation of detailed information on the characteristics of residual MSW management is discussed as a strategy to support CE. Finally, the expectations of the sector as a consequence of the adoption of circularity concepts were analysed.**

***Keywords* – Circular economy; circular information; municipal solid waste; selective collection; waste management.**

Nomenclature

CE	Circular Economy
EU	European Union
LE	Linear Economy
MSW	Municipal Solid Waste
RMSW	Residual municipal solid waste
SC	Selective Collection
SRF	Solid Recovered Fuel
RDF	Refuse Derived Fuel
WM	Waste Management

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1. INTRODUCTION

Circular Economy (CE) is one of the most discussed topics in recent years. Its origin can be clearly found in the last decades connected to the industrial developments and environmental pollution. Today this concept is used in almost all the sectors and its aim is to link economic growth and use of natural resources with an environment sustainable and able to protect human health. Life Cycle Analysis can integrate this scenario supporting decision makers who act in a CE context [1].

In 2008, that is 15 years ago, the presence of 'circular economy' as keyword in the Scopus international database was very limited: only 54 products published in that year. The progression in the following years was remarkable: today the production of that kind of articles has reached two orders of magnitude higher on yearly basis, as reported in Figure 1. The same Fig. 1 shows a comparison with the CE production related specifically to waste management: the trend is similar.

The present paper focuses on the role of MSW in circular economy. In Figure 1 data on this subject are not reported because not clearly visible if introduced with the scale of the graph. However, the sector of MSW was declared strategic from the European Union when the CE package was issued [2].

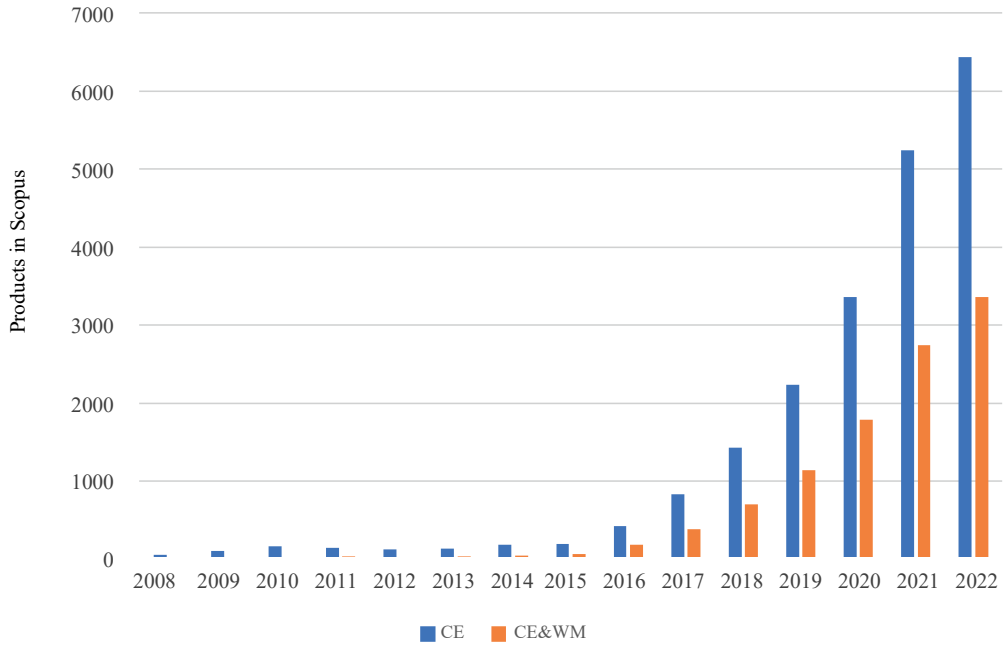

Fig. 1. Products in Scopus with CE or CE and WM as keywords (data refer to single years).

2. MATERIALS AND METHODS

The present article analyses CE and MSW from three points of view:

- The role of MSW in the literature related to CE;
- The potentialities of an enhanced information on MSW;
- The effects of CE on MSW management.

The first point was developed seeking literature since a few decades ago at worldwide level in order to analyse starting point and evolution of CE. No limitation in the approach considered in this analysis was put, because the concept of circularity in origin was included inside visions that belong to a wide variety of sectors: biochemistry, ecology, etc. The literature analysis was performed to point out when and how MSW emerged in the discussion on CE.

Concerning the second point of view, a case study chosen among regions with highly detailed information on residual MSW (RMSW) was analysed to verify if an enhanced approach of CE must be managed only at a wide scale (with a top-down adoption) or it is strategic to concentrate the generation of information in a reduced area of the territory before integrating it (with a bottom-up approach).

Finally, the presented analysis allowed the elaboration of the third point, dedicated to what can be expected in the evolution of CE in the EU concerning MSW management. Data from EU countries were used as reference.

3. RESULTS AND DISCUSSION

3.1. Dynamics of the CE vision and MSW role

The first concepts tied with the material circularity were introduced through the terms of Industrial Symbiosis and Industrial Ecology since 1940s. In 1947, Renner [3] included in his works the term ‘reuse – exchange’ as processes by which wastes or by-products of an industry or industrial processes become the raw materials for another one (exchange).

In 1966, Boulding [4] – with the paper ‘The Economics of the Coming Spaceship Earth’ presented the idea of a circular loop for the materials, considering open and closed systems.

Moreover, in the 70s, Stahel [5] introduced the concept with the expression ‘cradle-to-cradle’ in opposition with ‘cradle-to-grave’. As a consequence of the environmental revolution, the industrial ecology gained more and more importance.

In the 80s, Frosh [6] proposed an analogy of natural ecosystems, for the eco-industrial ones: in addition to reducing the production of wastes, they should maximize the efficient use of residue materials and end-of-life products, as an input for other production processes.

Ayres went ahead using the metaphor of the biosphere (ecology) – technosphere (economy) [7]. In 1994, Pauli G., through ‘Zero Emissions Research and Initiatives’ divided the economic models in three: red, green and blue economy [8]. Following, Benyus in 2002 went on with his ‘Spiral of Life’ [9].

Circular Economy was introduced in 2015 by the European Union [2], and its aim is connected with the concept of a more efficient and sustainable use of resources and a new integrated model of production, distribution and consumption. Five main priority sectors were indicated as being the ones that must be ‘rethinked’: plastics, food waste, critical raw materials, construction and demolition waste and biomass and biobased products.

In Table 1 an overview of documents of interest, vision, and role of MSW are presented, concerning the period until 2015. In that year EU issued a package on CE [2]. There, the EU officially decided to put MSW central in a strategy to stimulate the industry starting from the citizens. The targets, were recalibrated in 2018 [2].

TABLE 1. DYNAMICS OF CE VISION UNTIL 2015

Year	Author	Ref.	Vision	Role of MSW
1947	Renner G.	[3]	Industrial Symbiosis is the process by which waste or by-products of an industry / industrial process become the raw materials for another (through an exchange based on consorting together of two or more dissimilar industries); the adoption of this concept allows materials to be used in a more sustainable way and contributes to the **creation of a circularity**	Implicit
1966	Boulding K.	[4]	Earth is a closed sphere, a sort of a spaceship, without unlimited resources and infinite capacity to endure pollution and resource extraction; thus, humans must find ways for recycling resources, adapting to the **Earth's ecological cycles**	Implicit
1976	Stahel W.R. and Reday G.	[5]	Materials are viewed as nutrients circulating in healthy, safe metabolism. All materials used in industrial or commercial processes, fall into one of two categories: 'technical' or 'biological' nutrients. A correct design of then allows **adoption a cradle-to-cradle strategy**	Implicit
1982	Frosh R.A.	[6]	An eco-industrial system, must reduce the production of waste and maximize the efficient use of residue materials and **end-of-life products**, as an input for other production processes	Implicit
1989	Ayres R.	[7]	**The metaphor of the biosphere** (ecology) – technosphere (economy) can explain the concepts of industrial ecology: the metabolism of industry is the whole integrated collection of physical processes that convert raw materials and energy, into finished products and waste.	Implicit
1994	Pauli G.	[8]	Red Economy refers to entrepreneurs and industries which generally focus on one core business and one niche product, whilst Green Economy refers to the emerging business models which builds on green technologies, renewable energies and biomaterials. A **new model is Blue Economy** that relies on innovative business models which restore the environment, provide many jobs, enhance skills and produce high quality and cheap products.	Implicit
2002	Benyus J.	[9]	**Innovation must be inspired by Nature**: the science that studies natural biological systems by emulating their forms, processes, mechanisms of action, strategies, to find the most sustainable solutions to man's design and technological problems, to replicate their designs and processes in new technological solutions.	Implicit
2015	EU	[2]	This is the year when European Commission adopted its first circular economy action plan. This plan included measures to stimulate Europe's transition towards a circular economy, but also to boost global competitiveness, to favour a sustainable economic growth and to generate new jobs. **MSW and circularity are starting points** expected to positively contaminate all the waste sector	Explicit

These targets for EU are:

- A common target for recycling set at 65 % of MSW by 2035;
- A common target for recycling set at 70 % of packaging waste by 2030;
- Some recycling targets for specific packaging materials:
  - 85 % for paper and cardboard,
  - 80 % for ferrous metals,
  - 60 % for aluminium,
  - 75 % for glass,
  - 55 % for plastic,
  - 30 % for wood.
- A binding landfill target is set to reduce landfill to maximum of 10 % of MSW by 2035;
- SC obligations are strengthened including textiles;
- Prevention objectives are significantly reinforced (waste minimisation and reuse).

There is an apparent delay towards a technological discussion of CE as only in 2015 MSW became central. Possibly that depended also on the fact that the definition of waste, specifically MSW, is recent.

In the following years, an important vision is the one related to Green Deal [10]–[12] issued in 2019 and supported also by initiatives as the 'FIT for 55' package of legislation [13]. In [10] the word 'waste' can be found 12 times (out of 24 pages). It is a sort of zoom out, compared to the role that MSW had in 2015 [2] because the abbreviation MSW is not present in the document.

3.2. RMSW analyses to support CE

The importance of managing information on MSW to support CE is often discussed in the literature [14]–[18]. Keeping high the attention on MSW, even inside a small community, the territory and the population behaviour can make visible important differences. A demonstration can be the data published recently on the composition of MSW divided into 14 areas of the related province of Trento (Italy) and referring to 33 fractions [19]. Data refer to a community of around half a million people. The analysis of these data, all accessible online, points out the following variability in the RMSW characteristics, also in subcommunities of some tens of thousands of people:

- Tourist seasons are related to SC efficiency variations specifically for packaging that is separated with criteria probably different from the region of origin of the tourists. A potential problem can come from composite materials that are often managed differently in SC. An example of a possible action based on information on specific areas is the increase of the communication of SC criteria before the tourist seasons in areas of interest followed by the check of the effect after a cycle of seasons [20].
- Differences between countryside and urban areas can be steady showing a different way of buying goods. Consequences on the RMSW content can be related to packaging. An example of possible action is the local introduction of reusable packaging in countryside areas as the relationship between buyer and seller can be steadier and closer than urban areas. These differences can be seen not only for the reported case but also for other EU countries, cities, etc. [21], [22].
- A general wide use of packaging, specifically light packaging, can be found in all the territory of the considered case; focussing on RMSW composition on small areas

help to check if local strategies adopted as pilot actions should be replicated; that can be done after a cyclic verification of the effects.

Of course, an intensive characterisation of waste is done not only for improving SC but also for checking if actions aimed to redesign products have effect in what can be found in RMSW (it is not only a matter of people behaviour). SC aims to have materials that can be easily reused after very simple treatments as secondary materials for other industries to produce new or similar products with the initial ones. By this way the CE concepts are complied with.

There is a particular case that showed the need of redesign goods and surely not only at local level: pandemic criticalities like COVID-19 can cause the presence of non-recyclable materials in RMSW. Only rethinking masks, we can change the situation from non-recyclable to recyclable [23].

3.3. Effects of CE on MSW management

The introduction of CE concepts in the EU is changing the role of the available options of treatment. The priority is material recovery according to potentially extreme strategies, as explained below [24]–[26]. In Fig. 2, the MSW management situation in EU in 2020 is reported. The options directly connected with CE are material recovery and composting/anaerobic digestion. In some cases, their sum is higher than 60 % (e.g., Germany, Italy, Slovenia, Austria).

In order to deeply understand Fig. 2, some characteristics of the options available in the MSW sector are explained in Table 2.

The production of Solid Recovered Fuel (SRF) and/or Refuse Derived Fuel (RDF) through bio-mechanical treatment plants is often parallel to material recovery [30]–[34].

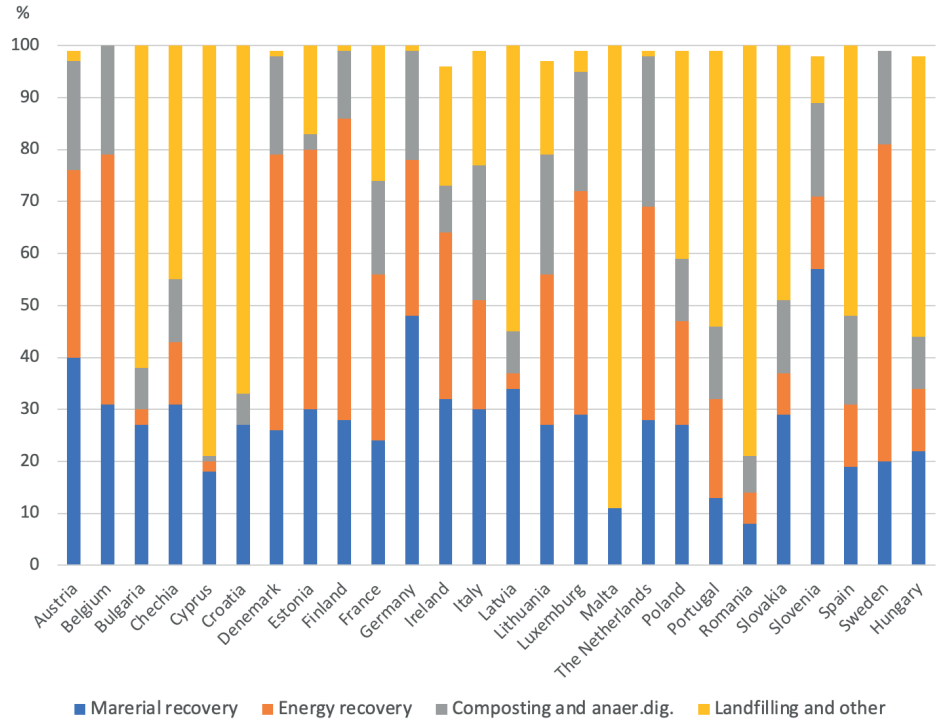

Fig. 2. MSW management situation in EU in 2020 (data from [27]). Data from Greece is not available.

TABLE 2. OPTIONS OF MSW MANAGEMENT AND CE

Characteristics	Role in CE
Direct composting Aerobic process to convert food waste and green waste into a product compost. In order to guarantee high quality compost, source separation is compulsory. If we zoom on the composition of the source separated streams, the impurities can be various (plastic bags in place of biodegradable bags, unbiodegradable packaging delivered with fractions of food waste, etc.).	Compost generation is coherent with the principles of CE. A composting plant needs electricity for its operation. If this energy comes from fossil fuels, its operation gives an impact from CO_2 release into the atmosphere; that is, the circularity of compost does not mean neutrality of greenhouse gases.
Indirect composting Anaerobic process, followed by post-composting, to generated energy and a final product, still named compost, similar to the previous case. The generation of energy is made by the conversion of a part of the organic matter into biogas; the stream of biogas, rich in methane, and its exploitation is not considered material recovery but energy recovery (in form of renewable energy, as the food waste entering the first stage of treatment, i.e., the anaerobic reactor, is a residual biomass).	The amount of renewable energy generated from biogas gives to this approach a positive balance in terms of greenhouse gases. The connection with CE depends on the production of compost (always present).
Recycling (of dry fractions) Collection of dry materials like plastic, glass, metals, paper and cardboard is performed to valorise them in industrial sectors to generate new products. Recycling of wet fractions refers to composting.	In the dry fractions case, the interest for CE concerns mostly plastic, glass, metals, paper and cardboard, all at low or near-zero moisture and all aimed to material recovery.
Waste to energy at high temperature In the EU, direct combustion of RMSW with energy recovery (incineration) is the dominant case among the processes at high temperature. Its approach presents solutions of energy recovery that are normally based on electricity generation and district heating.	The generated bottom ash until recent years have been recycled only partially. The interest in CE is connected to the recovery of bottom ash and flyash (this second stream depends on the characteristics of the off-gas treatment line) [27]–[29].
Landfilling In the EU there is a contemporary presence of conventional sanitary landfills with biogas generation and recent sanitary landfills with no biogas generation as RMSW is biostabilised before landfilling. In this second case, the landfill is no longer a biological reactor.	According to the CE principles, landfilling must be avoided.

The first effect of CE on MSW management is an increased attention to SC: values around 80 % of the MSW have become a reachable target [19] but a lot of work must be still made in some EU countries as it can be seen in Fig. 2 if we sum the contributions of recycling and composting (with and without anaerobic digestion). However, a big problem is the presence of impurities in the source separated streams; a consequence is the generation of significant streams of residues from the treatments of valorisation; these streams can be considered RMSW-like; a need is to overgo the limit of a vision based only on recycling and not on valorisation rates. In practice, the virtuosity of two territories showing an 80 % of SC can be significantly different if the impurities in the source separated streams are different. Often, this important information is not pointed out in general reports (for countries, regions, etc.).

Another limit of information concerns the real fate of source separated materials. It is not a matter only of recycling: recycling, downcycling, upcycling, are very different. Indeed, recycling refers to the case of producing a PET bottle from PET obtained from a bottle, source separated; downcycling refers to a PET bottle, source separated, that is transformed for instance into car mats; upcycling refers to the transformation of a PET bottle into a product of higher value. The simplification of the regional/national reports on WM often does not

allow accessing this kind of information. Thus, two territories showing the same percentage of recycling can be significantly different in terms of circularity.

Coming back to the treatment options, what can be expected at country level in case of high SC rates is:

- *Direct composting* will reach extreme rates of interception as kerbside collection makes the user more motivated (as personally traceable) to correctly separate his/her waste. The circularity of this stream will be more and more efficient.
- *Indirect composting* (anaerobic digestion + post-composting) will be more technological thanks to the evolution towards biomethane extraction; however, the fate of the remaining CO_2, as residual gas after extraction of methane from biogas, is not clear for economic reasons. In term of CE, the focus is expected to remain on compost quality.
- *Dry recycling* will be limited by the percentage of recyclable materials effectively recyclable. Modifications at design level of some products are expected thanks the 'pressure' of CE.
- *Waste to energy* (at high temperature) will have a new vision in terms of CE thanks to the recyclability of bottom ash (downcycling). The option of recovery of metals and inert for civil non-structural cement products is already viable at full scale.
- *SRF/RDF* is expected to remain a niche sector in countries where the adoption of co-combustion in cement works will remain limited.
- *Bio-mechanical treatment plants* will be less and less visible as SC is expected to play better their role.
- The decision of EU to limit *landfilling* of MSW to 10 % or less could make more visible a scenario with zero landfilling like already present in some countries (e.g., Belgium in Fig. 2).

In practice an extreme CE vision of the expected scenario has:

- Zero landfilling (thus preventing problems from biogas release and leachate management)
- SC made only of recyclable materials (dry and wet streams obtained mainly from kerbside systems of collection)
- Integration of energy and material recovery: biogas and compost production from high quality food waste/green waste streams
- Energy recovery from (only non-recyclable) RMSW coupled with bottom ash recycling
- In this frame, zero waste remains a target based on prevention.

4. CONCLUSION

The present article contributed to the analysis of CE and MSW focussing mainly on three subjects.

I. *The role of MSW in the literature related to CE.* According to the performed analysis, this role became explicit in 2015 in EU thanks to the CE package. In the previous decades its role was implicit as the vision put forward was related mainly on production of good, preservation of resources, processes. In practice the vision was few technological. This apparent delay towards a technological discussion of CE depended also on the fact that the definition of waste, specifically MSW, has a recent history.

II. *The role of enhancing information on MSW*. That can be seen as an opportunity to calibrate by iteration the strategies for a better CE applied to MSW. The considerations presented in this article demonstrate the central role of MSW composition analysis, both seasonally and locally (in medium-size areas). Checking, periodically, the variation of percentages and typology of products in RMSW (recyclable and non-recyclable) and using this kind of information for setting actions of substitution of non-recyclable materials, even at local scale, makes feasible to perform the targets of CE with a rational approach. These criteria should be adopted for decision makers involved in CE strategies.

III. *Effects of CE on MSW management*. These effects are clear: WM plans are giving priority to material recovery through SC but also through residues of treatment, all aimed to a scenario of zero landfilling. As discussed in the article, this last concept is technically reachable and should be a priority for decision makers involved in waste management plans.

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