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Circular Economy and Waste to Energy

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Abstract. Waste management in European Union has long being regulated by the 4Rs principle, i.e. reduction, reuse, recycling, recovery, with landfill disposal as the last option. This vision recently led the European Union (especially since 2015) to the introduction of virtuous goals based on the rejection of linear economy in favour of circular economy strongly founded on materials recovery. In this scenario, landfill disposal option will disappear, while energy recovery may appear controversial when not applied to biogas production from anaerobic digestion. The present work aims to analyse the effects that circular economy principles introduced in the European Union context will have on the thermochemical waste treatment plants design. Results demonstrate that indirect combustion (gasification + combustion) along with integrated vitrification of the non-combustible fraction of treated waste will have a more relevant role in the field of waste treatment than in the past, thanks to the compliance of this option with the principles of circular economy.

INTRODUCTION

In 2015 the European Commission proposed a set of recommendations on the current waste legislations linked with Circular Economy (CE). The official aim was "to stimulate Europe's transition towards a circular economy which will boost global competitiveness, foster sustainable economic growth and generate new jobs" [1]. The EU program of action contained measures involving the whole cycle: "from production and consumption to waste management and the market for secondary raw materials". The environment, economic, social sectors were taken into account[1-4]. The common action plan proposed by the EU for CE, considered specific key targets for all the member states such as:

- to reach up to a recycling common target of 65% of municipal waste and 75% of packaging waste by 2030;
- to reduce landfill to maximum of 10% of municipal waste by 2030;
- to prohibit landfilling of separately collected waste through the promotion of economic tools;
- to have clear and simplified definitions, methods and standards for recycling rates all over EU;
- to have concrete forms that promote the close-loop of the re-use material option;
- to stimulate EU towards a sustainable market place by offering greener products and service programs that support recovery and recycling systems.

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Small modifications were introduced recently, without modifying the overall vision given by the 2015 document. In particular, a proposal to change the target for landfilling down to 5% has been put forward recently [2].

The above objectives relate to municipal solid waste (MSW) because European Union (EU) has considered that Circular Economy introduction in that field may also be driving for special waste.

If we consider CE a priority in the EU waste management, the above mentioned “package” underlines the importance of reuse and recycling before energy recovery [6-9]. The target indeed is to close the loop of product lifecycles by an increase and an optimization of and re-use. This target can be achieved only knowing the characteristics/composition of the waste flows [10-12]. It is important to point out that this target is seen also in terms of favourable balances for both the environment and the economy [13].

In this scenario, the landfill disposal option will disappear, while energy recovery may appear controversial when not applied to biogas production, to biomethane in particular, from anaerobic digestion [14-18]. Biomethane production appears in fact more adherent to CE principles, because biomethane is a real fuel that can also be used away from the production plant.

The present work aims to analyse the effects that CE principles will have on the termochemical waste treatment plants design, specifically in EU. Considering that waste management in Europe differs significantly from region to region, part of this work was dedicated to a comparison between two virtual areas featuring different capabilities in pursuing 4R efficiency principles.

MATERIALS AND METHOD

This paper was developed according to the following steps:

- Identification of the EU vision, not only by analysing international databases (e.g. Scopus) but also by analysing the main technical documents produced on the topic by the EU; indeed an important EU production refers to the issue of thematic reports;
- Analysis of the consequences on design of future plants; the importance of this step can be fully understood if we consider the economic consequences of undersized or oversized plants;
- Discuss the consequences in contexts optimized and not optimized in terms of Selective Collection (SC); the fact that SC is compulsory in EU does not mean that its implementation is already homogeneous in the territories.

RESULTS AND DISCUSSION

The analysis of the papers available on Scopus, filtered by using the key words “Circular Economy” and “Waste”, highlighted the following:

- The scientific production in these areas is growing following an almost geometric progression, showing a doubling (approximately) of publications every year since 2015;
- The scientific literature focuses mainly on specific recycling operations, aiming in particular to avoid special waste generation by the alternative production of outputs suitable for production cycles.
- The articles dealing with CE and MSW were only two in 2015; the following years the scientific literature showed a growing interest but the sector of MSW shows a delay compared to special waste in spite of the priority that EU is giving to MSW management according to CE principles (in 2017 only 45 paper);
- Articles concerning waste strategy and CE are not very present in Scopus, percentage-wise.

For this last reason, the analysis extended to the strategic documentation produced by various EU sources became crucial. The analysis of this literature therefore allowed identifying the role assigned by the EU to the thermochemical waste treatment in a circular economy scenario [19-21]. To this role, EU dedicated in particular a document from which important criteria valid for the future can be drawn. This document was drafted during early 2017 [22].

The paper points out some guide lines to be implemented (analysed in the next paragraph) in order to achieve the coexistence of a thermochemical waste treatment plant in a CE scenario. In particular, the energy recovery feature is reported as relevant for the management of a transition phase that cannot be ignored.

Table 1 shows EU criteria and useful comments to understand the design consequences on design of waste to energy plants.

TABLE 1. Circular economy criteria and consequences on design of Waste to Energy plants

EU criterion (Circulare Economy – WtE)	**Effects on WtE design**
Co-generation or tri-generation preferable to electric only production	This aspect has implications on the choice of the area where to build the plant. With the lack of significant civil and industrial services for the heat (usually determined by remoteness from numerically significant population centers) the electric production is a priority. The plant can still be configured with a partial co-generation setup, installing an exhaust gas heat recovery system. Obviously, the variation in terms of environmental impact caused by the lower temperature of the emission source must be checked.
Avoid over-capacity plants	The concern expressed by the EU is related to the plants designed for residual municipal waste only as there is a public responsibility to guarantee the best solution also in terms of costs. The expected maximization for SC of MSW in EU will lead to a smaller amount of residual MSW as potential input. This problem can be solved co-treatment with special waste. To this concern, a stronger integration between MSW and special waste management is compulsory.
Plastic waste treated preferably with matter recovery systems	Plants must be designed knowing that input plastic waste will decrease over time.
Recyclable residues	Integrated vitrification can transform a residue into a product. The integration avoid the construction of a separate inertization plant that should treat also hazardous waste such as flyash. On the contrary, thanks to integration, flyash can be directly included in the vitrification of slag/ash. Concerning RMSW, its heterogeneity makes it more interesting the vitrification of ash from SRF. Vitrification needs high temperature (e.g.1350 °C) thus an option (common in Japan) could be the design of a zone of the reactor where an auxiliary fuel (coke) can guarantee the required energy without contributing to the production of electricity. The use of coke is controversial, thus an effort should be made to create a bio-coke by innovative solutions. In order to maximize the recovery of matter, double stage acid gas removal system from flue gases should be implemented, with the second stage based on the sodium bicarbonate injection technology. In this way, the ashes from the second filtration stage can be sent to a regeneration plant able to recover the sodium bicarbonate as a product, thus closing the cycle.
Respecting the EU waste hierarchy	Only residual waste and scraps as input. RMSW should be converted into SRF if valuable materials to be extracted are still present. Indeed the generation of SRF allows the recovery of metals, glass and other materials as a result of the need to preserve in this product only combustible materials..
Supporting new low-impact technologies	Indirect combustion allows reducing the emission of PCDD/F. The reduces excess air that characterises indirect combustion allow a reduction of NOx formation.
Do not interfere with separate collection	Design must be related to only non-recyclable streams of MSW and special waste.
Input waste availability in the next 20 years	The evolution of the sector of MSW management allows implementing forecasting models for MSW generation and their composition (specifically the one of RMSW) can be assessed in detail. On the contrary the variability of the sector of special waste makes more difficult a long-time forecast.
Proximity principle	Most of the input of a plant must be available locally. That avoid anomalies in the cost for transport and polluting emissions for long away carrying.
High electric efficiency technologies	Steam cycles with high T and P values can be performed with a reduced risk of corrosion.
No competition with funds for "waste prevention, reuse, separate collection and recycling"	Private capital should be the only solution when a plant is proposed only for special waste not related to residues from services (as sewage sludge)

An important aspect is the possibility to recover CO_2 from flue gases to be used in industrial processes, with clear benefits in regards to greenhouse gas emissions. In the case of indirect combustion, oxygen content in the off gas can be restricted (about 6%) thanks to the better mixing obtainable between fuel and oxygen. That leads to a more compact off gas with a CO_2 content higher than the case from direct combustion (which have an O_2 content of 10-12% in general). It must be pointed out that Carbon Capture and Storage (CCS) cannot be considered in line with the principles of CE as CO_2 is not valorised as a product. On the contrary, the design of a recovery of CO_2 from flue gas could be calibrated depending on the reachable industrial users of this product.

In Europe, there is a waste incineration full-scale plant which in going to adopt this option by 2020: it is the Klemetsrud plant, in Norway [23]. This plant is favoured by the location: it is close to the harbour of Oslo. This aspect could keep low the cost for transport of liquid CO_2. The test facility (2015-2016) at Klemetsrud has captured 2,000 tonnes of CO_2 per year. CO_2 has been stored in five containers feeding exhaust gases through a series of pipes and filters. All the emissions have been again released into the atmosphere. As the results of the experiment were positive, a full-scale carbon capture plant has been planned by 2020. This project is a Carbon Capture and Storage (CSS) example.

According to the CE principles, an industrial use of CO_2 extracted from off gas should be promoted. Moreover, the Norvegian plant is a conventional grate system, thus not showing optimised conditions of CO_2 percentage in the off gas. Indirect combustion can be more advantageous in this sense. More in general CO_2 sequestration should become an option to take into account for each future design of waste to energy plants, as the waste in input is and will be only partially biodegradable whilst the targets for future generation of electricity needs an enhanced approach for reducing CO_2 emissions.

One last aspect to take into account is the need to design plants able to treat waste with much higher Lower Heating Value (LHV) than those usually used in grate system plants. The features of Residual Municipal Solis Waste (RMSW) produced in areas with high separate waste collection efficiency and their mixing with special waste, which typically have high LHV, might lead to a progressive abandon of the grate incineration technology. Solutions of this type are already available in Japan, and they are also suitable for treatment capacity lower than those normally used for grate systems (thus coherent with the expected scenario of CE, that is small capacity plants).

In some European regions, SC has reached such levels that already bring the urban waste management near to the desired standard set by the EU [24]. A controversial topic is the role of the waste-to-energy, as already showcased in this paper.

From a technical point of view, extreme efficiency levels in terms of separate waste collection mean:

- Lesser quantity of residual urban waste to be treated;
- Not negligible quantities of scraps from separated waste valorisation plants to be treated.

At the same time, special waste (combustible and non-hazardous) in the area needs to be managed. In this type of scenario, the design criteria established in Tab. 1 fit perfectly.

More complex is the case of regions in which the separate waste collection is still in a transitional phase. The recovery of materials can't be maximized where the separate waste collection has not yet been optimized [25-28]. At the same time, in that scenario, a power increase of the thermal plants of the region is required in order to avoid the landfill disposal. A support for the material recovery and a greater sizing flexibility can be provided by the adoption of bio-drying systems, functional to Solid Recovered Fuel (SRF) production, which allow the recovery of recyclable materials (those still present in the residual urban waste due to imperfect separation) in a post-treatment phase. With SRF it can also be avoided the problem of thermal power oversizing since SRF can be treated in extra-regional plants. Note that bio-drying can be implemented only if it is certain that the organic content of the waste will remain sufficient to support the process [29, 30].

Regions (in a transitional phase) located in countries which "recently" joined the EU have the problem to rely heavily on the landfill disposal in regards to their urban waste management. That is the case of Romania and Bulgaria. In this context, until the separate waste collection has reached high and stable levels of efficiency, it is advisable to avoid the construction of thermochemical plants, while it appears more reasonable to set up the urban residual waste management on the SRF production to be treated in co-combustion in cement factories. This approach is coherent with the principles of CE as SRF is exploited energetically and its ash is included into a product, the cement. However, from the environmental point of view, a dedicated plant of waste to energy emits less into the atmosphere thanks to the performances obtainable in the off gas treatment line.

CONCLUSIONS

This work highlights how the Circular Economy principles can impact on the thermochemical waste processes sector. The need for more compact plants, able to treat waste with higher LHV and to turn ash into a product which can avoid the landfill disposal will make more attractive the indirect combustion process (gasification + combustion) along with integrated non-combustible fraction vitrification. In this way, risks of the adoption of a pure gasification, in which the syngas is the objective product but for which problems regarding its use in gas turbine are yet to be solved, are limited. The integrated vitrification has an additional significant advantage: avoiding the generation of a hazardous waste stream from the off gas treatment line as fly ash can be managed internally. The lower excess air that characterises indirect combustion opens to a potential adoption of solution to extract CO_2 (for industrial use) from the off gas.

CE and waste to energy give different treatment frameworks depending on SC evolution (SC can vary strongly from region to region in EU). In particular, the recovery of materials can't be maximized where the separate waste collection is not optimized. At the same time, in that scenario, a power increase of the thermal plants of the region is required in order to avoid the landfill disposal. A support for the material recovery and a greater sizing flexibility can be provided by the adoption of bio-drying systems, functional to SRF production, which allow the recovery of recyclable materials in a post-treatment phase (e.g. thanks to the adoption of automatic systems for extraction of glass, metals and inert). It is also possible to avoid the thermal power oversizing since the SRF can be treated in extra-regional plants during a first phase. Note that bio-drying can be implemented only if it is certain that the organic content of the waste will remain sufficient to support the process: an input poor of readily biodegradable materials makes not feasible this process.

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