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CO-PROCESSING - TOWARDS ECONOMIC SUSTAINABILITY

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Abstract

Co-processing is the process allowing the recovery of useful components from wastes. It represents a trade-off between reducing the volumes and toxicity of the produced wastes and recovery of valuable energetic or non-energetic components, ensuring that the new obtained products have similar quality as those produced from virgin raw materials with same or even less environmental impact during their life cycle. In this context, the dedicated information networks about produced wastes at national and international level is the most important element in order to integrate and optimize such process based on technical and environmental objectives. The aim of this paper is to fulfill such need at national level offering a possible general integrated waste management conceptual scheme based on technological and environmental information needed to progress towards co-processing. We designed it in two functional versions one for non-hazardous and the other for hazardous wastes. This should be the first step for developing a totally new information network concept, special dedicated to the waste management practical needs at national level. In the proposed conceptual scheme we embedded three conceptual models for gathering technical data with technological environmental - friendly options for recovery of two types of components namely "the non-energetic ones" - components that can be used as secondary raw materials to produce everything except energy and "energetic"ones to produce only energy, hoping to contribute this way to the implementation of circular economy and waste management sustainability in Romania..

Keywords: co-processing, management, recovery, sustainability, waste

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1. Introduction

Co-processing is targeting the economic sustainability that aims to decouple the economic growth from natural non-renewable or hard renewable resources consumption and to avoid the unbalancing of the planet ecosystem equilibrium due to the uncontrolled discharged environmental pollutants including the mismanaged wastes. Co-processing is an endeavor that is part of the implementation of waste hierarchy principle stating that avoiding generation of wastes is better than reusing, reusing is better than recovery which is actually better than disposing waste on landfills with cheapest or even no treatments. Waste hierarchy principle sets the premises for circular economy implementation, part of any sustainable development economic process. Formulated for the first time in 1987 by the Bruntland Commission in the document known as Bruntland report, the sustainable development concept pleads for satisfying the necessities of current generation without compromising and restricting for the generations to come the options to satisfy their own necessities. Sustainable development represents a challenging concept trying to integrate industrial interests with social and environmental protection components in our society. The world economic model was and continue to be a predominantly linear system based on raw materials extraction with the lowest price, their transformation into products, and the disposal of the generated wastes. By applying sustainable development and circular economy concepts society is trying to change the linear model into a circular one in order to reduce the pressure on natural resources (Deu

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et al., 2017). Circular economy concept started several decades ago in Europe and has been adopted by countries all around the world as a representative concept of the economic sustainability. It is actually a virtuous economic endeavor trying to make the integration of the market offer and demand for the secondary raw materials products into the market offer and demand for virgin raw materials ones as a viable technical and economical mechanism. It is a very ambitious practical task because it states that products obtained from secondary raw materials should be similar in quality with those from virgin raw materials, should not produce a greater environmental impact during their life cycle and last but not least be also competitive as price. To accomplish those ambitious goals, there is one single way, that of finding innovative solutions to obtain value from waste protecting in the same time environment and human health from pollution and depletion of non-renewable resources. Why we need such a change? It is mainly because pollution is showing its hidden, ugly face when it comes especially to the environmental and human health effects. The examples of strong pollution are all over the world for quite some time but we all continued to neglect or ignore them. We preferred the cheapest environmental protection solutions not thinking that generated pollution effects on human health might be so insidious. One such example is waste incineration. As Thompson and Anthony (2005) have shown, although waste incineration facilities are recognized to reduce the volumes of processed wastes and their toxicity, they are still a major source of toxic heavy metals particulates and more than two hundreds toxic organic chemicals. The incinerators' atmospheric pollution equipment "merely transfer the toxic load, from airborne emissions to the fly ash" creating just a false public perception of environmental safety. They cite the National Research Council - an arm of the National Academy of Sciences that was established to advise the US government that show for example that "persistent air pollutants such as dioxins, furans and mercury can be also dispersed due to the fly and bottom ashes over large regions far beyond the incinerators locations being a real danger for human".

To mitigate the waste pollution effects produced along the years, there is an acute need for a change in our behavior towards the environmental protection. A civilized society cannot claim its sustainable development success when this is done on the expense of health of its members and, in this respect, here are some undeniable facts: increase in mortality from cerebrovascular disease (76%), lung cancer (37%) and increased risk of vein thrombosis in diabetic patients (DVT-Diabetic Vein Thrombosis) of 70% due to an increase of 10 $\mu g/m^3$ in fine particulates atmospheric pollution along with the prevalence of respiratory infections, asthma, allergies and COPD (Chronic Obstructive Pulmonary Disease), life-threatening arrhythmias, exercise-induced ischemia, thrombotic disease leading to heart failure, as US research studied have shown in the last decades (Thompson and Anthony, 2005). For all these reasons co-processing is a must.

Academic community all around the world joined the common effort by offering different alternatives solutions to sort, collect (Sidique et al., 2010) and pretreat/treat the wastes with different technologies. Some of those technologies are even state of the art. We hope this way that in quite some time we will reach to decouple our economic growth from resources consumptions and we will prevent damages made by pollution to the environment and human health. Here are some innovative co-processing relevant examples found in the literature addressing the current pollution issues: *recycling plastics from solid wastes* (Al-Salem et al., 2009; Siddiqui, 2009; Siddiqui and Redhwi, 2009), *use of waste containing PET in mortar composite products* (Benosman et al., 2017), *separation of aluminum and plastic for recycling waste pharmaceutical blisters* (Wang et al., 2015), *obtaining energy from biomass* (Dhanya et al., 2020; Gavrilescu, 2008; Srivastava et al., 2020; Zeman et al., 2019), *soil reclamation* (Yarbasi et al., 2020), *growing plant in fly ash for biodiesel* (Mohan, 2011), *using biomass oil in combination with vacuum gas oil in refinery FCC units* (Fogassy et al., 2010), *metal recovery from coal fly ash* (Sahoo et al., 2016; Tolhurst, 2015), *metals recovery from fly ash from the incineration of peat and wood residues* (Poykio et al., 2011), *rare earth metal recovery from coal fly ash* (Taggart, 2015), *uses of coal fly ash* (Blissett and Rowson, 2012; Yao et al., 2015), *use of coal fly and bottom ashes* (Uliasz-Bochenczyk and Bak, 2018), *waste use in concrete and cement products* (Mohan, 2011); *obtaining glass-ceramic from mixture of bottom and fly ashes* (Vu et al., 2012), *obtaining ceramic from bottom ash* (Schabbach et al., 2012), *fly ash for sulfoaluminate cement clinker production* (Wu et al., 2011), *municipal incinerator bottom ash used in concrete and cement* (Kuo et al., 2013), *different uses of bottom ash from municipal waste incineration* (Pei, 2017), *use of sewage sludge ash in construction industry* (Smol et al., 2015), *recycling metallurgical slag* (Reuter et al., 2004), *use of aluminum salt slag* (Tsakiridis, 2012); *fly ash from coal and biomass thermal processes for zeolites synthesis* (Belviso, 2018), *zeolitic type material synthesis for heavy metal adsorption from bottom ashes municipal waste incineration* (Chiang et al., 2012), *Zn from electric arc furnace dust (EAFD) for multi-metal doped ferrite with enhanced magnetic property* (Wang et al., 2017), *use of fly ash in agriculture* (Basu et al., 2009).

As Deu et al. (2017) mention in the view of circular economy concept *"products or by-products should circulate throughout the economy and continue to generate value"*. In order that this model to be functional, an information network is mandatory to exist among different interested parties. In line with such essential requirement and in order to fulfill such need at national level, we proposed in this paper a *possible general integrated waste management conceptual scheme* assisted by databases with technological and environmental information needed for co-processing purpose to recover useful non-energetic and energetic type components. When choosing a new recovery technology we should see if it is an environmental safe one and the obtained products do not create new hazards for environment and human health. And this directs to the next comment to be open for discussion. For example, finding solutions for using fly ashes from thermal processing sometimes directs towards using them in nanoparticles production. Almost 2 % from annually nanoparticles production is discharged in the environment. Nanoparticles interactions with biological systems when they reach our lungs for example can lead to chronic inflammatory responses and the development of diseases such as multifocal granulomas, peri bronchial inflammation, progressive interstitial fibrosis, oxidative stress etc. (Bundschuh et al., 2018, Ferreira et al., 2013) that is why they have no safety environmental discharge limits. Although it is an imperious need for co-processing we need information pros. and cons. when it comes to choose a certain technology. For example, if plants for biofuel can be grown on ash, there is a gain for the society because old landfills that look like desert landscapes can be made more environmental friendly blocking in the same time the spread of ashes with those plants. If those plants can be further used to produce biofuels that can mitigate greenhouse gas emissions by up to 50 % as shown by Srivastava et al. (Srivastava et al., 2020) and have lower NOx and particulates matter emissions having in the same time for the produced biofuel "higher oxidation stability for storage purposes, a lower temperature of loss of filterability for the winter time, a lower boiling point for cold starts and more as shown by Zeman et al. (2019) this is actually a double or even a triple gain for the society. A sustainable development energy approach in the energy sector is going towards converting organic waste to bioenergy because as Dhanya et al. (2020) showed, bioenergy production is "associated with mitigation of environmental negativities at waste disposal". Reducing environmental impact is an essential element for achieving sustainable development. In this respect, we should mention that in the past decades, our main research interests have been linked to different projects we worked for, interacting with a lot of Romanian waste producers that asked us for consultancy in order to be able to reduce the volumes and the toxicity of their produced wastes recovering in the same time useful components. (Arama, 2007a, 2007b; Arama and Nicolau, 2009a, 2009b, 2009c; Arama et al., 2010, 2011; Arama and Kim, 2016; Arama et al., 2017a, 2017b; Arama et al., 2018a, 2018b; Gheorghe et al., 2010; Guta et al., 2014; Guta et al., 2017; Kim et al., 2017; Kim et al., 2018a, 2018b, 2018c, 2018d; Kim and Arama, 2019; Mihaila et al., 1994; Serbanescu et al., 2018). Romanian wastes producers repeatedly expressed their need for information in relation to the way they can manage their produced wastes in order to fulfill the set recovery targets at the European and national levels. This is actually how the idea of this study came up being linked actually to Romanian waste producers practical needs.

In Romania, as is also the case in other countries (Dino et al., 2017; Westarb Cruz et al., 2013), there is a real need for such dedicated information network when it comes to find practical environmental friendly solutions to recover useful components from waste. In order to sustain the application of circular economy both at the national and European levels, the European legislation for harmonized waste classification based on the LoW (List of Waste) and connected environmental legislation at 2020 year level - EC Commission Decision (2000); EC Regulation (2006); EC Directive (2008); Directive 2008/98/EC; EC Regulation (2008); EC Regulation (2014) - created the legal necessary framework for the implementation of an integrated waste management strategy. But in Romania, for circular economy implementation we need a step forward. We know that this is a global effort. We know also that the updated information exchange can bring us more closer to the achievements of the set European recyclable targets therefore, we found that an integrated waste management general conceptual scheme to structure the waste co-processing management options is that step forward we need. And that is a totally new concept in Romania. In this dedicated network, the waste producer/holder can log on and find *if its code for the generated waste is on national priority list of waste* in the Romanian plan at the level of year 2019. This way, producer can see what might be done regarding the recovery of the useful components. It is common knowledge that co-processing is a management option that offers a viable alternative both from the economic and environmental and human health protection prospective so consequently, the waste producer wants to find usually quick answers to questions like:

- Can be a waste with a certain code managed alone with no treatment or with ordinary treatment technologies to recover either non-energetic or energetic products?
- Can be managed a waste with a certain code with no treatment or with ordinary treatment recovery technologies only combining it with a waste with same code but from different sources or with wastes having different codes? Who are producers of wastes with the same codes? Are they nearby or within Romanian territory etc.?
- Are there any known complex technologies that can recover useful components from the waste adding this way more value to waste recovery process?

The current status in co-processing in the world is mainly related to the activities from metallurgy and siderurgy, cement production, construction and road materials production and refinery sectors. For the products resulting from co-processing of ashes, the goal is to bind for example toxic leaching compounds in solid matrices. From these products different pollutants like heavy metals are not expected to leach in use, in the following 100 years in local weather conditions as is for example the regulatory framework in Netherlands. Also Germany and France have been adopted special regulatory rules to be sure that the quality of the produced products coming from co-processing is strictly followed. In USA the situation is the same, they collect fly and bottom ashes from municipal incinerators together and try to use them in road and highways construction with strict reinforcement of the obtained product quality (see also Table 1). However co-processing is in plain development because it is a must if we want go towards economy sustainability.

2. Material and methods

The conceptual data modeling is the process of structuring the information with sense, to understand general concepts about the topic and relations among them when a search is performed. This is a step of paramount importance in any intention to make a knowledge sharing platform with waste information. The three types of the developed conceptual models for gathering waste technical data that we propose to be used, have been focused on the possibilities to obtain secondary raw materials from both non-hazardous and hazardous types of wastes, considering for the practical management reasons their mixing compatibilities only when this action is meant to facilitate their treatment.

The three models have been constructed avoiding too technical specific languages (jargons) in order to be easy understood both by database designers/developers and by the target main audience - waste producer/holder - and are based essential on the concepts used in the harmonized waste classification and current waste European legislation. When a search for waste recovery technologies will be done through a DBMS - Database Management System (Teorey et al., 2011) the producer/holder will have to enter only the waste code according to the harmonized European Legislation as a search key. In Fig.1 is presented an information flow chart used to construct the proposed general waste management conceptual scheme with its two versions 1 and 2 for hazardous and non-hazardous solid, liquid and mixed waste. It explains in a synthetic way the basic flow of information presented in more detailed in Figs. 2a and 2b. Information from Modules I, II and III feed the two Data Base Modules - Version 1 for non-hazardous solid/liquid/mixed wastes and Data Base Modules - Version 2 for hazardous solid/liquid/mixed wastes in attention to the National Waste Strategy and Plan 2019.

3. Results and discussion

The following three conceptual models for gathering data used within the proposed waste general integrated management conceptual scheme are presented next.

The **CONCEPTUAL MODEL OF TYPE I** is applicable to both non-hazardous and hazardous wastes that can be managed alone with and without special recovery treatment technologies - including also when is possible the untreated option (that is shown in flow chart from Fig. 1 by the dashed lines from Module 1 going to the two Data Bases modules version 1 and 2 from underneath).

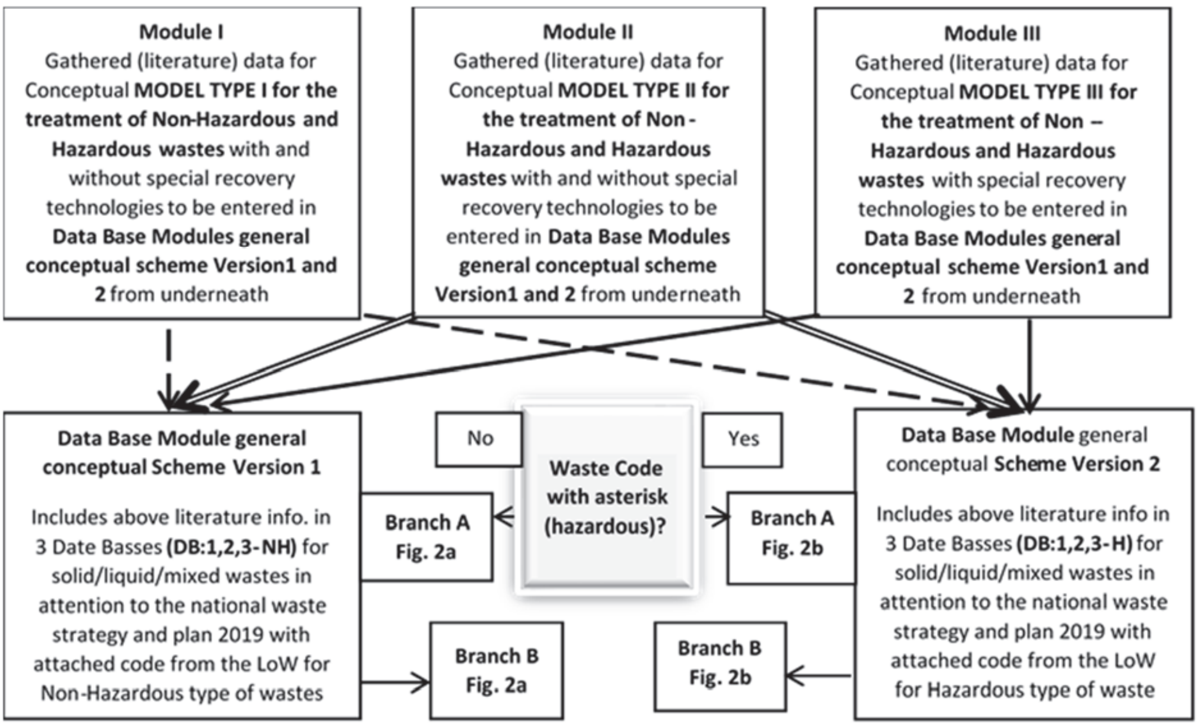

Fig. 1 - Flow chart with information integrating Modules I, II, III with co-processing technologies data with modules Data Bases (version 1 and 2) based on waste code key search

The **CONCEPTUAL MODEL OF TYPE II** is applicable to both the non-hazardous and hazardous wastes that can be managed in combination with and without special treatment recovery technologies - including also when is possible the untreated option (that is shown in flow chart from Fig 1 by the double lines from Module 2 going to the two Data Bases modules version 1 and 2 from underneath).

The **CONCEPTUAL MODEL OF TYPE III** is applicable to the non-hazardous/hazardous wastes that can be managed alone or in combination but only with special treatment recovery technologies (that is shown in flow chart from Fig. 1 by the single lines from Module 3 going to the two Data Bases modules version 1 and 2 from underneath).

Based of complexity and novelty of treatment technologies, we should mention that we did not consider as special treatment recovery technology a waste incineration process. However, we have included technologies such as obtaining nanocomposites (Wang et al., 2017), the treatment of biomass (bio-oil-mixtures) co-processed in FCC refinery units (Fogassy et al., 2010) or mixed plastics pyrolysis for feed stock recycling (Siddiqui and Redhwi, 2009).

So, for the practical purpose we have realized a single general conceptual scheme for the integrated management for the non-hazardous waste version 1 (Fig. 2a) and for the hazardous waste version 2 (Fig. 2b) comprising the three proposed conceptual models for data gathering. This general conceptual scheme includes six specific types of conceptual schemes having attached six databases, (three within Data Base Module version1 – (***DB:1,2,3 - NH)*** and three within Data Base Modul version 2 – ***(DB:1,2,3 - H)*** see Fig. 1) being documented by six research studies. The structured information about useful components that can be recovered with different waste treatment technologies is filling in those six databases for hazardous/non-hazardous solid, liquid and mixed type of wastes which can be linked with specialized sites for continuously updates. So, to each database corresponds a specific type waste management scheme included in the general conceptual scheme (version 1 and 2) identified as follows:

- Scheme of type I_NH_(UN)/T_A/C_1 abbreviation for: (I)-Integrated; (NH)-Non-Hazardous; (UN)-Untreated; (T)-Treated with usual and special technologies; (A)-Alone/(C)-Combination; (1)-Solid Wastes; It is attached to one specific ***(DB1-NH)*** Data base within Data Base Module version 1 (Fig. 1 and Fig. 2a);
- Scheme of type I_H_(UN)/T_A/C_1 abbreviation for: (I)-Integrated; (H)-Hazardous–(UN)-Untreated)/(T)-Treated with usual and special technologies; (A)-Alone/(C)-Combination; (1)-Solid Wastes; It is attached to one specific ***(DB1-H)*** Data base within Data Base Module version 2 (Fig. 1 and Fig. 2b);
- Scheme of type I_NH_(UN)/T_A/C_2 abbreviation for: (I)-Integrated; (NH)-Non-Hazardous; (UN)-Untreated/(T)-Treated with and without special technologies; (A)-Alone/(C)-Combination; (2)-Liquid Wastes; It is attached to one specific Data base ***(DB2-NH)*** within Data Base Module version 1 (Fig. 1 and Fig. 2a);
- Scheme of type I_H_(UN)/T_A/C_2 abbreviation for: (I)- Integrated; (H)-Hazardous-(UN)-Untreated)/(T)-Treated with usual and special technologies; (A)-Alone/(C)-Combination; (2)-Liquid Wastes; It is attached to one specific Data base ***(DB2-H)*** within Data Base Module version 2 (Fig. 1 and Fig. 2b);
- Scheme of type I_NH_(UN)/T_A/C_3 abbreviation for: (I)-Integrated; (NH)-Non-Hazardous; (UN)-Untreated; (T)-Treated with usual and special technologies; (A)-Alone/ (C)-Combination; (3)-Mixed Wastes; It is attached to one specific Data base ***(DB3-NH)*** within Data Base Module version 1 (Fig.1 and Fig. 2a);
- Scheme of type I_H_(UN)/T_A/C_3 abbreviation for: (I)-Integrated; (H)-Hazardous; (UN)-Untreated)/(T)-Treated with usual and special technologies; (A)-Alone/(C)-Combination; (3)-Mixed Wastes; It is attached to one specific Data base ***(DB3-H)*** within Data Base Module version 2 (Fig. 1 and Fig. 2b).

Next will present an example from the Research Study 1 that generated the Scheme of type I_NH_(UN)/T_A/C_1 abbreviation for:(I)-Integrated; (NH)-Non-Hazardous; (UN)-Untreated/(T)-Treated with usual and special technologies; (A)-Alone/(C)-Combination; (1)-Solid Wastes that is attached to one specific ***(DB1-NH)*** Data base within - Data Base Module version 1 (Fig. 1 and Fig. 2a).

The Study 1 has been realized in order to structure information about the recovery technologies applied to the ***non-hazardous solid wastes***. In this respect the wastes have been divided in wastes coming from thermal, mechanical and mixed processes that are usually carried out in the following areas: energetic, metallurgical industries, waste incineration including municipal wastes, building/demolition, pulp and paper industries etc. in attention to the waste strategy and plan 2019 in Romania. Those processes all over the world have some specific particularities. Those particularities have been considered in order to recover useful components. Those particularities direct towards certain uses and in this spirit each category has been characterized considering those aspects of interest linked to the waste generation processes so that to be useful to the integrated management recovery technological possibilities. A synthesis is presented in Table 1.

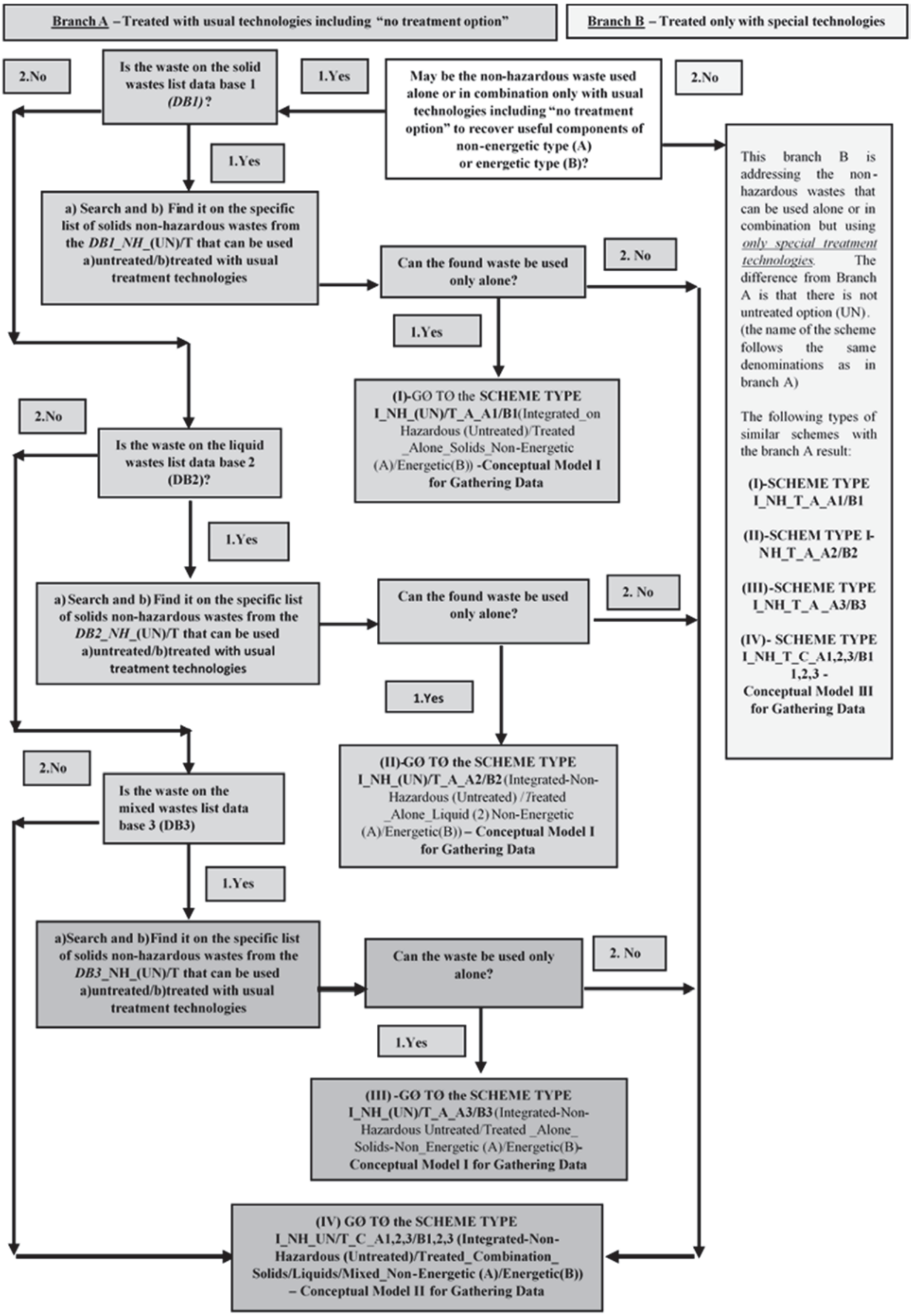

Fig. 2a. General Conceptual Scheme - Version 1 for non-hazardous waste

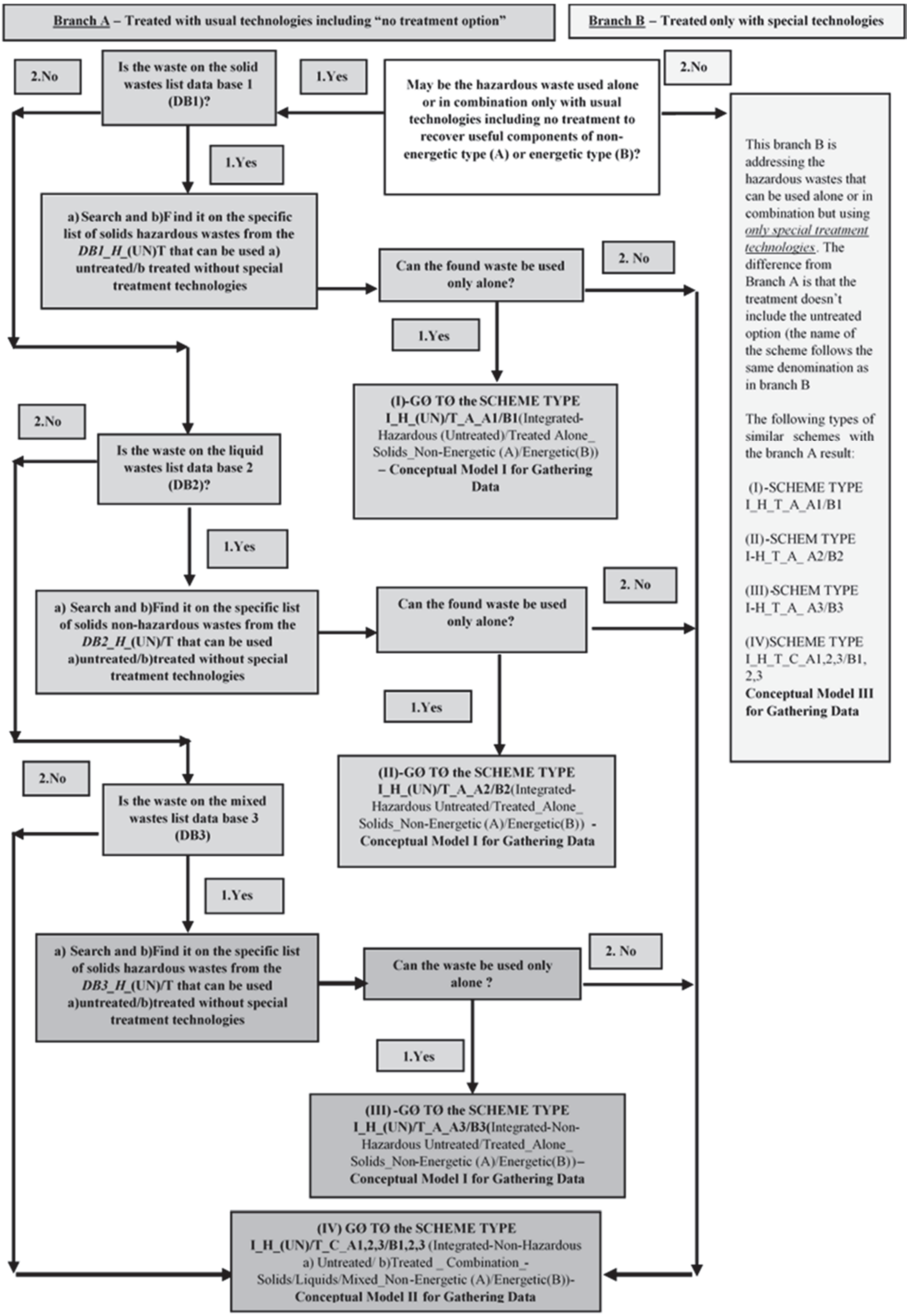

Fig. 2b. General Conceptual Scheme - version 2 for hazardous waste

Table 1. Example of non-hazardous waste solids from thermic processing incineration/pyrolysis of the municipal wastes – heavy and light fractions that can be managed alone or in combination with no treatment, usual treatment or special treatment technologies to recover non-energetic components of type A and energetic components of type B

Useful components of non-energetic type (A)-secondary raw materials		
(0)	***(1)***	***(2)***
Areas of applications	Bottom Ash when collected separately ***Heavy fraction (bottom ash)*** alone or in combination with the same type of fraction from different sources e.g. of waste codes form LoW : 19 01 02, 19 01 12, 19 01 18, 19 01 19	Fly Ash when collected separetely ***Light fraction (fly ash)*** alone or in combination with the same type of fraction from different sources e.g. of waste codes form LoW: 19 01 14, 19 01 16
Recovery of ferrous material for siderurgy - secondary raw materials (ISWA-WG, 2006)	Applied in proportion 87- 100 % in Austria, Check Republic, Danmark, France, Germany, Netherlands, Norway, Portugal	
Recovery of non-ferrous materials for the metalurgy - secondary raw materials (ISWA-WG, 2006)	Recovery of non-ferrous materials is generally less applied in countries like France, Germany, Netherlands and Norway	
In civil engineering and construction works (ISWA-WG, 2006)	50 - 80 % in Check Republic, Danmark, France, Germany, Netherands with adapted standards for building materials	Applied in European countries where the management of fly ash is done separately from the bottom ash
In building materials (cement, concret, light concret, thermic insulator material) (Kuo et al., 2013; Vu et al., 2012)	Bottom ash is a composite material that is made of aggregate, pozolanic agents and additives. Can be used as cementous/binder agent as powder that can act as a cohesive agent for the sands to form elements of hardening and to keep the desired form. Improvement of the mechanical properties	
In ecological application as - sorbent (zeolitic) (Chiang et al., 2012) - catalitic suport for Volatile Organic Carbon compounds oxidation (Chiang et al., 2012).	Hydrotermal Conversion in alkaline conditions in adsorbant material BET 22.1 m^2/g - improvements relative to the simple untreated bottom ash that has a BET 4.6 m^2/g due to the formation of micro and meso pores (some heavy metals like As, Cd, Ni and Zn). Superior performance of the natural zeolit clinoptilolit for VOC oxidation (Volatile Organic Carbon compounds)	
In agriculture applications (Schabbach et al., 2012)	Soil fertilizer/stabilizer	Soil amendment
In the production of glass and ceramic industry (Vu et al., 2012; Wu et al., 2011)	The fabrication of vitrous ceramic from the mixture of bottom and fly ashes	The fabrication of vitrous ceramic from the mixture of bottom and fly ashes
Useful components of energetic type (B) - secondary raw materials		
Energy recovery (Pei, 2017)	Only in the context of specific plant energetic management depending how the fractions are colected (for e.g. in US the bottom ash is collected together with the fly ash while in Europe they are collected separately). Part of the energetic recovery of the incineration can be theoretically assigned to the ash fraction	Only in the context of specific plant energetic management depending how the fractions are colected (for e.g. in US the fly ash is collected together with the bottom ash while in Europe they are collected separately) Part of the energetic recovery of the incineration can be theoretically assigned to the ash fraction

4. Conclusions

To have an integrated waste management strategy at European level in order to recover waste components and to sustain the implementation of circular economy concept, information at national levels should be ready available. If something should be integrated in a practical way the information should be ready accessible to the local waste producers/holders. This way they can find alone technical and economic partnerships for their endeavors. Consequently, for practical implementation of circular economic concept we need first the integration of information.

Circular economy concept cannot be implemented without such technical information sharing platform about: waste technologies, recovered components and sites where waste are generated or disposed. The necessity of such study came from the very core of the circular economy concept and the novelty of the proposed conceptual scheme resides in level of data integration and types of data to be integrated according to the practical waste management necessity in Romania.

Without such a knowledge sharing platform the practical implementation of circular economy remains elusive and the waste pollution will continue to produce its damages to our environment and human health.

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