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Selected papers (2)

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Editor-in-Chief: Maria Gavrilescu

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Aims and Scope

Procedia Environmental Science, Engineering and Management (P - ESEM) is a journal focusing on publishing papers selected from high quality conference proceedings, with emphasis on relevant topics associated to environmental science and engineering, as well as to specific management issues in the area of environmental protection and monitoring.

P - ESEM facilitates rapid dissemination of knowledge in the interdisciplinary area of environmental science, engineering and management, so conference delegates can publish their papers in a dedicated issue. This journal will cover a wide range of related topics, such as: environmental chemistry; environmental biology; ecology geoscience; environmental physics; treatment processes of drinking water and wastewater; contaminant transport and environmental modeling; remediation technologies and biotechnologies; environmental evaluations, law and management; human health and ecological risk assessment; environmental sampling; pollution prevention; pollution control and monitoring etc.

We aim to carry important efforts based on an integrated approach in publishing papers with strong messages addressed to a broad international audience that advance our understanding of environmental principles. For readers, the journal reports generic, topical and innovative experimental and theoretical research on all environmental problems. The papers accepted for publication in *P – ESEM* are grouped on thematic areas, according to conference topics, and are required to meet certain criteria, in terms of originality and adequacy with journal subject and scope.

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GUEST EDITORS

Fabio Fava, born in 1963, is Full Professor of "Industrial & Environmental Biotechnology" at the School of Engineering of University of Bologna since 2005.

He coordinated the FP7 projects (collaborative projects) NAMASTE (on the integrated exploitation of citrus and cereal processing byproducts with the production of food ingredients and new food products) and BIOCLEAN (aiming at the development of biotechnological processes and strategies for the bioremediation and the tailored depolymerization of major oil-deriving plastics). He also coordinates/coordinated the Unit of the University of Bologna participating/participated in the FP7 projects (collaborative projects) ECOBIOCAP and ROUTES (on the production of microbial polymers from different organic waste and food processing effluents), MINOTAURUS and WATER4CROPS (on the intensified bioremediation of contaminated waste- and ground-water and the integrated valorization and decontamination of wastewater coming from the food processing industry and biorefinery), and ULIXES and KILL SPILL (on the development of strategies for intensifying the in situ bioremediation of marine sediments contaminated by (chlorinated)hydrocarbons and the isolation and industrial exploitation of microbes from such contaminated matrices). He also participated in the FP7 BIORICE addressed to produce added value bioactive ingredients (semi-purified digestates and small molecular weight peptides) starting from protein by-products contained in the processing water of the rice starch production stream. He is vice-chairman of the "Environmental Biotechnology" section of the European Federation of Biotechnology (EFB). He is the Representative of the Italian Ministry of Education, University and Research in the "Working Party on Biotechnology, Nanotechnology and Converging Technologies" at OECD (Organization for Economic Co-operation and Development), Paris, in the "European strategy for the Adriatic and Ionian Region" (EUSAIR) and in the "Western Mediterranean Initiative" (WEST MED). Further, he joined the "High Level Group on Key Enabling Technologies" and he is member of the "Expert Group on biobased products", both at the DG-GROW of European Commission (Brussels). Further, he is member of the Scientific Committee of the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI). Finally, he is the Italian Representative at the European Commission (Brussels) in the Horizon2020 Programme Committee of Societal Challenge 2: European Bioeconomy Challenges: Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and inland water research" (DG RTD) and in the BLUEMED initiative (Chair of the Strategic Board) (DG RTD and DG MARE), and in the "State Representative Group" (as vice Chair) of the Public Private Partnership "Biobased Industry" (BBI JU) (Brussels).

Grazia Totaro, born in 1976, has a degree in Chemistry (University of Ferrara), a Master's Degree in Science, Technology & Management with a specialization in Environmental Chemistry (University of Ferrara) and a PhD in Materials Engineering, about modification, characterization and applications of technopolymers (University of Bologna).

She worked at the R&D Centre of Basell Polyolefins in Ferrara for 2 years in the frame of a project addressed to the development of a novel methodology for qualitative and quantitative analysis of additives in polymers. She also worked at ARPA, Regional Agency for Environment in Ferrara, division Water Analysis. Then she started working at the school of Engineering of the University of Bologna for a Ph.D. in Materials Engineering (2007-2010). After that she had a scholarship "Spinner 2013" in cooperation with Reagens spa (San Giorgio di Piano) on novel PVC nanocomposites. Now she is post doc fellow at the same school on new polymer-based nanocomposites from renewable sources and inorganic fillers. She also worked at the laboratoire de Chimie et Biochimie Pharmacologique et Toxicologique (Université Réné Descartes) in Paris in 2001 and was visiting professor at the Ecole Nationale Superieure de Chimie (Université Blaise Pascal, Clermont Ferrand, FR) in 2012 and 2015.

Dr. Totaro has about 20 scientific papers and several participations at conferences and scientific schools. She collaborates on Ecomondo from 2013.

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INNOQUA: INNOVATIVE ECOLOGICAL ON-SITE SANITATION SYSTEM FOR WATER AND RESOURCE SAVINGS*

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Abstract

The paper discusses the main concerns of an European project, within "H2020-EU.3.5.4. - Enabling the transition towards a green economy and society through eco-innovation". As described on the EC website "INNOQUA will accelerate the path to market of a modular set of innovative, patent protected, award winning and scalable fully ecological sanitation solutions that address wide market needs in rural communities, for agricultural industries, for sustainable home-builders or collective housing owners and for developing countries worldwide".
The project is built based on a modular system addressing the purification capacity of biological organisms (worms, zooplankton and microalgae) so as to bring the necessary ecological, safe and affordable sanitation capacity, "by fully addressing the thematic and cross cutting priorities of the European Innovation Partnerships (EIP) on Water".
The integrated solution proposed by the project is a new and innovative one. The final reuse of wastewater offers a particularly attractive strategy in European communities characterized by small to medium remote water stress, but also with high water demand for agricultural purposes and/or in the view of natural freshwater ecosystems conservation. This way, the proposed strategy can prove to be a sustainable solution for 'zero' wastewater production with the complete reuse of this resource, at small to medium scale situations. However, to reduce the waste directed to surface freshwaters, an integrated solution for the treatment of wastewater is required. This will lead to the attainment of good quality of water, as stated by the Water Framework Directive. The robust but efficient technologies are also perfect for distribution in markets where resources are restricted and trained staff inaccessible.

Keywords: environmental impact, innovation, sustainable solution, wastewater treatment

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1. Introduction

In Europe there are still significant non addressed water concerns. Directive 91/271/CEE, related to the treatment of urban wastewater, establishes criteria and deadlines for the purification of wastewater in all EU Member States, while the Directive 2000/60/CEE (Council Directive, 1991; WFD, 2000) establishes a community framework of action for water policy aspects, which had to be achieved before the end of 2015. Both Directives state the need for an appropriate spill treatment with the purpose of maintaining a good ecological status of water resources. Although 91.4% of EU settlements have less than 2000 inhabitants, making up 20% of the total population of the EU (Somogyi et al., 2009), a large proportion of these communities still fall short of the standards that were stipulated in these measures in terms of wastewater purification and sanitation.

The percentage of the EU population connected to central water supply systems ranges from 55.6% to 99.3%, depending on the country (EEA, 2012), while the proportion of the population coupled with waste water treatment plants (WWTPs) varies from 40% to 90% (EEA, 2007). Data from individual countries show that EU countries have established target ranges from 75–90% of their populations to become connected to sewerage and treatment systems (Somogyi et al., 2009). Despite the fact that EU Water Framework Directive (EU WFD) obliges all countries to achieve the "good status of all the waters" in their territories, there is a gap of 10–15% of the population, equivalent to about 20 million rural inhabitants, who will endure the lack of proper sanitation systems after 2015.

Worldwide, one of the great challenges of the twenty-first century is to reach a global level of development that eliminates inequalities ensuring a decent quality of life and minimum standards for all peoples across the globe. Without a doubt, one of the most important objectives to achieving this global goal is to find a solution for the lack of access to potable water and basic sanitation, which are key aspects to be considered in national development strategies (Benetto et al., 2009; Chianura, 2014; Miksch et al., 2015). Currently, more than one billion people across the globe do not have access to clean water, while 2.6 billion people do not have access to adequate sanitation. Differences between rich and poor communities and urban and rural populations further aggravate this situation, whilst the lack of basic sanitation negatively affects health and social development, especially in the case of women and children and impacts seriously on the environment and the capacity for a society to develop economically. Climate change is also bringing new challenges. In many European Mediterranean countries a severe drought is in many cases cutting people off the water grid or wells have run dry. Water scarcity is a growing concern (Allouche, 2011; Ozkan, 2014; Pagano et al., 2014; Sorlini et al., 2015).

It is in this context that the main economic and technical limitations occur. In order to be able to offer a solution that is of practical benefit to rural areas both in the developed world and countries, and regions that face serious economic constraints, it is necessary to guarantee the elimination and adequate treatment of wastewater with minimum implementation costs and affordable service costs and in a socially acceptable manner. Decentralized, small-scale systems and non-conventional purification technologies such as those presented in INNOQUA offer a solution to the problem faced by these communities. They resemble natural purification processes, are simple, low energy consuming and easy to manage and are cost effective (https://www.openaire.eu/search/project?projectId=corda__h2020::bac817591510efce0aae9ae0064be1db).

The main objectives of this study are to integrate individual low cost, sustainable and biologically based water sanitation technologies capable of performing a whole water treatment cycle and available in multiple modular configurations adapted to local contexts and markets (5 technologies in total, 5 possible configurations).

To demonstrate across 10 countries in 4 continents the long term viability of innovative, modular and sustainable solutions for wastewater treatment in real-environment, to support the commercialization of the proposed solutions in order to encompass pre-commercialization challenges of innovative water solutions and to start stimulating economic growth, business and job creation in the water sector both inside and outside Europe. To eco-design and optimize the proposed solutions to increase the sustainable performance of the water sector through an optimized environmental performance (reduced water consumption, increased resource efficiency, reduced carbon footprint...), a socially accepted and affordable wastewater treatment system (Allouche, 2011; Garrote et al., 2015; Pagano et al., 2014).

2. Concept and approach

The project concept is to develop and demonstrate an innovative, modular and sustainable wastewater treatment technology based on the purification capacity of certain biological organisms (earthworms, zooplankton and microalgae) and alternatively sun light exposure (Fig. 1). State-of-the art technological processes will be employed; in particular, the combination of biodegradation and photo degradation to increase the chemical and ecological quality of the final water effluents (http://cordis.europa.eu/project/rcn/203388_en.html).

The project will perform commercial scale planning and exploitation of the resulting system to include commercial development, technology integration, eco-design, controlled environment demonstrating, real use demonstration actions and market uptake preparation in several European and non-European countries (France, Ireland, Romania, Italy, Scotland, Turkey, Peru, Ecuador, India and Tanzania), and further preparation for post project uptake. The entailed integrated solution for the treatment of wastewater with final reuse of wastewater is innovative and has not been applied in the past, being also particularly attractive for small to medium remote temporal water stressed European communities (http://cordis.europa.eu/project/rcn/203388_en.html).

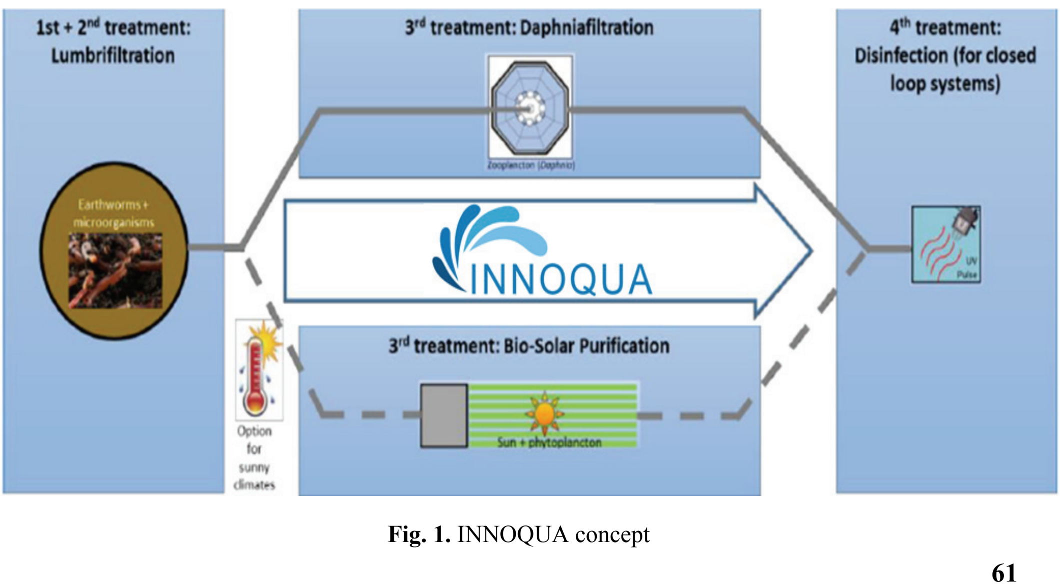

Fig. 1. INNOQUA concept

These communities are generally characterized by high water demand for either agriculture and/or the conservation of natural freshwater ecosystems. Also, this innovative system is ideal to provide an integrated solution for the treatment of organics from wastewater, essential to diminish the amount of pollutants concentrating to surface freshwaters, in the view of the attainment of good quality water resources, as stated by the Water Framework Directive. This requirement is particularly important in South-Eastern (Romania and Bulgaria) and Eastern (Slovenia, Poland etc.) European countries. Figure 1 provides an overview of the INNOQUA modular system.

3. Results and discussion

INNOQUA intends to build on these projects and address key gaps in market including key concerns surrounding the sustainability of implemented solutions in remote and decentralized areas (technical, cost and environmental sustainability), sludge production, presenting commercial offerings that can be modular and site-specific and promoting re-use of treated wastewater where feasible and desirable.

5. Concluding remarks

This project will address demonstration and pilot activities in real environments, the first application and market replication of proven solutions for small-scale wastewater treatment facilities and address two of the thematic priorities identified in the EIP on Water: water reuse and recycling; water and wastewater treatment, including the recovery of resources.

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HOUSEHOLD SOLID URBAN WASTE MANAGEMENT AND DISPOSAL: CASE STUDY IN THE CITY OF JUAZEIRO DO NORTE – CE, IN THE NORTHEAST OF BRAZIL*

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Abstract

The high levels of consumption of goods in today's society have been responsible for the large quantities of urban solid waste generated, impacting environmental quality. The present study aimed to assess the habits of urban household solid waste management and disposal in the city of Juazeiro do Norte, State of Ceará, in the Northeast of Brazil. For this purpose, 53 households distributed in 6 socioeconomic strata (A, B1, B2, C1, C2, D) were interviewed, according to the classification of ABEP - Brazilian Association of Research Companies (ABEP, 2012). The data collected express the perception of respondents regarding the waste generated. The most significant results follow: greater generation of organics (47.17%) obtained from the sum of food scraps and garden waste, followed by plastics (24.53%), paper (24.53%) and diapers/sanitary items (3.77%). In higher socioeconomic status neighborhoods most respondents used conventional waste management to discard food waste (scraps); concerning paper waste, regardless of the socioeconomic stratum, all respondents used the conventional municipal household solid urban waste management to discard these items; 100% of the plastic waste generated was disposed through conventional waste management by respondents living in neighborhoods from strata A, B1 and D. Regarding the disposal of health materials, there were lower prevalence rates of use of conventional waste management in higher socioeconomic status households (strata A and B1): 33.33% and 20%, respectively; regarding the disposal of batteries, respondents from socioeconomic stratum B1 reported discarding such items at municipal waste collection facilities (40%), followed by disposal in neighborhood waste collection facilities, for respondents in stratum C1 (7.69%). However, most respondents still use conventional waste management to discard batteries. Thus, it is necessary to invest in campaigns to encourage awareness and knowledge of appropriate household urban waste sorting and management among users of all socioeconomic strata.

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Keywords: disposal habits, socioeconomic stratum, solid waste

1. Introduction

The current patterns of consumption have dramatically increased the volume of waste generated, which directly impacts environmental quality. Piva (2008) stresses that environmental degradation can range "from the shortage of some natural elements to widespread pollution of biosphere ecosystems that reaches the air, soil and Waters, caused by inappropriate disposal of liquid, solid and gaseous waste". Therefore, in order to reach environmental sustainability, consumption habits and waste disposal practices must be changed" (Medeiros et al., 2015).

Consumption habits deserve special attention in order to minimize waste generation, according to the 'Reuse' and 'Recycle' elements or '3 R's'. Since, by reducing, reusing and recycling waste, raw material waste is prevented and the amount of waste generated is reduced (Guimarães, 2011; Piva, 2008). However, Franco (2012) reported that waste is being improperly disposed by the population, and this prevents the environmental benefits of reuse and recycling

The city of Juazeiro do Norte, in the inland of Ceará, in the Brazilian northeast, which is undergoing an intensive process of urbanization and industrialization, disposed 86, 437 tons of household and public waste in 2014 at an open dump called "Lixão da Palmeirinha" (BRASIL, 2016) for conventional household solid waste collection (SEMASP, 2013), where dry residues are mixed with organic residues and waste, without compliance with any health and environmental measure.

The present study aimed to analyze population habits regarding the handling and disposal of household solid waste in the city of Juazeiro do Norte, CE. "Such information may be useful to environmental education programs, by raising awareness of appropriate handling and correct disposal of waste at the source in the population" (Franco, 2012), "strengthening the consequence relationship between consumption and waste generation" (Guimarães, 2011).

This work is divided in three main parts:

- selection of case studies: in the municipality of Juazeiro do Norte, located in the meso-region Sul Cearense and Microrregião Cariri, forming the Metropolitan Region of Cariri – RMC, in the Northeast region of Brazil;
- evaluation of the habits of the population of Juazeiro do Norte regarding some types of household waste disposal;
- analysis of results and final considerations.

2. Materials and methods

A field research was conducted, through interviews, to obtain knowledge on the habits of the population of Juazeiro do Norte regarding some types of household waste disposal. To support analysis and compare information, based on the characteristics of the population, households located in 6 residential neighborhoods representative of the socioeconomic strata of Juazeiro do Norte were selected, according to the classification of ABEP – Brazilian Association of Research Companies, namely: A, B1, B2, C1, C2 and D. Thus, the six households with the highest number of households in each socioeconomic stratum were identified and selected. Subsequently, the sample required for representation of the neighborhoods in each stratum was calculated.

In total, 53 interviews were conducted in April 2016, One adult respondent (18 years or above) was interviewed in each previously registered household, as follows: 3 households in neighborhood A; 5 households in neighborhood B1; 13 households in neighborhood B2; 13 households in neighborhood C1; 15 households in neighborhood C2; and 4 households in neighborhood D.

Selection of households was made by simple random sampling (Gil, 2008) and data analysis was made by content analysis, which consists in obtaining through “systematic and objective procedures of description of message content, indicators (quantitative or not) that allow the inference of knowledge on the conditions of production/reception (inferred variables) of these messages” (Bardin, 2011).

3. Results and discussion

The main results of the analysis of data obtained with the interviews follow. Fig. 1 shows the most frequent types of waste generated in the registered households, according to respondents’ perception.

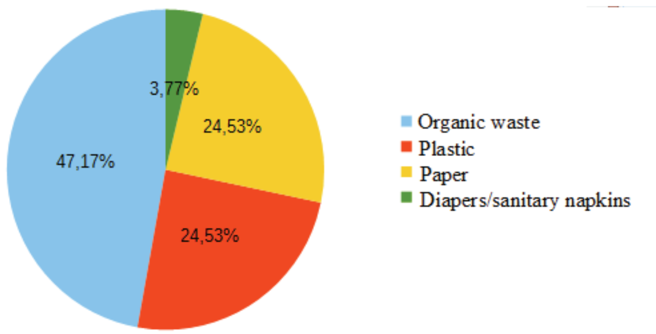

Fig. 1. Typology of waste generated

As it can be seen, according to the respondents’ perceptions, most waste generated is organic (47.17%), resulting from the sum of food leftovers and garden/yard waste, followed by plastics (24.53%) and paper (24.53%). Comparison of these values with those reported by SEMASP – Department of Environment and Public Services (SEMASP, 2013) of the city, which indicate a higher generation of organic materials (58.69%), paper (18.94%) and plastic (8.62%), showed a difference that can be explained by the population’s perception that minimizes organic waste and maximizes the quantities of plastic and paper waste.

Regarding the residents’ food waste disposal habits: 62.27% of the population discarded this waste in the conventional municipal household solid waste collection, while 28.30% donate such waste to animal breeders and 9.43% use it to feed dogs, cats and chicken. According to Franco (2012), “a considerable percentage of the population feed animals with food leftovers” or donate it to “pig farmers that go door to door collecting this waste”. This occurs in most households surveyed in Juazeiro do Norte.

When the population’s food waste disposal habits are related with household socioeconomic stratum, it can be seen that in households classified into socioeconomic strata C2 and D, the habit of donating food leftovers to animal breeders is more frequent, 60% and 25%, respectively. In turn, in neighborhoods of B2 and C1 strata, the respondents reported discarding 61.54% and 69.24% at conventional municipal household solid waste collection facilities, and the other waste are donated to animal breeders or use to feed domestic animals. As for respondents from a neighborhood of socioeconomic stratum B1, 80% of reported discarding food waste at conventional municipal household waste collection facilities. In the households classified into stratum A, all respondents reported disposing their organic waste in conventional municipal household solid waste collection. Thus, in neighborhoods where residents have a higher socioeconomic status, a tendency to dispose food leftover into conventional municipal household solid waste collection was observed. This association was also found by Franco (2012) in a study on the perception of waste disposal habits in southern Minas Gerais.

The results related to plastic waste disposal habits indicate that 81.14% of the population used conventional waste management, while 15.09% donate such waste to door-to-door collectors that and 3.77% sell these items. Among the respondents who reported the use of conventional waste management, 20.93% said they used separate bags for this type of waste and 16.28% reported that these door-to-door collectors usually passed by their houses before the municipal collection vehicle and picked the plastic items, especially PET (polyethyene terephtalate) materials.

When the population's plastic waste disposal habits were related with household socioeconomic stratum, it was observed that respondents from neighborhoods classified as A, B1 and D strata reported disposing 100% of plastic waste generated to conventional municipal household waste collection. In B2 and C1 neighborhoods, in addition to disposing plastic waste to conventional municipal household solid waste collection, they had the habit of donating part of such waste to door-to-door collectors, 23.08% and 7.69% respectively. Only in C2 neighborhood some respondents sold plastic waste (13.33% of the respondents).

The results related to paper waste disposal habits of the population showed that, regardless of socioeconomic stratum, all paper waste generated in the surveyed households are discarded into conventional municipal household solid waste collection.

According to the respondents, plastic and paper waste materials were those that generated the highest quantities of recyclable materials, but were not discarded in the conventional municipal household solid waste collection, but rather picked by door-to-door collections. Also, when pickers fail to collect such materials, they are disposed at the municipal open dump or "lixão". In this regard, Guimarães (2011) stresses the need for conducting public campaigns "aimed to encourage awareness and knowledge of […] appropriate consumption and responsible disposal of waste and increased recycling of solid waste." Corroborating this assertion, Bringhenti (2004) claims that "lack of/discontinuation of actions of dissemination and mobilization discourage the population". Therefore, population involvement depends on investment on effective actions of dissemination, mobilization and information associated to adequacy of support infrastructure to programs of selective collection of recyclables. These waste materials could be sorted at the source, and recycled, generating economic profit and environmental mitigation.

Regarding disposal of health care wastes, the population answered the following question: "Do you throw health waste in your trash?" The health care materials mentioned were drugs, syringes, gloves, bandages, among others. It was found that 71.70% of the surveyed households used health care waste at conventional municipal household solid waste collection to dispose health care waste, 16.98% of the respondents did not generate this type of waste, 9.43% said they disposed health care waste in the sewage and 1.89% handed their health care waste to the health agent of the neighborhood.

Analysis of health care waste disposal habits among the different socioeconomic strata showed a lower prevalence of disposal of health care materials in conventional municipal waste collection in A and B1 households, respectively 33.33% and 20%. In these neighborhoods most respondents do not generate health care waste in their households. They said that when they need a health care service, instead of taking drugs, they seek a hospital or health clinic, Based on these results, it can be affirmed that only in B2 neighborhood respondents (7.69%) admitted referring health care waste to a health community agent of the basic health unit of the residential neighborhood.

Regarding the population's battery disposal habits, 84.91% of the respondents used conventional municipal household solid waste collection and 1.89% take the batteries after their useful life to farms where they are disposed by burning or burying. One respondent used conventional municipal household solid waste collection for disposing batteries, and provided the following justification for the practice "I know it is not correct, by I don't have time to take this waste to another location". It should be stressed that batteries can contaminate the environment.

Only in 5.66% these materials were sent to establishments eligible for reverse logistics of hazardous materials. In turn, 7.54% reported not generating this type of waste. Most respondents were unaware of the existence of collection points for these materials and believed that disposing them in conventional municipal household solid waste collection was the right thing to do.

When battery disposal was related to socioeconomic strata of the neighborhoods included in the research, it was found that appropriate disposal of batteries was prevalent among respondents from households in B1 stratum (40%), followed by C1 (7.69%). However, most respondents used to dispose batteries in conventional municipal household solid waste collection: all surveyed households from stratum D, 93.33% of respondents in stratum C2; 92.31% in stratum B2; 84.62% in stratum C1; 66.67% in stratum A; and 40% in stratum B1.

According to CONAMA's Resolution no 401/2008, used or unserviceable batteries should be sent to business establishments or authorized service networks and be appropriately disposed of by the manufacturer or importer (BRASIL, 2008). In Juazeiro do Norte, according to the City Hall, Engenho do Lixo association of pickers receives and disposes of batteries and electronic waste. Some small business establishments also provide collection points for this type of waste in the city. Therefore, it is necessary to disseminate these points of collection and, particularly, inform the population on the correct disposal of batteries, through investments in environmental education to raise the community's awareness of the need to proper handling and disposal of waste (Arancibia, 2012; Franco, 2012; Roth and Garcias, 2008).

6. Concluding remarks

According to the results obtained, household waste generated in Juazeiro do Norte has been almost entirely discarded in conventional municipal household solid waste collection, for final disposal at the municipal open dump (lixão), without considering the potential reuse of recyclable materials, nor the appropriate disposal specified in the current legislation. The interviews showed that part of the local population use different collection bags to separate organic and dry waste, a habit that may favor the implementation of selective waste collection and composting based on previous screening of waste in the households

We stress the need for investment in campaigns to encourage awareness and knowledge of appropriate household urban solid waste disposal among users of all socioeconomic strata. The community should also have easy access to collection points for waste batteries, and collection points for health care waste should be provided since inappropriate management and disposal of hazardous materials may pose risk to humans and the environment.

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AN INTERDISCIPLINARY APPROACH FOR INTRODUCING SUSTAINABLE INTEGRATED SOLID WASTE MANAGEMENT SYSTEM IN DEVELOPING COUNTRIES: THE CASE OF LA PAZ (BOLIVIA)*

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Abstract

Solid waste management (SWM) has become one of the most difficult environmental and political issue in developing countries worldwide. The increase of diseases from uncollected waste, inadequate informal collection and/or waste open dumps are only few unsustainable practices that affect low income countries population health. The international cooperation between developing and developed countries can be an affordable solution in order to implement new recycling policies and environmental sustainability. In fact, the lack of management instruments and insufficient monitoring and accounting can be solved by introducing long term processes and by involving all local institutions. However, this challenge includes several social, economic, environmental aspects, and implies the development of technical abilities in many disciplines. This article moves from a field research work aimed to develop sustainable integrated waste management policies. That has been made possible by applying university international agreements and public-private partnerships. The work took place in the Bolivian capital city (La Paz), with the direct collaboration of three Universities (*University of Trento – DICAM*, *Major University of S.Andrés – IIDEPROQ*, *Salesian University of La Paz*). During the field study the NGO *Swisscontact* and the La Paz Municipal Government were involved. They helped to investigate directly

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city waste management daily difficulties. Furthermore, an Italian waste recycling company (*EliteAmbiente*) has been involved in the project, in order to estimate the process cost and the management needs for introduce a recycling industry. The process is going to continue with an enlargement of the working group and with other agreements that will involve other institutions.
The main issues are widely discussed in order to explain the advantages and the difficulties that have been found while implementing this integrated process. Moreover, the methods to implement the study are focused and some future objectives are presented.

Keywords: Developing countries, International Cooperation, Integrated approach, Waste management

1. Introduction

SWM emerged as an essential specialized sector for keeping cities healthy and livable. Rapid population growth, urban spread and change in consumption styles are just three examples of primary factors causing increase in waste generation (Ragazzi et al., 2014; Saeed et al., 2009; Sukholthaman and Sharp, 2016). Due to economic crisis that is troubling emerging cities (Kinobe et al., 2015) and due to high recyclable waste fractions (Mohee et al., 2015), recycling is now seen as a sustainable approach to SWM. Additionally, recycling has become a successful waste management method to solve environmental pollution and increase in human disease, which leads to increase collected recyclable waste and to decrease waste inflow to landfills. However, lack of recyclable materials markets, inconsistent waste separation campaigns and lack of public participation do not allow recycling activities improvement (Potdar et al., 2016). Municipal authorities in emerging countries are starting to promote recycling as an industry (Batool et al., 2008; Ghinea et al., 2014) although it is necessary to considerate that economic, environmental and social factors should be studied and improved simultaneously in order to achieve visible results in long time prospective.

Bolivia SWM organization lacks in technological facilities, public financing and national clear regulation systems that aim to reduce solid waste in order to decrease environmental pollution and increase human life quality. Like it happens in other developing countries, most of landfill sites are open dumping areas, which pose serious environmental and social threats (Manaf et al., 2009). Effective solutions need to be urgently developed and specifically to local needs and conditions. Users and potential users must need to be involved and services must be provided at a cost that is locally affordable (Wilson et al.., 2013). Furthermore, measures to avoid the negative impacts from irregular solid waste flows and to introduce recycling polices must go beyond public regulations, education and legal framework (Gutberlet, 2015). In order to achieve new management systems and integrated approaches stakeholders involvement is required.

This study introduces and applies the concept of sustainable, affordable and integrated approach as regard improvement of SWM for emerging big cities, in particular for La Paz case. It has been possible due to the cooperation process involved between Bolivian and Italian Universities, private Italian companies, local authorities, NGOs and local users. The objective of our paper is to explain the feasibility in introducing, within developing countries municipalities, integrated SWM and recycling policies by a cooperation process that involve all local and international stakeholders. Steps and issues are fully explained in order to suggest this method for other new cooperation processes, between Europe and worldwide emerging countries, useful to overcome financial, technological and human barriers.

The present work is divided in four main parts:

- description of La Paz current waste management difficulties;
- analysis of the La Paz stakeholders and the actors involved within the integrated process;

- description of the studies made for the introduction of waste recycling companies. The example and the flow chart that we are going to propose are useful both for developing and developed countries;
- final discussion on the integrated approach used and proposed to the local Government. Conclusions and remarks are described to suggest an integrated approach in recycling processes introduction, highlighting the involvement of multiple stakeholders and specialized experts. After this research, new agreements will be signed and new initiatives will be proposed.

2. Case study, materials and methods

2.1. Working team

The work started with an international agreement, between two Bolivian Universities (Major Universities of S.Andrés – Department of chemical Engineering and Salesian University of La Paz) and University of Trento – Department of Civil, Environmental and Mechanical Engineering, inserted in a Thesis work for a graduation in Environmental Engineering with specialization in emerging countries and international cooperation. In the frame of this agreement a three month field work has been carried out in La Paz, where current municipal solid waste collection and treatment were studied and local stakeholders were involved. Before the field research, an Italian special waste recycling company (*EliteAmbiente*), expert in plastic and metal materials treatment, has been involved in the work giving industrial knowledge in recycling process and accounting. Needs for industrialize recycling processes were highlighted and analyzed for the specific La Paz study area.

Preliminary knowledge and agreements allowed working with the La Paz local Government that, after the useful results obtained from this research, would be interested in implementing the project and continue the cooperation process through future programs. An NGO (*Swisscontat*) has been involved during all the field work, for its specific knowledge in La Paz SWM and for the interest in introducing new recycling policies. The stakeholder involvement, with a preliminary study of documents and past studies, allowed understanding difficulties, threats and opportunities in La Paz SWM system. Preliminary knowledge about solid waste collection and treatment are necessary in order to understand difficulties and opportunities in La Paz case study: so, the current situation within La Paz SWM is now shortly presented.

2.2. La Paz current municipal solid waste management and treatment

La Paz, Bolivian capital city located between the Andean plateau and the Bolivian Royal mountain chain at an altitude of 3,600 m, is facing with the typical SWM problems of developing countries even though is one of the most developed cities in Bolivia. Lack of efficient environmental monitoring, poor education and public awareness, unsuitable waste collection for low income areas, not well-structured and executed recycling programs, low recycling rate (about 8%) and low financing sustainability are only few of the current issues that La Paz Government must solve. The first Law in solid waste organization was established in October 2015. Because of its recent introduction in public management system, that Law is not yet enforce and regulations are still lacking. However, that Law is the first step in introducing sustainable aspects in SWM like the “polluter pays” principle or pollution monitoring.

The total waste generated in La Paz achieves 600 tons/day, about 0.63 kg per person. The 92% is disposed at the *Alpacoma* landfill, disposal site 15 km far from the city center, where all kind of waste fractions are discharged. The *Alpacoma* area is bounded and constantly controlled; waste discharged is daily covered. Environmental monitoring is present although not perfectly and continuously in coherence with European standards. Local Government introduced a vermicomposting facility for the organic matter that comes from markets and the zoological park and a manual selection plant, where plastic, cellulosic, glass and metal fractions are divided though in low rate. Despite that, sustainable plans for future waste material exploitation were not introduced and new recycling policies were not proposed by the local authorities. In the city the distribution of the collection containers is often counterproductive and the number of collection vehicles is inadequate, similarly in other developing cities (El-Hamouz, 2008). In addition, the landfill can be used just three years more: after this period, new projects for the enlargement of the area will be introduced. Nevertheless, near the city are not available new free areas where a new landfill could be built. So, after 15 years, where will be disposed the municipal solid waste?

Like typically happen in developing countries, the recycling rate is improved by the informal sector and from scavengers who separate exploitable materials from street containers and informal dump sites along the city, building a little informal recycling chain (Batool et al., 2008). This activity avoid waste inflow to the landfill, helping municipal economic save, however these people, that mostly are poor, woman and children, are in low working condition hence affected of disease and low public recognition. Organized recyclers are an important link in the resource recovery chain but in Bolivia are not recognized by the public institutions.

The local Government, in particular the Environmental Services Secretary, pays three private companies for collection, treatment and final disposal of solid waste. Moreover, local Government has the power to change the current service provision, introducing new developing plans and sensitivity campaigns for the population. Nevertheless, financing is not sufficient to improve new program because 60% of the total costs are covered by the national Government. The agreements between private and public sector are going to be renewed in November 2016: this represents a good opportunity to implement new sustainable practices: reverse logistic could be introduced within SWM service. This context is perfectly useful to change current collection and treatment systems and the lack of financial resource and know how could be overcome by international cooperation and new alliances with recycling companies and foreign institutions.

3. Results and discussion

The results of this paper present the international cooperation and the introduction of sustainable aspects that aim to involve all the stakeholders into developing recycling polices in La Paz case study. The sustainable aspects of international cooperation are introduced.

3.1. Stakeholders analysis and actors involved within the process

Stakeholders' analysis, appropriately adjusted for a certain system, can provide an useful integration to traditional methods by assessing additional aspects to ensure a comprehensive picture of the situation in SWM and other public services (Caniato et al., 2014). Stakeholder involvement is the primary tool to implement new integrated systems in order to achieve sustainable policies in all environmental aspects (Zortea and Lucatello, 2016). Like suggested in other studies, problems tackled by multiple stakeholders are likely to acquire more attention in near future, while more opportunities will rise thanks to the provision of newer waste treatment techniques (Soltani et al., 2015). Hence, this study introduces a method to realize a multi-stakeholder approach with multi-disciplinary studies in the frame of an international cooperation. Actors involved in this survey are:

- Universities (Salesian University of La Paz, Major University of S.Andrés-IIDEPROQ, University of Trento-DICAM);
- Governmental authorities (Environmental Services Secretary);
- Private sector (Bolivian engineers and services providers and an Italian company);
- Non-Governmental organizations (NGOs) and local media (Swisscontact and the Major University of S.Andrés television).

Salesian University had an important role in users survey implementation. Indeed, the field survey started into the University, interviewing students and professors about environmental issues and waste management problems within the city. This approach allowed entering rapidly into local citizens thought, understanding which issues are most dangerous for the local population. The field study has been completed in collaboration with the department of chemical engineering of the Major University of S.Andrés since it is the University where all engineers expert in waste management work. Moreover, links with the local Government and local NGOs had been made thanks to this collaboration. The NGO Swisscontact works from 2008 in La Paz SWM and has many knowledge in the field, whereas local Government is the direct actor of SWM in the city and is the main subject of the work. All field work has been made in order to introduce new sustainable systems in La Paz SWM in collaboration with the local Government that has a direct contact with collection and treatment providers. In addition, our work had been exposed to the local University television in order to explain to the region population the project involving Bolivian and Italian Universities.

The aim of the work is to introduce the reverse logistic system in the city, suggesting methods and collaborations useful to implement this approach. Italian private sector involvement is considered an effective solution to implement a circular economy model within the city, because an industrialized recycling system is still lacking. According to Ahmed and Ali (2004) some conditions are required to establish successful public-private partnerships: a positive culture that encourage leaderships and public participation, a realistic commonly accepted vision among all the stakeholders involved, participatory methods within local policies and long term policy with ability to change circumstances and to reduce uncertainty for business and individuals who want to take economic risks. Private sector involvement, for instance, has been revealed as an effective solution whether introduced in the collection system (El-Hamouz, 2008). In La Paz case study this involvement results in a good option also for the recycling process, since lack of public financing do not allow implementing big recycling chains. The example suggested in this work is the introduction of the private company *EliteAmbiente*, specialized in plastic and metal recycling processes. The collaboration with an industrialized company, capable to well exploit recyclable waste materials, can provide a new way to local authorities and improve public awareness in environmental subjects.

Within the process suggested in this study, universities had the most important role in introducing new agreements between private companies and public institutions. Moreover, students and professors helped us to study preliminarily SWM current situation, saving costs and time to local authorities and international companies. A scheme explaining strengths of these collaborations is suggested in Fig. 1. The scheme sums up the project influencing, capabilities of each actor useful to achieve sustainable objectives in SWM, and, finally, opportunities for all. Within a public-private partnership, Universities are an important actor in the effort of providing integrated approaches into public services.

Actors / *Functions*	**University** ⟷	**Private** ⟷	**Public**
Project influencing	• Preliminary studies • Future intervention evaluation and scenarios suggestion	• Know How • Initial financing	• Solidwaste collection organizing • Public awareness raising campaigns
Capabilities useful to achieve the objectives	• Direct contacts with local institutions • Deep knowledge in local solid waste management dynamics	• Local workers training during project implementation • Industrial system control	• Law and regulation design and enforcement • Municipal hierarchy organization • Public and private system control and monitoring
Strengths and opportunities	• Knowledge development • Students direct experience • New international agreements	• Economic scaling down in raw materials procurement • Financial return in mid-short time	• New local jobs • Environmental sustainability • Circular economy development • Socio-economic development

Fig. 1. Actors involved in La Paz case study and related functions.

Collaboration among all actors above described allows even to save monetary resources, to promote international partnerships and to introduce new technological approaches taking into account local needs. In a theoretical approach, partnerships between such actors must start along with a global vision of integrated attitudes where environmental protection, financial sustainability, human healthy, international collaboration and multi-disciplinary studies are introduced like a common objective. Every actor can provide specific knowledge and capabilities, helping the implementation of new programs. As in La Paz case study, Universities agreements provide new integrated management tools to the Governments, preliminary studies for Italian companies and new collaborations useful to introduce a reverse logistic system within La Paz SWM. Indeed, a multi-disciplinary international benchmark indicator had been provided to the local Environmental Services Secretary to compare SWM of other cities worldwide and to understand current waste collection and treatment services quality within the city. So, the collaborations born within this research are going to move in agreement with the theoretical approach principles above listed.

University agreements are the backbone allowing the current project to be developed with a recyclable materials market survey and with a pollutant effects and technological solutions study and it will guarantee also the financial sustainability: low additional will be required. The collaborations with all stakeholders described in this paper are still in action. Another agreement, between Insubria University (Italy) and Bolivian Universities, is about to be signed, in order to enlarge the collaboration activity and the experts involved in the process. Additionally, an agreement between local Government and Italian Universities is in progress. The study proposed to recycling companies and the field work applied in La Paz are schemed in the following section.

3.2. Sustainable studies and recycling company introduction

In La Paz case study, like it happens in other developing cities, circular economy is not yet developed; hence no specific regulations regarding quality of the recycling products have been introduced by local institutions (Kinobe et al., 2015). However, participation by local private factories is increasing, even though they are not so developed due to the lack of knowledge and market surveys. Like suggested in other studies, setting up recycling industries generate revenues, new jobs and city wellness at the same time (Batool et al., 2008). Moreover, high waste separation rates mean less amount of waste brought to landfills, less total management costs and higher public collection service efficiency (Sukholthaman and Sharp, 2016). Therefore reverse logistic approach has been introduced in this project and its implementation has been recommended to La Paz local Government. However, with respect to private investors considering risks and returns, waste management projects are quite unattractive in developing countries due to insufficient stakeholder awareness and public perception (Bufoni et al., 2016). Despite that, private company involvement in environmental initiatives always leads to service costs saving and waste quality processes improvement albeit the 'environmental respect' principle required high managements costs in the short term (Flores, 2009).

In this article recycling companies introduction is suggested. However, waste flow analysis, economic survey and local area current SWM situation assessment are required in order to estimate intervention feasibility (in all typology of study areas). Collaborations with Universities and *EliteAmbiente* private company allow studying recycling process general needs for the recovery procedure. Fig. 2 illustrates the steps useful to understand the feasibility for recycling company introduction in a specific area.

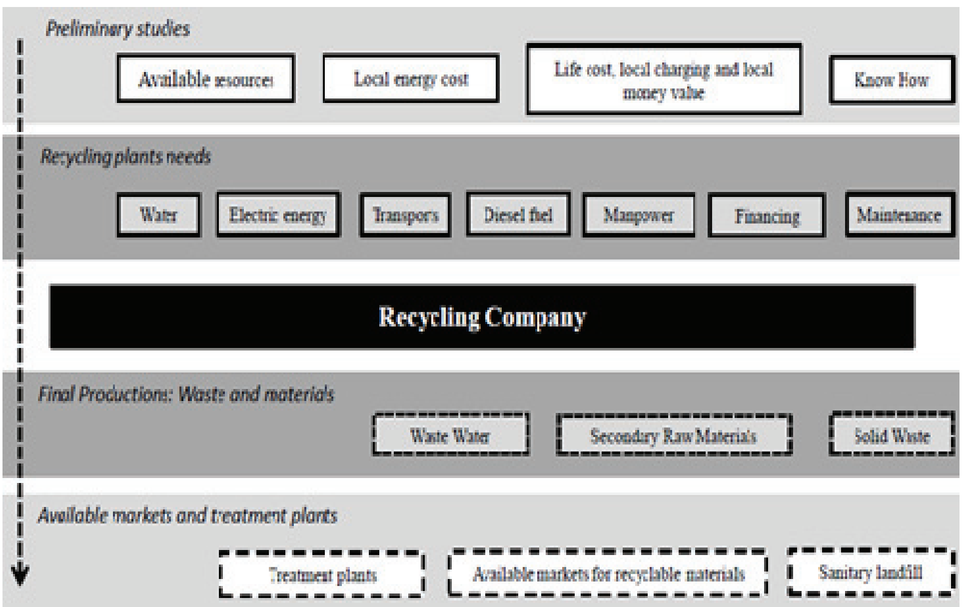

Fig. 2. Flow chart of the four steps useful to introduce recycling companies in new areas

Available resources, local energy costs, life cost, local charging, money value, local know how, waste water treatment plants, available markets for recycling materials and appropriate sanitary landfills have to be accurately assessed through further field study, where stakeholders' collaboration will provide useful information. These preliminary surveys are necessary to better understand the feasibility of recycling company intervention: for instance, this methodology has been used for La Paz case study where all main data have been carried out.

As suggested in other papers, in order to develop a new waste management system it is necessary, first of all, to assure good data collection and available waste fractions amounts (Ghinea et al., 2014; Murariu et al., 2015; Wilson et al., 2012). The field work will allow gathering these information and summing up the current La Paz SWM situation. The chart, presenting schematically all steps needed to achieve such objectives is depicted in Fig. 3. The first part of the survey regards the study of local laws and regulations: without solid legal framework, international investments to introduce technological facilities are considered a high economic risk by private sector. The second step is setting up the waste material fraction and amounts analysis. As common in developing countries, waste fraction and quantities information are not available.

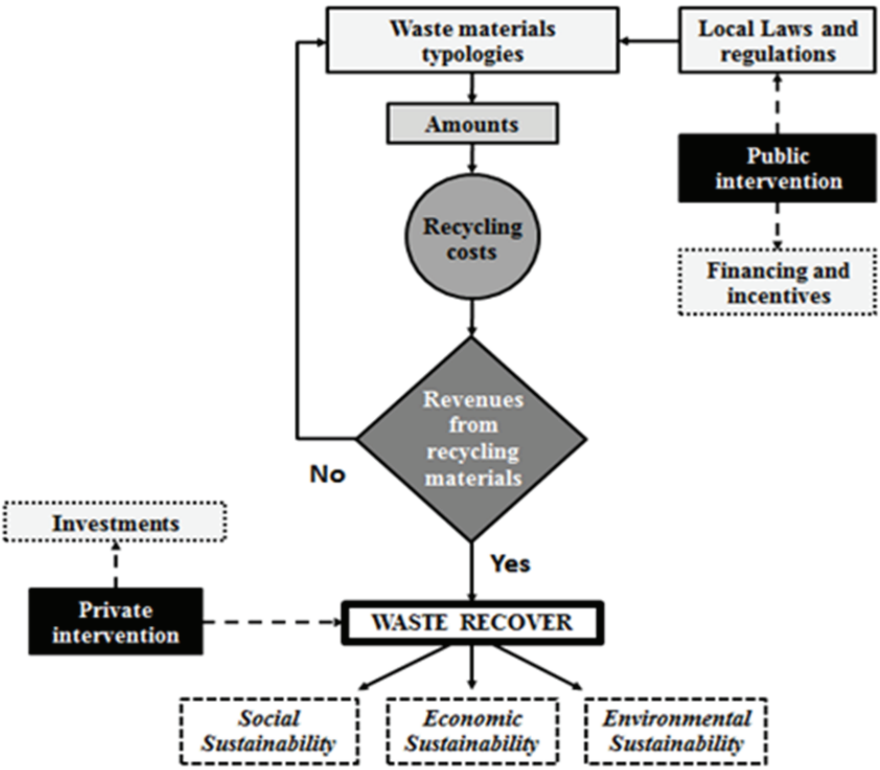

Fig. 3. Steps needed to assure the recycling chain feasibility

Nevertheless, some useful indication can be obtained by analyzing past local studies. More difficult is the assessment of recycling process costs because local institutions and past studies did not focused on this aspect. However, thanks to the collaboration with *EliteAmbiente,* the university and the experts in the economic sector involvement, it has been, as usual in developing countries, it cannot be implemented in the future due to the economic autonomy weakness of local institutions. Then, ample recycling markets surveys are required to complete the reports in order to assess material prices fluctuations and most advantageous markets. However, in La Paz case study, recycling company introduction is feasible and potentially affordable for what concern the process costs and exploitable materials quantities (about 30,000 tons of plastic waste per year).

Municipal solid waste is a valuable resource offering several social, economic, environmental and technological benefits if introduced in a "clean developing mechanism", as exposed in other studies in developing countries (Potdar et al., 2016). The exploitation requires public-private partnerships, municipal awareness, financing sustainability and current SWM updated surveys. International cooperation and collaborations between stakeholders can help to achieve these objectives in order to reach Social, Economic and Environmental Sustainability.

Moreover, social inclusion programs might be developed in order to include population involved in the recycling process and increase public awareness, like suggested in other studies in developing countries (Vaccari et al., 2012). Sustainability of the solutions should be evaluated considering both the results of Life Cycle Assessment (LCA), the costs of the different operating scenario and the stakeholders involvement, that should take part in selecting the most appropriate solution (Bamonti and bonoli, 2014; Ghinea et al., 2014; Torretta et al., 2015).

So, future researches will be focused on: LCA of SWM processes; surveys about recyclable materials markets; impact assessment of pollutant in water bodies; air and soil degradation assessment from illegal waste dumping and burning and, finally, monitoring the introduction of private recycling facilities in La Paz solid waste treatment systems as suggested by other studies (Guerini et al., 2015; Vaccari et al., 2012). All activities will be carried out, in collaboration with local stakeholders and users.

6. Concluding remarks

La Paz is facing the typical emerging countries SWM issues due to poor financing sustainability, low public awareness and lack of recycling programs. Public private partnership can improve efficiency in SWM and create new opportunities for employment, environmental protection and city cleaning by the introduction of new industrialize recycling facilities. In order to develop a reverse logistic chain and recycling policies in La Paz, an integrated approach and coherent management programs are required. To that purpose, stakeholders cooperation, Universities inclusion and international agreements among all partners, can allow improving current SWM rapidly and in a sustainable manner, avoiding typical mistake made in the past by developed countries, resulting in environmental pollution and human healthy. An important aspect that cannot be underestimated is time necessary to draw up the agreements between stakeholders.

The incorporation of circular economy into SWM systems is also effective in increasing landfill useful life, reducing collection costs, and also in providing economics improvements. Moreover, it sends in environmental benefits that can be also translated into greenhouse gases reduction and climate change mitigation.

Such multi-stakeholder and interdisciplinary cooperation approach represent a sustainable way to ensure a long term process aimed to improve human health and environmental protection, capable to involve all local institutions.

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BUSINESS MODELS FOR INDUSTRIAL SYMBIOSIS: A GUIDE FOR FIRMS*

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Abstract

Industrial symbiosis (IS) is a collaborative approach concerning physical exchange of materials, energy, and services among different firms: accordingly, wastes produced by a given firm are exploited as inputs by other firms. This approach is able to generate economic and environmental benefits at the same time, the former for the involved firms and the latter for the collectivity as a whole. For these reasons, the implementation of IS is largely recommended. However, despite its huge potentialities, the IS approach seems to be actually underdeveloped and not fully exploited. Firms without any prior experience of IS exchanges suffer from lack of awareness about how to integrate the IS practice into their current business models and how to gain economic benefits from IS. Since the willingness to obtain economic benefits is the main driver pushing firms to implement the IS practice, this issue constitutes an important barrier to the development of new IS relationships.

In this paper, we contribute to this issue by identifying the different business models that each firm can adopt to implement the IS approach. In particular, we identify several business models for both firms producing waste and firms requiring waste. For each model, we highlight how firms can create and get economic value from IS. Moreover, from the interaction among firms, each of them implementing its own business model, several business scenarios at inter-firm level can arise. These scenarios are also presented: for each of them, strengths and weaknesses are identified and a short case study is discussed. The identified models can be useful at the company level since they provide indications about how to integrate the IS approach within their current business model.

Keywords: circular economy, industrial symbiosis, sustainable business models, value creation

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1. Introduction

Industrial symbiosis (IS) is a collaborative approach concerning physical exchange of materials, energy, and services among different firms: accordingly, wastes produced by a given firm are exploited as inputs by other firms (Chertow, 2000).

The IS approach allows to achieve environmental, economic, and social advantages (Mirata, 2004; OEDC, 2012). The environmental benefit is the result of the potential reduction in wastes, emissions, primary inputs, and energy (Chertow, 2000). The economic convenience comes from the savings due to lower costs for both wastes disposal and primary inputs purchase (Albino et al., 2016). Finally, from the social benefits point of view, the IS approach may foster the creation of new firms and new jobs (Mirata, 2004). Moreover, the European Commission (2011) explicitly recommended the adoption of the IS approach to boost production efficiency and resource productivity. As a result, policymakers of many countries have introduced the IS practice in their environmental agenda (Costa et al., 2010; OECD, 2012; Van Berkel et al., 2009).

Waste exchanges among firms can either be designed by adopting a top-down approach or, conversely, emerge from the bottom, as the result of spontaneous self-organized process undertaken by firms (Chertow, 2007). Empirical cases demonstrated that both these models can be successful (e.g., Jacobsen, 2006; Mirata, 2004). In fact, for both these approaches, firms are interested to collaborate exchanging wastes each other because driven by the willingness to obtain economic benefits (Lyons, 2007).

However, despite its huge potentialities, the IS approach seems to be actually underdeveloped and not fully exploited. In particular, several technical, economical, and organizational barriers to the creation of new IS relationships arise, discouraging firms to collaborate each other (Fichtner et al., 2005; Tudor et al., 2007). In such a context, firms with prior successful IS experiences tend to develop new symbiotic relationships more easily, as they profit from their earlier successes (Paquin et al., 2015). Alternatively, firms without any prior experience of IS exchanges suffer from lack of awareness about how to integrate the IS practice into their current business models and how to gain economic benefits from IS. This is recognized as one of the main factors hampering the development of the IS practice (Ficthner et al., 2005; Radtke, 2011; Sakr et al., 2011).

Many case studies have been analyzed by the literature with the aim to disseminate successful experiences of IS, which may be guide for firms interested to adopt the IS approach. However, since these experiences may be highly case-specific, not all findings can be generalizable. Alternatively, in order to foster companies to adopt the IS approach, general models are needed, describing the different strategies through which firms can create value and obtain economic benefits by IS.

In this paper, we contribute to fill the gap by identifying the different business models that each firm can adopt to implement the IS approach. In particular, we recognize several business models for both firms producing wastes and firms using wastes as inputs. For each model, we identify how the firm can create and get economic value from IS. Moreover, we found that from the interaction among firms – each of them implementing its own business model – several business scenarios at inter-firm level can arise. These scenarios are also presented; for each of them, strengths and weaknesses related to its implementation from strategic and organizational point of view are highlighted and a short case study is discussed.

The paper is organized as follow: Section 2 introduces the concept of business model. Business models supporting the IS practice at the firm level are presented in Section 3. Section 4 presents the business scenarios at the inter-firm level. Finally, discussion and conclusions are provided in Section 5 and Section 6, respectively.

2. Business models and Industrial Symbiosis

2.1. Business model: definitions and main elements

The business model is a conceptual tool providing an abstraction of how a firm do business (Eriksson and Penker, 2000; Magretta, 2002). It reflects the firm realized strategy, highlighting the combination of production factors needed to implement such a strategy and the functions of all the involved actors (Casadesus-Masanell and Ricart, 2010; Wirtz, 2010). The business model serves as a strategic tool for designing business activities as well as for a comprehensive, cross-company description and analysis.

Many formal definitions of business models have been provided by the literature (e.g., Zott et al., 2011). Though a comprehensive review of these definitions, Richardson (2008) proposed a consolidated view of which main elements should compose business models:

- *Value proposition*. What the firm will deliver to its customers, why they will be willing to pay for it, and the firm's basic approach to competitive advantage;
- *Value creation and delivery*. How the firm will create and deliver that value to its customers and the source of its competitive advantage;
- *Value capture*. How the firm will generate revenues and profits.

2.2. Sustainable business models

One of the key challenges to tackle the pressure of a sustainable future is designing business models able to ensure that firms capture economic value for themselves through delivering social and environmental benefits (Schaltegger et al., 2012). In this regard, sustainable business models are models that "*create competitive advantage through superior customer value and contributes to a sustainable development of the company and society*" (Lüdeke-Freund, 2010). In particular, the value proposition of a sustainable business model must include positive effects for society and environment in addition to the economic value for the firm. Firms can create such a proposed value by implementing technological, organizational, and management innovations (Boons and Lüdeke-Freund, 2013).

With the aim to support the development and the implementation of sustainable business models, Bocken et al. (2014) identified eight archetypes for these models, i.e., groupies of mechanisms and solutions that may contribute to building up the business models for sustainability. The archetypes are: i) maximize material and energy efficiency; ii) create value from 'waste'; iii) substitute with renewables and natural processes; iv) deliver functionality rather than ownership; v) adopt a stewardship role; vi) encourage sufficiency; vii) re-purpose the business for society/environment; and viii) develop scale-up solutions.

2.3. IS as sustainable business model

Business models implementing the IS practice have been recognized as sustainable business models, classified under the archetype "create value from waste" (Bocken et al., 2014). In general, the value proposition by such an archetype is turning existing waste streams into useful and valuable inputs to other products. Moreover, the IS approach can also be related to the archetype "maximize material and energy efficiency". In fact, by using waste α from production process A to replace input β in production process B, the amount of waste α landfilled per unit of output generated by process A is reduced; similarly, the amount of input β used to produce the same amount of output by process B is reduced. Accordingly, by adopting the IS approach, technical efficiency of both production processes and the industrial system as a whole is increased (Fraccascia et al., 2017).

The sustainability of business models oriented to the IS approach stems from the economic value created for firms simultaneously with the environmental benefits generated for the collectivity as a whole. In particular, the economic benefits are in form of lower production costs or higher revenues. As a result, the competitiveness of the firm can be increased by implementing such an approach (Esty and Porter, 1998). The environmental benefits come from the lower environmental pressure due to less amount of both wastes disposed of in the landfill and virgin input used in production processes (e.g., Jacobsen, 2006).

3. Business models supporting the IS approach at the firm level

According to the IS approach, wastes are used as inputs in production processes instead of landfilled. Two key actors are involved in waste exchanges: firms producing wastes and firms using wastes.

In this section, we identify the business models that each of these firms can adopt to implement the IS approach. In order to formalize these models, we used an inductive approach (Eisenhardt and Graebner, 2007): we reviewed secondary literature (academic literature, professional literature, companies' websites) about the implementation of IS projects and we analyzed business models adopted by the involved firms. To characterize the business models formalized in this paper, we use the framework proposed by Richardson (2008). Accordingly, for each model, we highlight the value proposition, the value creation, and the value capture.

3.1. Firms producing wastes

The IS approach is successfully implemented when the amount of wastes disposed of in the landfill is reduced. To avoid that wastes will be landfilled, firms producing wastes can implement two different strategies: i) using the produced wastes within the firm (*internal exchange*); ii) sending the produced wastes to other firms (*external exchange*).

Internal exchange. Firms can use wastes produced by a given production process to replace inputs in other production processes within the firm boundaries. The value proposition of this model is related to higher production efficiency, due to lower amount of wastes disposed of in the landfill per unit of output generated by the firm. Such a value can be created by implementing organizational innovations to manage the additional flows and stocks of wastes within the firm boundaries. Firms can capture the value in form of lower production costs, in particular due to the lower waste disposal costs. Moreover, the increased environmental sustainability of production processes may generate additional value in form of improved firm's reputation from stakeholders.

External exchange. Instead of using the produced wastes within the firm boundaries, firms can send their wastes to other firms, which will use them in their production processes. Also in this case, the value stems from higher production efficiency. However, differently from the previous model, the value is created by producing wastes with features making them able to be used by other firms (e.g., with adequate qualitative levels). Finally, from the side of value capture, the lower production costs and the higher firm's reputation from stakeholders can be backed up by additional revenues from selling wastes to other firms.

Table 1 shows value proposition, value creation, and value capture for both the models previously presented.

Table 1. Value proposition, value creation, and value capture for "internal exchange" and "external exchange" models

	Internal exchange	***External exchange***
Value proposition	Higher production efficiency (lower waste from output production)	Higher production efficiency (lower waste from output production)
Value creation	Organizational innovation	Producing wastes useful for other firms
Value capture	Lower production costs Better reputation from stakeholders	Lower production costs Better reputation from stakeholders Additional revenues from selling wastes

3.2. Firms using wastes

Firms can implement three different business models oriented to use wastes in their production processes: i) input replacement; ii) co-products generation; and iii) new products generation.

Input replacement. Firms can use wastes to replace inputs in their production processes. The proposed value is related to higher production efficiency, in form of lower amount of virgin inputs used to produce one unit of output. Such a value can be created by innovating the production process from the technical point of view, making it able to use the waste as input. Finally, the value is captured though lower production costs, in the form of lower virgin input purchase costs, and additional revenues from offering disposal service to firms producing wastes. Moreover, also in this case, the improved environmental efficiency may generate additional value, in form of better reputation from stakeholders.

Co-product generation. Firms exploit wastes to generate at least one new product, different to those currently generated, destined to be sold on the market. Two kinds of new products can be generated: i) products whose production process is more environmentally sustainable than traditional products, *ceteris paribus*; ii) products with some features better than traditional products, *ceteris paribus*. Therefore, products so generated can be considered as "differentiate products", more profitable that the traditional one. The proposed value is related to the business enlargement allowed by the IS approach, since new products are added to the current product portfolio. So that such a value is created, firm needs to implement product and process innovation. In fact, firms have to design how to integrate wastes within new products and how to make production processes able to use these wastes. The created value can be captured by gains from selling the new products.

New product generation. New firms arise exploiting wastes to generate new products, which are sold on the market. This could sound quite similar to the previous model; however, since in this case the new products are the main business of the firm, the arisen firms are completely based on the IS approach. Hence, the value proposed by this model is to create new businesses by exploiting wastes. To create such a value, product and process innovations are needed. The value is captured by gains from selling the new products.

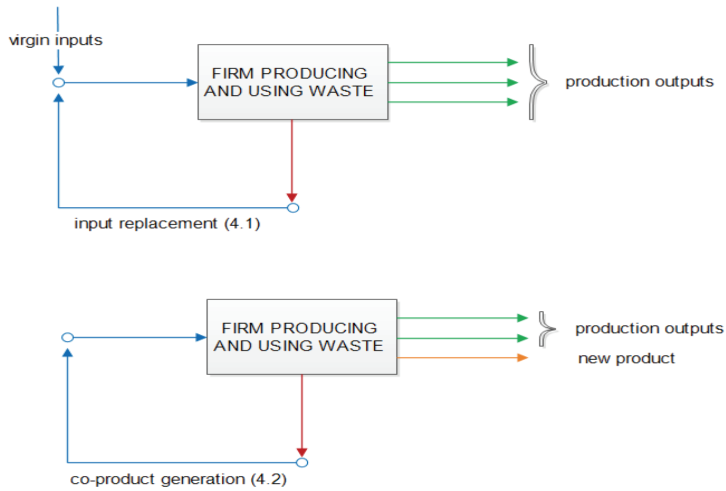
Table 2 shows value proposition, value creation, and value capture for all the models previously presented.

4. Business scenarios at inter-firm level

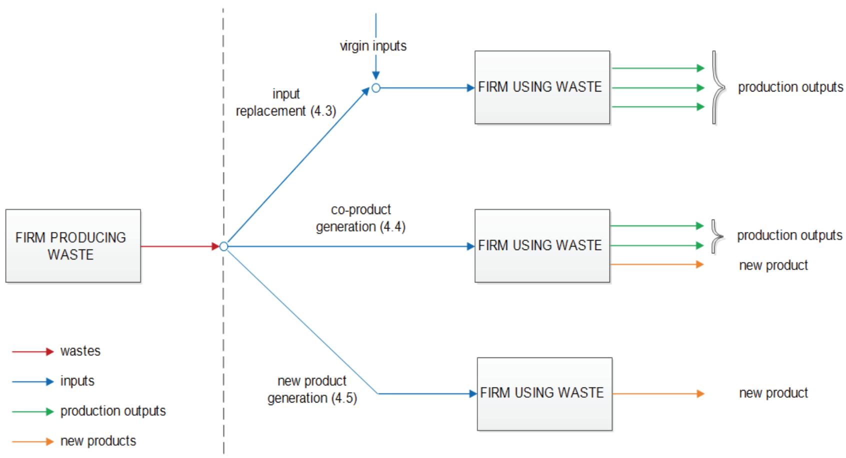
From the interaction among firms producing wastes and firm using wastes, each of them implementing its own business models, five business scenarios at inter-firm level may arise. In this section, we present these scenarios. For each of them, we highlight strengths and weaknesses related to the implementation from strategic and organizational point of view and we present a short case study. These scenarios are graphically depicted in Fig. 1 and discussed in the following sub-sections.

Table 2. Value proposition, value creation, and value capture for "input replacement", "co-products generation", and "new products generation" models

	Input replacement	***Co-product generation***	***New product generation***
Value proposition	Higher production efficiency (lower virgin input to produce output)	Business enlargement	Creation of new business
Value creation	Process innovation	Product innovation Process innovation	Product innovation Process innovation
Value capture	Lower production costs Better reputation from stakeholders	Gains from selling new products	Gains from selling new products



(a)



(b)

Fig. 1. Graphical representation of business scenarios at inter-firm level: a) in case of internal waste exchange; b) in case of external waste exchange. For each scenario, the number on the arrow indicates the sub-section presenting that scenario

4.1. Internal exchange + input replacement

This scenario arises when wastes are used within the firm's boundaries to replace production inputs.

Strengths. As main strength of such a scenario, no cooperation with partners is required. This means that firm does not need to disclose personal information or to negotiate the economic terms of the relationship, which is one of the strongest barriers hampering the adoption of the IS practice (e.g., Fichtner et al., 2005). Moreover, in the phase of input replacement, the firm is strategically independent because the amount of wastes that it can use does not depend on any other firm. Finally, from the economic point of view, two issues can be highlighted: i) the firm does not sustain any waste transportation costs; ii) the benefits from the IS approach have not to be shared with other firms.

Weaknesses. Symbiotic exchanges within the firm's boundaries may be limited in case of low diversity among production processes, not enough to allow technical match among wastes and inputs (Korhonen, 2001). Moreover, from the economic point of view, the additional costs needed to activate symbiotic processes cannot be shared with any partner. These weaknesses could make such a scenario hardly sustainable by small firms.

Case study. In UK, McDonald's produces biodiesel from the used cooking oil generated in its kitchens. The biodiesel so produced is used to fuel the company delivery vehicle. Hence, both fried oil disposal costs and fuel purchase costs are reduced. In 2013, 3,7 million liters of used cooking oil was converted in 3,1 million liters of biodiesel, fueling around 42% of the company delivery fleet.

4.2. Internal exchange + co-products generation

This scenario arises when wastes are exploited to create new products within the firm's boundaries.

Strengths. All the strengths of the previous scenario can be recognized also for this one. Moreover, we want to highlight that the amount of new products generated is dependent on the amount of available wastes. Therefore, the low waste supply risk is a particularly relevant strength for this scenario, since it makes the new product generation independent on contributions from other firms.

Weaknesses. This scenario suffers from all the weaknesses of the previous one. Moreover, since the amount of new products depends on the available amount of wastes, firms would be unable to satisfy demand of new products exceeding the highest amount that can be produced. Similarly, in case of reduced waste production, the amount of new products generated will be reduced.

Case study. Guitang Group, the largest sugar farm in China, has successfully applied this scenario. The group has exploited wastes from sugar production processes (molasses, bagasse, filtered sludge) to create new production chains (alcohol, paper, fertilizer) within the group boundaries. By implementing such an approach, from 1997 to 2004 Guitang Group increased its revenues by 153% (from 807 to 2.045 million CNY), due to the new products sold on the market, and its profit by 5.521% (from 3 to 170 million CNY), due to lower production costs and waste disposal costs (Yang and Feng, 2008).

4.3. External exchange + input replacement

This scenario arises when wastes generated by a given firm are used to replace input in another firm.

Strengths. Potential additional costs arising from IS can be shared among firms: for this reason, such a scenario could be sustainable even by small firms. Moreover, both firms can gain additional benefits than those arising from internal use of wastes: the firm producing wastes from selling wastes whereas the firm using wastes from selling disposal service.

Weaknesses. Firms need to find economic agreements related to waste exchange and to negotiate the cost-sharing policy (Albino et al., 2016). Moreover, since the economic benefits that each firm can obtain depend on the willingness to cooperate of the other firm (Yazan et al., 2012), a strong cooperation among firm is needed in order to implement such a scenario (Lambert and Boons, 2002). Transaction costs arise from such a cooperation, eroding the gross economic benefits created by using wastes in place of inputs.

Case study. DENSO Manufacturing UK produces automotive air conditioning units and engine cooling systems for the automotive industry. Potassium aluminum fluoride is generated as hazardous waste by its production processes. Instead of be disposed of in the landfill, such a waste is used by Mir-Ver Metals, a company working in metal industry, as inputs for its production processes. Cooperation between these firms allows to divert from landfill 15 tons of waste per year, creating 45.000 euro of economic benefits shared among firms. This synergy has been implemented under the National Industrial Symbiosis Programme (NISP) in UK.

4.4. External exchange + co-product generation

This scenario arises when wastes generated by a given firm are exploited by another firm to create additional products to its main business.

Strengths. This scenario may support cooperation among firms belonging to very different sectors (that would be unable to cooperate otherwise), playing an important role for enhancing environmental innovations (Mirata and Emtairah, 2005).

Weaknesses. As highlighted in the “internal exchange + co-product generation” scenario (Section 4.2), the amount of new products generated depends on the amount of available wastes. In this case, the amount of available wastes may also depend on cooperation among firms. If the symbiotic relationship was interrupted, firm using wastes will no more be able to produce its new products. For this reason, the structure of bargaining power among firms could be unbalanced, negatively affecting the cooperation among firms (Yazan et al., 2012). Moreover, in case the waste should have fixed qualitative features to be used in new product generation, it may be difficult for firm using waste to find adequate waste supplier. Finally, high R&D investments may be needed to create the new product.

Case study. CSC is an Italian firm producing and supplying concrete to the local construction industry. Since the financial crisis in 2008 negatively affected the firm business by reducing final demand of its products, the firm decided to introduce new products within its current portfolio in order to enter in new market segments and increase revenues. It developed a new concrete product that mixes a percentage of chopped plastic into the concrete mix in place of conventional aggregate. In fact, plastic is 50% less weight than aggregate and has positive performance about impact resistance and noise absorption. Moreover, plastic used for concrete production stems from urban wastes. CSC founded a joint venture company collecting urban wastes, in order to reduce supply risk by directly managing the supply chain. By adopting this model, CSC reduced its production costs because of lower amount of virgin aggregates used in concrete production, increased its revenues by selling the new product, and finally obtained additional gains because of payment from the municipality for managing the waste (Short et al., 2014).

4.5. External exchange + new product generation

This scenario arises when a new firm is created *ad hoc* to generate new products exploiting wastes from another firm.

Strengths. All the strengths recognized for the "External exchange + co-product generation" scenario (Section 4.4) can be recognized also for this one.

Weaknesses. All the weaknesses recognized for the "External exchange + co-product generation" scenario (Section 4.4) can be recognized also for this one. However, differently from the previous case, the business model of the firm using wastes is completely supported by the IS relationship. Hence, the new firm has high economic and strategic dependency from the firm producing wastes. In fact, in case of lack of cooperation, the new firm will be unable to sustain its main business. This aspect may generate an additional displacement of bargaining power.

Case study. Kazmok is a Dutch company started in 2010, producing bags from end-life conveyor belts used in flower industry, postal depots, distribution centers, and the recycling industry. Conveyor belts mainly comprise PVC and rubber, an incredibly strong material that produces bags to last a lifetime. Bags so produced are not only environmentally sustainable but they are unique products, for which customers are willing to pay premium price. So doing, firm differentiated from the competitors and gained the reputation of sustainable firm.

Table 3 resumes all the scenarios at inter-firm level and the case study discussed for each of them.

Table 3. Case study discussed for each business scenario at inter-firm level.

		FIRM USING WASTES		
FIRM PRODUCING WASTES		***Input replacement***	***Co-products generation***	***New products generation***
	Internal exchange	McDONALD'S	GUITANG GROUP	---
	External exchange	DENSO + MIR-VER	CSC + *waste plastic suppliers*	KAZMOK + *end-of-life conveyor belt suppliers*

5. Discussion

Firms can adopt the IS approach by implementing different business models. However, the choice of what model to implement may be affected by at least three factors: i) technical factors; ii) economic factors; and iii) strategical factors.

From the technical point of view, two aspects should be considered: the possibility to internally replace inputs with wastes and the typology of both produced wastes and required inputs. Only firms whose wastes are able to replace internal inputs can implement the "internal exchange" model: if McDonald's did not use trucks, it could not internally use the biodiesel produced from fried oil but it should sell such a biodiesel on the external market, implementing in such a case the "External exchange + co-products generation" scenario. Moreover, not all wastes can be used to generate new products but some wastes can only replace inputs. In these cases, the "co-product generation" model as well as the "new products generation" one cannot be implemented.

From the economic point of view, firms can choose to implement the more profitable business model for themselves. For instance, McDonald's could sell the biodiesel from the fried oil on external markets, hence adopting the "internal exchange + co-product generation" scenario instead of the "internal exchange + input replacement" one. However, since it prefers to use biodiesel internally, we may suppose such a use more profitable.

Moreover, the internal models may be more difficult to adopt for small firms because of the impossibility to share costs with partners.

Finally, from the strategic point of view, not all the business models have the same implementation risks. In particular, the "co-product generation" as well as the "new product generation" model seem having high risks related to waste supply. Firms could be not willing to sustain high risks, preferring to adopt a less risky model.

6. Conclusions

This paper firstly identifies and discusses business models supporting the IS approach at the firm level. We found that two different models can be implemented by firms producing wastes, whereas firms using wastes can implement three business models. For each of these models, we discuss how the firm can propose, create, and capture value. Moreover, from the interaction of firms, business scenarios at the inter-firm level have been identified. For each of these scenarios, strengths and weaknesses have been discussed and a short case study has been presented.

These models show all the possible strategies that can be implemented to adopt the IS approach. Hence, they can be useful to force both bottom-up (where each firm decides the business model to adopt) and top-down (where business models of firms are designed *a priori*) IS relationships. Hence, this paper can be a guide for firms interested to implement the IS approach as well as for policymakers interested to design new symbiotic exchanges within a given geographic area.

Further development of this guide may include how to overcome barriers arising from each model as well as how to reduce the identified weaknesses.

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REDUCING WASTE DISPOSAL OF METALWORKING FLUIDS BY ELECTRICAL IMPEDANCE MONITORING*

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Abstract

MetalWorking Fluids (MWFs) are widely used in mechanical industries for machine cooling and lubrication. Most MWFs are oil-in-water emulsions, with oil concentration ranging from 1% to 10%. In addition, anti-microbial compounds, corrosion inhibitors, emulsifiers, pressure additives and anti-foam agents are also normally added. MWFs degrade over time due to: growth of bacteria and fungi (that change the fluid pH); presence of contaminants (such as tramp oil); water characteristics (hardness, pH, high concentrations of chloride, sulphate and phosphate ions).
Once worn-out, the fluid becomes a waste to be properly disposed according to legislation and regulations, using techniques such as chemical waste treatment, evaporation, membrane filtration, electrocoagulation or biological treatment. The frequency of MWFs disposal should be as low as possible since this operation: a) represents a cost for both fluid disposal and replacement; b) has an impact on the environment. Thus, MWFs conditions should be regularly monitored and counteracting actions should be taken to make the product life as long as possible.
In this work we present a study on the possibility of monitoring MWF degradation by the analysis of the fluid electrical characteristics. Samples of MWFs (both fresh and degraded) have been analyzed measuring their impedance in the frequency range 20Hz to 2MHz. The acquired spectra were used in conjuction with Principal Component Analysis (PCA) for sample clustering and a model to estimate the fluids' pH, a key factor to assess wear-out, has been found that correlates well with values measured using the reference technique (R^2 = 0.894).

Keywords: fluid degradation, impedance spectroscopy, instrumentation, metalworking fluids, multivariate analysis, pH, sensors

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1. Introduction

MetalWorking Fluids (MWFs) are products widely used in mechanical industries to cool and lubricate both worked pieces and machine tools during different metal finishing processes (Stephenson and Agapiou, 2005). MWFs can be classified in three main groups according to their composition: mineral oils (petroleum based), semi-sinthetic oils (obtained by emulsion or microemulsion of mineral oil with water) and synthetic oils (based on alkaline compounds). Water based MWFs contain oil concentration in the range 1% to 10% depending on the specific product and the type of material to be worked. In addition they also contain anti-microbial compounds, corrosion inhibitors, pressure additives and anti-foam agents.

MWFs degrade over time with use due to different causes, among which one of the most important is microorganism growth (Bakalova et al., 2007; Mattsby-Baltzer et al., 1989). Bacteria and fungi can grow in most MWFs products (especially the water-based ones) due to the nutrients present in the emulsion, such as glycols, fatty acid soaps and amines. Microorganism growth makes the fluid become "rancid", with bad smell (in particular in presence of sulphate reducing bacteria), decrease in lubricating properties, increase of corrosion of both machine tools and worked pieces, reduction of production quality and higher probability of machines malfunction. High concentration of microorganisms (> 10^7 cfu/mL) results in a decrease of the fluid pH (due to microbial metabolism) that, in turn, makes the environment more favorable to further microbial growth.

To counteract this process, a biocide is often added to the fluid at regular intervals to decrease the microbial concentration and restore the fluid pH at a level (about 9.0) where microbial growth is very slow. While biocides are effective in contrasting microbial growth (Marchand et al., 2010), problems are in order concerning toxicity (most of biocides can release formaldehyde, a well known irritant for the respiratory tract and a carcinogenic agent) and potential generation of biocide-resistant microorganism strains. Since during use MWFs are dispersed in the air in the form of aerosol, studies have shown how respiratory problems of exposed workers increase with higher concentrations of MWF mists (Kriebel et al., 1997; Zacharisen et al., 1998). And even if MWF mist concentration is within legal standard, 20% of workers have been found to suffer from work-related respiratory problems (Rosenman et al., 1997).

To optimize MWFs performance and extend their lifetime it is important to maintain the proper oil concentration, which varies with time due to water evaporation, bacterial attack, oil adhesion to metal parts, etc. The industrial standard for oil concentration measurement is refractometry (Canter, 2011), a technique that allows quick and in-situ measurements but is strongly affected by fluid contamination. Alternative approaches are based on the measurements of viscosity (Grossi et al., 2016), density (Navarro de Andrade et al., 1999) and ultrasound speed (Meyer and Saiz-Jabardo, 1994).

Another factor that contributes to the degradation of MWFs is contamination. MWFs are often contaminated by metal particles with composition that varies widely with cutting process and operating conditions. Another source of contamination is non-soluble oil (tramp oil) leaking into the MWFs tank (Rakic and Rakic, 2002). Contamination has negative effect on corrosion inhibition, while lubrication and cooling are negatively affected only if contamination is so high to affect the emulsion stability (Greeley and Rajagopalan, 2004).

Once degraded, MWFs become a waste and must be disposed according to legislation and regulations. The first step in the disposal process is the separation of oil and water, that can be achieved by means of conventional techniques (such as gravity separation, dissolved air flotation and de-emulsification) or with the more recent membrane technology (Cheryan and Rajagopalan, 1998; Hesampour et al., 2008) that includes microfiltration, ultrafiltration, nanofiltration and reverse osmosis. Other techniques for MWFs disposal are electrocoagulation (Kobya et al., 2008) or biological treatment by means of inoculum of bacteria to degrade the chemical constituents and additives present in the fluid (Van Der Gast et al., 2004).

MWFs disposal represents a serious problem from both a monetary and an environmental point of view. Thus the fluid lifetime must be extended as long as possible.

In this paper we present a technique, based on Electrical Impedance Spectroscopy (EIS), to monitor the degradation of water based MWF samples. EIS is a powerful techniques that is based on the measurement of electrical properties of the material of interest in a wide range of frequencies and has been used for sensing applications in wide range of different fields, such as: quick detection of microbial concentration (Choi et al., 2009; Grossi et al., 2008; Grossi et al., 2009; Grossi et al., 2010; Grossi et al., 2011a; Grossi et al., 2012a; Grossi et al., 2013a; Grossi et al., 2013b; Grossi et al. 2014a; Hardy et al., 1977; Johnson et al., 2014; Mancuso et al., 2016; Pompei et al., 2012; Puttaswamy and Sengupta, 2010; Settu et al., 2015; Uria et al., 2016; Wang et al., 2012) analysis of human body composition (Gudivaka et al., 1999; Ibrahim et al., 2005; Kyle et al., 2001; Rush et al., 2006); the characterization of food products (Ferrero et al., 2014; Grossi et al., 2011b; Grossi et al., 2012b; Grossi et al., 2013c; Grossi et al., 2014b; Grossi et al., 2014c; Jackson et al., 2000; Yang et al., 2016); study of the degradation of organic coatings for metallic surfaces in contact with acid electrolytes (Bonora et al., 1995; Loveday et al., 2004).

For this work, 10 MWFs samples (both fresh and contaminated) have been studied in the frequency range 20Hz – 2MHz using a LCR meter Agilent E4980A. Acquired impedance data have been modeled using an equivalent electrical circuit and processed using multivariate data analysis. The results have shown that: a) it is possible to discriminate between fresh and contaminated samples; b) the fluid pH can be estimated with good accuracy.

The possibility to monitor the fluid degradation by non-destructive electrical measurements (that can be done directly in fluids' tanks, even remotely) is very important since it allows on-line monitoring of MWFs without the need to ship samples to a laboratory, thus resulting in lower costs and lower time response for the analysis. This, in turn, provides the possibility to extend MWFs lifetime, with less costs for fluid replacement and benefits for the environment.

2. Materials and methods

All Samples Under Test (SUT) used in this work are oil-in-water emulsions (both fresh and contaminated) with oil concentration in the range 1% to 10%. Ten different MWFs have been tested: SUTs #1, #2 and #3 are fresh MWFs created mixing a soluble oil produced by Total with tap water in different oil concentrations (2% for #1, 6% for #2 and 10% for #3, respectively). SUTs #4, #5 and #6, instead, are MWFs used for some time in a metalworking plant and are characterized by a moderate level of contamination. SUTs #7, #8, #9 and #10 are MWFs used for a long time and strongly contaminated. For each sample, the pH was measured using a portable pH meter (HI 9811-5N) and the obtained values have been used as reference for this work.

All experiments have been done using the set-up shown in Fig. 1 (a). A 50mL Falcon vial (hereafter called "the sensor") was modified to feature a couple of stainless steel electrodes (diameter 6mm, 12mm apart) to be used for electrical measurements, done by means of an Agilent E4980A LCR meter. A sine-wave voltage signal of amplitude 100mV and frequency ranging from 20Hz to 2MHz has been applied to the sensor electrodes measuring the complex impedance Z, with its real and imaginary components (Re(Z) and Im(Z), respectively). The data are transferred to a lap-top for data displaying, filing and further analysis.

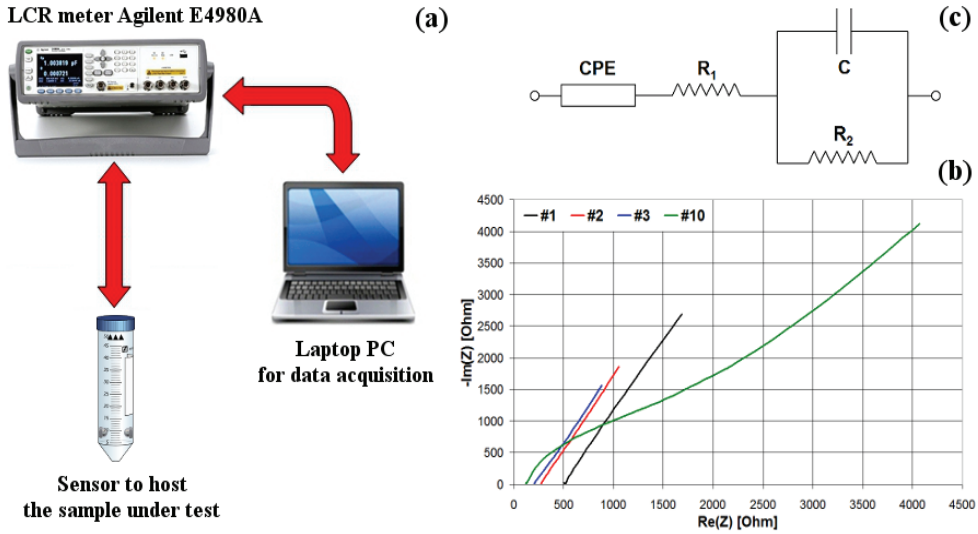

Fig. 1. Measurement setup used in this work (a). Nyquist plot for four different tested samples (b). Equivalent electrical circuit for the sample-electrode system (c)

Fig. 1 (b) shows the Nyquist plot (-Im(Z) vs. Re(Z)) for all frequencies in the case of four different samples, three fresh and one contaminated. As can be seen, while the fresh samples (#1, #2 and #3) are represented by a straight line, the contaminated SUT (#10) exhibits a more complex behavior with lower values of Re(Z) at high frequencies and higher values for both Re(Z) and –Im(Z) at low frequencies.

The measured impedance data have been modeled with the equivalent circuit shown in Fig. 1 (c): the MWF is essentially modeled by means of the resistances R_1 and R_2 and the capacitance C, while the Constant Phase Element (CPE) accounts for the non-linear electrode-electrolyte interfaces.

CPE is a non-linear circuit element whose impedance can be described by two parameters (Q and α) with Eq. (1):

$$Z_{CPE} = \frac{1}{Q \cdot (j\omega)^{\alpha}} \quad (1)$$

where Q represents the double-layer capacitance, while α accounts for the non-ideal electrodes-electrolyte interface (with α = 1 indicating an ideal capacitance).

The measured impedance spectra have been fitted to the electrical circuit of Fig. 1 (c) using the software Multiple Electrochemical Impedance Spectra Parametrization (MEISP) v3.0, by Kumho Chemical Laboratories and the values of the electrical parameters have been worked out.

Fig. 2 shows the Bode plots (Re(Z) and -Im(Z) vs frequency) for both measured and fitted data in the case of sample #10 and, as can be seen, the model fits very well the measured data. Since pH is a very important parameter used to monitor MWF contamination, for each SUT it was measured using a 9811-5N pH meter by Hanna Instruments.

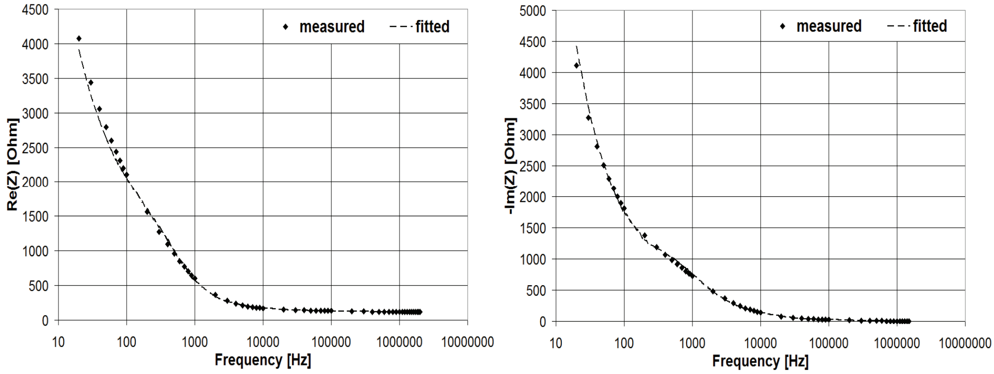

Fig. 2. Bode plot, of Re(Z) and –Im(Z) vs. frequency, in the case of SUT #10.

All the statistical analysis have been carried out using Microsoft Excel and its statistical package XLSTAT (by Addinsoft).

3. Results and discussion

The electrical parameters from the equivalent model of Fig. 1 (c) and the measured pH values are presented in Table 1 for all the SUTs.

Table 1. Electrical parameters fitting the equivalent circuit and pH values from the measured samples

Samples	*pH*	*Q (µF)*	*α*	*R₁ (Ω)*	*R₂ (Ω)*	*C (µF)*
#1	9.1	8.807	0.7544	438.85	74.75	0.0004362
#2	9.17	12.648	0.7594	271.73	37.79	24.96
#3	9.24	16.134	0.7433	202.65	24.57	20.96
#4	8.4	3.136	0.7606	166.47	5936.3	0.3404
#5	8.1	8.722	0.6523	197.2	2932	0.2695
#6	7.8	7.981	0.684	155.98	1067.5	1.198
#7	7.56	7.445	0.5903	142.34	4646.1	0.04682
#8	7.6	6.798	0.6201	200.1	3667.7	0.1037
#9	7.6	8.953	0.6296	134.34	1777.4	0.1432
#10	7.7	9.104	0.6293	116.43	907.2	0.3138

As can be seen, the pH value is clearly correlated with the fluid contamination level. The fresh samples (#1 to #3) are characterized by high pH values (from 9.1 to 9.24) because of the alkaline compounds of the oil from which they were produced. As the samples become more and more contaminated, the pH value gradually decreases, mainly because of the bacterial metabolic activity producing acidification. This is shown in Table 1, where contaminated samples (#4 to #6) exhibit lower pH values than fresh ones (7.8 to 8.4), while highly contaminated SUTs (#7 to #10) feature even lower pH values (7.56 to 7.7).

Regarding the system equivalent model, R_1 and R_2 are the parameters most influenced by the fluid contamination: R_1 is higher for fresh samples and decreases for contaminated ones, while for R_2 it is the opposite.

In both cases, however, the sample pH cannot be estimated with good accuracy from these parameters. As shown in Fig. 3 the correlation between the sample pH and R_1 or R_2 is rather low ($R^2 = 0.4906$ for R_1 and $R^2 = 0.2542$ for R_2).

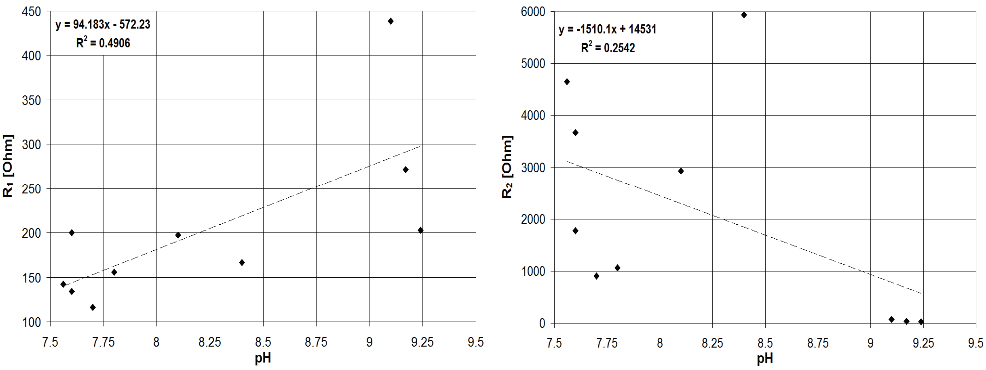

Fig. 3. Scatter plot of the electrical parameters R_1 and R_2 plotted versus the measured pH value

To improve the accuracy in sample classification, a multivariate data analysis has been implemented on the full acquired impedance spectrum: for each SUT, the data of Re(Z) and Im(Z) for every frequency have been used with a Principal Component Analysis (PCA) algorithm to obtain a set of linearly uncorrelated variables. The first two principal components (F1 and F2) are responsible for more than 98% of the whole spectrum variations and Fig. 4 shows a scatter plot of F1 and F2 for all tested samples.

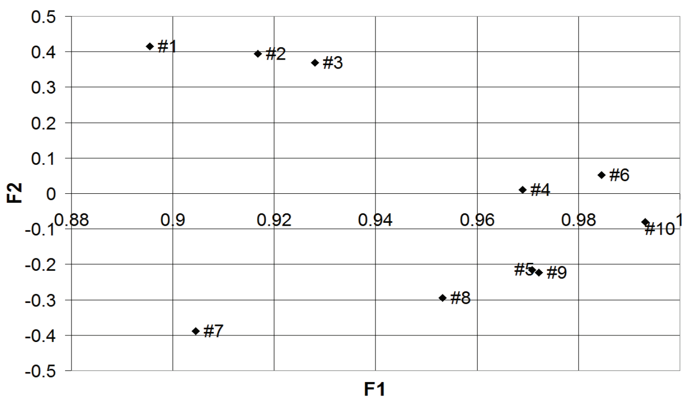

Fig. 4. Scatter plot of the first two principal components for all the tested samples

As can be seen the fresh uncontaminated samples (in the higher left portion of the plot) are strongly separated from the remaining contaminated SUTs. In particular, the second principal component F2 can effectively discriminate fresh samples (F2 > 0.2) from contaminated ones (F2 < 0.2). The discrimination between moderately (#4 to #6) and highly contaminated samples (#7 to #10), instead is more problematic, although the former ones are in general characterized by higher values of both F1 and F2 than the latter ones.

The possibility to reliably discriminate the three groups of samples has been investigated analyzing the results from PCA with two different clustering algorithms, Factorial Discriminant Analysis (FDA) and k-means clustering, and the results are presented in Table 2.

Table 2. Clustering of the investigated samples using FDA and k-means algorithm

Samples	*Group*	*Result from FDA*	*Result from k-means algorithm*
#1	Not contaminated	Not contaminated	Not contaminated
#2	Not contaminated	Not contaminated	Not contaminated
#3	Not contaminated	Not contaminated	Not contaminated
#4	Contaminated	Contaminated	Contaminated
#5	Contaminated	Highly contaminated	Highly contaminated
#6	Contaminated	Contaminated	Contaminated
#7	Highly contaminated	Highly contaminated	Highly contaminated
#8	Highly contaminated	Highly contaminated	Highly contaminated
#9	Highly contaminated	Highly contaminated	Highly contaminated
#10	Highly contaminated	Contaminated	Contaminated

Both these algorithms give the same results: fresh samples are always correctly clustered, while contaminated and highly contaminated SUTs are casted correctly with probability 66.6% and 75%, respectively.

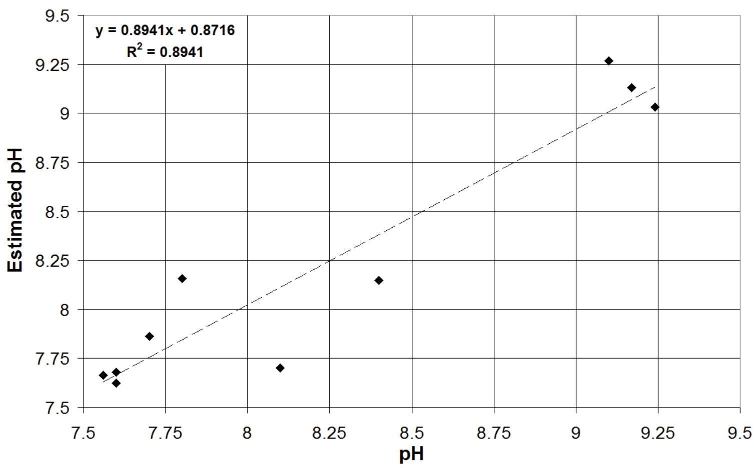

Fig. 5. Scatter plot of the estimated pH versus the value measured with a pH-meter

Finally, the output data of PCA (F1 and F2) have been used to estimate the pH value of the samples under test using Multiple Linear Regression (MLR). The regression line best fitting the experimental data was found to be:

$$pH = 12.5169 - 4.5298 \times F1 + 1.944 \times F2 \quad (2)$$

The scatter plot of the pH values estimated by means of Eq. 2 vs. those measured with the pH-meter is represented in Fig. 5. As can be seen, the use of PCA in conjunction with MLR results in much better accuracy for the estimated pH ($R^2 = 0.8941$) compared with the results obtained using the fitted electrical parameter R_1 or R_2.

4. Concluding remarks

In this work a novel technique has been presented to monitor the degradation of water based MetalWorking Fluids (MWF). The technique is based on impedance measurement of the sample under test on a wide range of frequencies (20Hz – 2MHz). The measured impedance data are analyzed using Principal Component Analysis (PCA) to extract a set of two linear uncorrelated variables (principal components) that describes more than 98% of the full spectrum variations. The two principal components are then satisfactorily used to discriminate between fresh and contaminated samples and to estimate the sample pH value.

The proposed technique can thus be used for on-line and in-situ monitoring of MWFs degradation. This, in turn, allows quick counteracting actions when the fluid contamination exceeds some critical threshold resulting in longer fluid lifetime, lower costs for product disposal and replacement. Hence ultimately also in less impact on the environment.

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SUSTAINABLE DEMANUFACTURING TECHNOLOGIES FOR PHOTOVOLTAIC PANELS*

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Abstract

This study is focused on the demanufacturing of Wasted Electric and Electronic Equipment (WEEE), a true 'treasure' of precious metals and rare elements. In particular, it will concentrate on one complex sub-class of WEEE, sharing the same multi-layer, multi-material and matrix-structured features: Photovoltaic panels (PVPs).
Due to their complex structure, effective and sustainable demanufacturing of these components is far from being achieved. Existing approaches are, in-fact, unsustainable because mainly based on trial-and-error methods that lack of theoretical basis and/or scientific evidences. The paper presents a new proposal for a more sustainable demanufacturing process of PVP, discussing pro's and con's.

Keywords: demanufacturing; LCA, recovery, special waste, electronic devices

1. Introduction

Product demanufacturing (i.e. disassembly, remanufacturing, recycling and/or recovery) is a promising economic activity under development worldwide, which could significantly reduce the consumption of non-renewable resources of our continuously growing population, considering also the energy demand profiles (Dassisti, 2012). The amount of EEE wastes yearly treated in the period 2007-2012 has been approximately less than 4000 million tons only in Europe (Eurostat, 2016); the reused and recycled fraction is slighter more than 2000 million tons with an increasing trend in the next years.

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Existing practices for the recovery of WEEE materials include thermal and chemical processes. In Europe only a few large companies treat this wastes by adopting melting, pyro-metallurgical and chemical end-refining processes, at large scale. These existing processes are high energy-demanding and mostly unsustainable. Nearly 80% of the PCBs collected in the world are processed in China with very poor ergonomic and safety conditions and with a low recovery performance.

This research subject is an hot topic, as witnessed by the recent research result of a team of South Korean researchers and scientists that has developed a sustainable process to reclaim silicon wafers from old photovoltaic units for use in the manufacture of new ones. With an estimated 50000 tonnes of solar panels wearing out in 2015 it is a clear sign of a growing market all over the world.

Lifecycle impacts of photovoltaic (PV) plants have been largely explored in several studies. However, the end-of-life phase has been generally excluded or neglected from these analyses, mainly because of the low amount of panels that reached the disposal yet and the lack of data about their end of life (Latunussa et al., 2016; Rusirawan and Farkas, 2015). It is expected that the disposal of PV panels will become a relevant environmental issue in the next decades. An innovative process for the recycling of silicon PV panel is presented based on patent (Dassisti, 2013). It consists on a sequence of physical (mechanical and thermal) treatments followed by acid leaching and electrolysis (Cynthia et al., 2016). Other interesting new procedure for the recovery of resources from waste photovoltaic modules is presented by Kang (2012).

The paper novelty funds in devising a new sustainable process-chain, to be proposed and tested to this aim. In particular, it funds in the sustainable integration of thermo-mechanical delamination process, mechanical size-reduction, separation pre-treatments and green hydrometallurgical refining processes for demanufacturing this subclass of layer-shaped WEEE.

2. Material and methods

The sustainable demanufacturing of complex multi-layered, multi-material, matrix structured WEEE is a very challenging task that has not been solved yet. This is mainly due to the variability of the end-of-life components and the intrinsic product complexity. Typically, these are made of several interconnected inhomogeneous layers, with different material properties and behavior; soft amorphous materials are interposed between two rigid layers. These soft layers are not valuable for secondary uses but are extremely difficult to disassemble. The study of their response to thermal actions is an interesting field of research related to possible sustainable approaches for the demanufacturing.

The object of this proposal is a process of conditioning upon cryogenic conditions (Dassisti, 2013) applied to multiple layers of rigid materials with different thermal behavior and elastic stiffness. As known, a good part of electronics and electrical waste, such as the artifacts described above, goes to landfill or alternatively undergoes incineration and recovery process without any preliminary treatment and therefore results in the subsequent dispersion into environment of highly polluting substances. In contrast, many end of life electronic products could be reused, restored or recycled, thus obtaining a clear benefit in protecting and safeguarding the environment and reducing pollution. Another advantage of recycling could derive from the recovery of materials that in many cases have a high economic value.

An example of an electronic system made with materials consisting of rigid layers alternated with plastic layers, i.e. the type to which it is possible to apply the process according to the invention presented, and upon which much attention has recently been focused regarding its end of life disposal, is represented by photovoltaic modules. At a structural level, photovoltaic modules are made of a sandwich of several layers joined by means of a hot lamination process.

The main component of each module is represented by photovoltaic cells which are contained within a polymeric layer made of Ethylene Vinyl Acetate (EVA). These panels are constituted by a plurality of layers, adjacent to each other, as follows: one rear polymeric waterproof coating layer, made according to requirement in either Ethylene Vinyl Acetate (EVA), polyethylene terephthalate (PET) or polyvinyl fluoride (Tedlar); a pair of layers approximately 0.6 mm thick realized in Ethylene Vinyl Acetate (EVA) that are protect the photovoltaic cells (said rigid layer); finally a rigid front layer of tempered glass approximately 3 mm thick that serves as a protective surface that is also receptive to light. At the end of their operational life, an average of twenty to thirty years, each PV module can be subjected to a special treatment that allows for the safe disposal of toxic materials (usually metal). This also allows for the recovery of some elements comprising the module, some of which are characterized by a high economic value (silicon and precious metals).

The prior processes related to demanufacturing processes of photovoltaic panel parts that cannot be removed, as already mentioned, consists in treating the rigid layers (electronic grade silicon) and plastic elements (copolymers) by melting processes. These processes consists in a series of different steps, both from the technological and industrial points of view (Bohland and Anisimov, 2000).

A further and different known demanufacturing process, which allows for the recycling of photovoltaic modules, is described in (Bohland et al., 2000). It is based on a process that provides for the recycling and recovery of the metallic constituents of a photovoltaic module by crushing the photovoltaic module itself and subsequently dissolving out the metals in an acid solution bath. The solution thus obtained is then separated from the solid fragments and treated with a precipitating agent that then allows for the recovery of the metals obtained from the photovoltaic module.

These process comprises a first step in which the photovoltaic module is crushed in order to obtain a plurality of fragments having a size sufficiently small to be chemically treated. The fragments of the module thus obtained are transferred to a container containing an acid (e.g., sulphuric acid, nitric acid or hydrochloric acid) which is capable of dissolving the metal material to be recovered thus separating it from the rest of the fragments. Upon the chemical reaction between the photovoltaic cell metals and the acid, the dissolution of the metal material occurs with the subsequent formation of a liquid phase consisting of metals combined with mordant acid and a solid phase formed by the non-metallic PV module fragments.

The solid phase present in the solution is then separated from the liquid phase by means of a filtration process, and on the contrary the non-metallic material contained in the solid phase is separated from the liquid phase by means of a vibrating screen. Finally, in the last phase of the process, the recovery of the metals from the solution occurs. A method for separating the components within the solution consists in precipitating the metals in solution through the addition of a suitable chemical precipitating agent.

Another possible solution to demanufacturing process for photovoltaic modules, as described consists in the separation of the components that constitute the photovoltaic module by means of a heat-treatment process which raises its temperature, such as to melt only the polymeric component of the module, leaving unaltered the tempered glass and the photovoltaic cells themselves (Dassisti, 2013). The purpose there is to solve the drawbacks of the existing demanufacturing processes by providing a new approach that allows minimizing the mechanical or chemical deterioration and therefore the need to proceed to subsequent treatments. This process uses cryogenic treatments for the recovery of rigid materials contained within artifacts composed of multiple rigid material layers interspersed with materials having different thermal and elasticity characteristics and different stiffness, with as such high added value or, as originally present in industrial type artifacts.

A further objective is to reduce the costs for the treatment of end of life for multi-layer materials with different thermal and elastic features and for their reuse into the recovery processes currently in use. This demanufacturing process allows the almost sustainable reuse of the components and materials recovered, thus lengthening the useful life of the components themselves and not requiring further treatment.

3. Main principles of the delamination process

The process, object of the present invention (Dassisti, 2013), claims to be a more sustainable methodology, with lower economic and environmental impact compared to the processes currently known in the field of recycling and/or the recovery of the recovery of silicon cells contained in photovoltaic modules. Apart from the energetic expenses for producing Nitrogen is from renewable sources, the process in fact tends to reduce the remanufacturing effort of the electronic-grade silicium.

The operating principle of this treatment process does not preclude its application in different fields of application, as far as separate layers of rigid materials (e.g. metals) connected by interposing materials with different levels of stiffness and thermal conductivity (e.g. plastic or amorphous) are present. The advantage of minimizing chemical and/or destructive treatment without altering the geometrical structure or mechanical properties and exploiting the physical properties of materials that exhibit different expansion should always be maintained.

The thermo-mechanical controlled cryogenic delamination process for the full recovery of rigid mono-, polycrystalline or amorphous materials coated with plastic materials according is here represented in Figs. 1, 2.

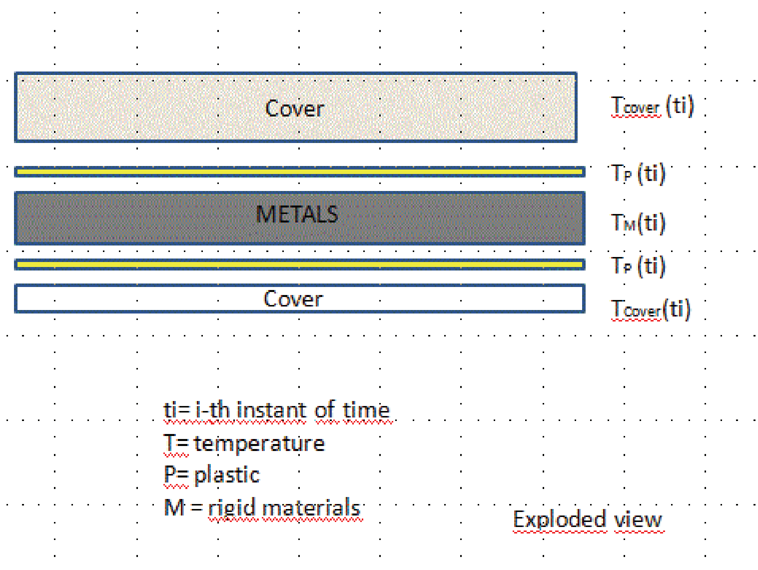

Fig. 1. A cutaway view of a generic multilayer component

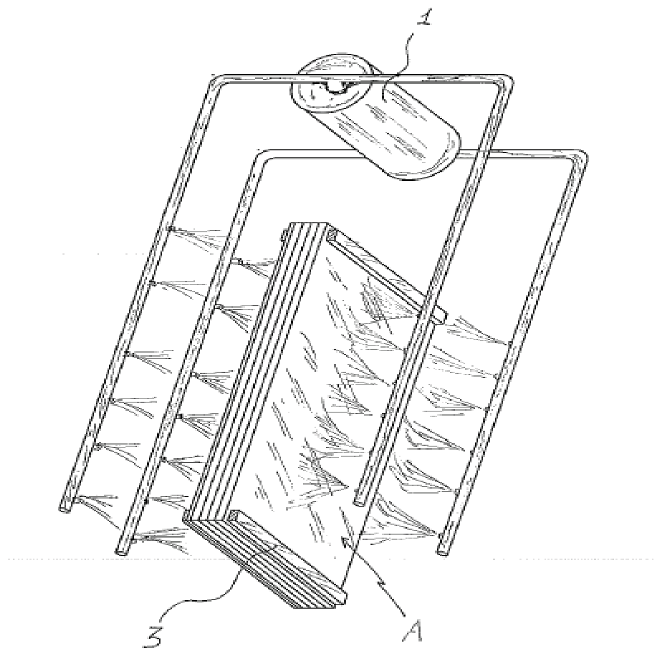

Fig. 2. An axonometric view of a photovoltaic module when subjected to the cryogenic cooling phase

4. Results and discussion

The thermo-mechanical controlled cryogenic delamination process according to the invention in (Dassisti,2013) is based on a methodology that relies on the exploitation of the different thermal expansion characteristics of the plastic materials adjacent to rigid components (mono-, polycrystalline or amorphous in the case of photovoltaic panels) and the different ductility/brittleness curves that producea controlled thermo-mechanical delamination effect.

The appropriate management of temperature transitions, combined with mechanical actions induced by thermal fields oscillation, is the mechanism that allows the delamination induced into materials of different nature and characteristics. This maes it possible to recover the useful constituents of a multilayer element so as they can be used again without any special treatment: this essentially represents an extension to the useful life of the component or its parts.

An initial feasibility experiment has been performed, imposing the thermal cycle shown in Fig. 3. The PVP considered is shown in Fig. 4. An example of an application of the process according to the present invention is one that provides for the recovery of the electronic-grade silicon present within a photovoltaic module.

The process involves the following steps:

1. temperature stabilization and homogenization for a given time of all the component layers to be treated so that all the layers reach the same cryogenic temperature by placing said component in a conditioned environment;.
2. imposing cycles of swift or super swift cooling of the photovoltaic module and in particular of the layers adjacent to the semiconductor material layer, by means of a cryogenic cooling system. This latter provides the continuous control of the flow rate and pressure of a cold carrier by means of a fluid compressor or other suitable system offering the possibility of temperature conditioning;

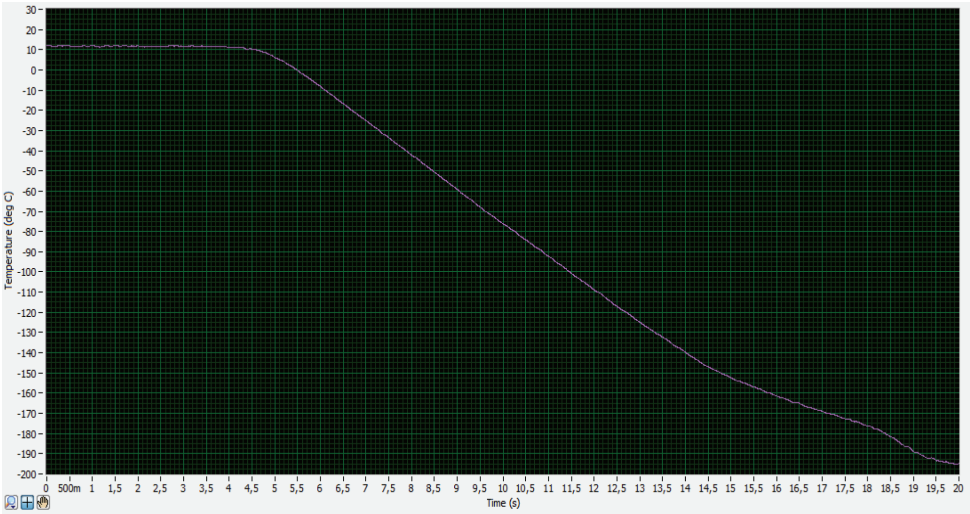

Fig. 3 Thermal cycle for delaminating a cell of PV panel

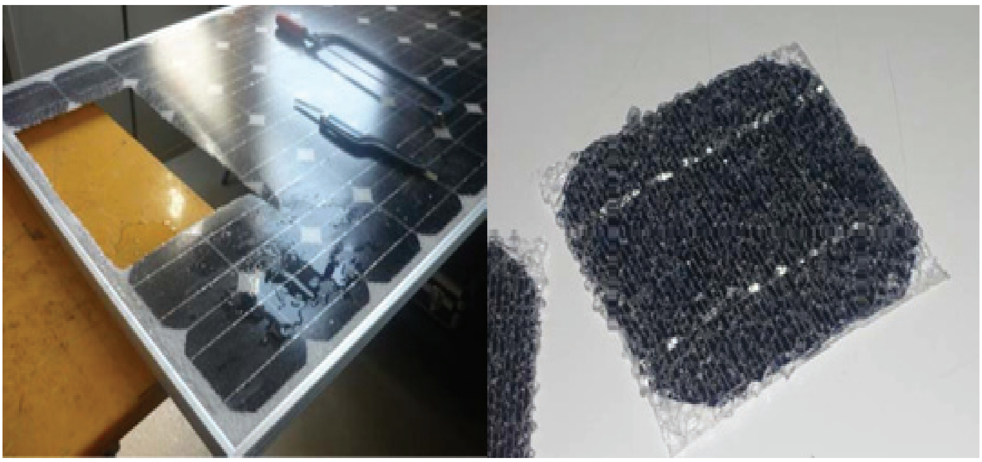

Fig 4. Dismantled panel considered and the cell experimented

3. a warming phase realized by a selective system, providing heat to the high conductivity layer only without warming the adjacent layers which are of low thermal conductivity;
4. induction of a final delamination by means of suitable systems a mixture of liquids at a controlled pressure and flow rate.
5. a final insufflation phase, where the process continues with a mechanical separation phase of layers with respect to the semiconductor material layer.

6. Concluding remarks

The cryogenic process described is based on thermo-mechanically induced delamination. It is based on a methodology that provides for the exploitation of the different thermal expansion characteristics of the plastic material adjacent the rigid components (in the case of the photovoltaic panels in mono, poly-crystalline or amorphous state) and the different behavior of ductile / fragile transition, possibly adding a simultaneous mechanical vibration, a thermomechanical controlled delamination.

The basic idea is to minimize the effort in recycling the value material (namely electron-grade silicium) by adopting thermo-mechanical treatment that does not destroy sub-components. The idea is still under a pre-industrialization study and it is challenging, since the sustainable demanufacturing of complex multi-layered, multi-material, matrix structured WEEE is a very complex task.

This is mainly due to the irreversibility of the manufacturing processes, which has not been designed for the end-of treatment. Interesting scientific challenges are still open and are under study in the next future in particular concerning the control of the induced delamination process.

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