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Selected papers (2)

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Guest Editors: Fabio Fava & Grazia Totaro

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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.

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Other projects are MINOTAURUS and WATER4CROPS (on the intensified bioremediation of contaminated waste- and ground-water and the integrated decontamination and valorization of wastewater of the food processing industry and of biorefineries), and ULIXES and KILL-SPILL (on the development of strategies for intensifying the in situ bioremediation of marine sediments polluted by (chlorinated)hydrocarbons and for the isolation and industrial exploitation of microbes from those matrices).He is the Past- and the current vice-chairman of the "Environmental Biotechnology" section of the European Federation of Biotechnology (EFB) . He is member of the "Task Force on Industrial Biotechnology" of the Working Party on Biotechnology of the Organisation for Economic Co-operation and Development (OECD, Paris). Further, he is joining the "High Level Group on Key Enabling Technologies" and the "Expert Group on biobased products" of the DG-Enterprise and Industry of European Commission (Brussels), as well as the "Expert Group on eco-industries" of the JRC Directorate at the European Commission. Finally, he is the Italian Representative for Bioeconomy in Horizon2020 Programme Committee.

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SOLID LIQUID EXTRACTION OF RARE EARTHS FROM AQUEOUS SOLUTIONS: A REVIEW*

Elena Maria Iannicelli Zubiani, Cinzia Cristiani, Giovanni Dotelli, Paola Gallo Stampino**

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Abstract

Rare Earths (REs) demand is constantly increasing in the global market because new technological applications exploit these materials for their unique properties. Since natural resources are located just in focused areas, lots of worldwide countries are arranging solutions to recover REs from end-of-life products. Currently each EU citizen produces about 17 kg of Waste Electrical and Electronic Equipment (WEEE) per year. These wastes are rich in precious and strategic metals and, in many cases, are characterized by higher REs contents than those of natural minerals. Accordingly, recycling can be considered a valuable opportunity: this perspective is known as "urban mining". From a technological point of view, recycling of WEEE and recovering of metals can be divided into three major steps: disassembly, upgrading and refining. Regarding the refining, different methods have been proposed. Among the others, hydrometallurgical method has been reported to be one of the most interesting. Some of the few disadvantages are related to the step of metal ions removal from aqueous solution. REs separation has always represented indeed a critical challenge in traditional chemical processing because of the similar chemical and physical properties of these elements.
Solvent extraction is usually the most used process to separate individual REs but solid-liquid extraction (SLE) presented as an alternative. This paper reviews the different SLE extraction systems proposed for REs separation with particular focus on the different kinds of solid sorbents used (resins, nanotubes, clays and modified clays, membranes, silica and ion-imprinted polymers) evaluating advantages and critical issues of the different systems.

Keywords: rare earths, recovery, solid-liquid extraction, WEEE

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1. Introduction

According to the IUPAC definition, the Rare Earths (REs) are a family of elements in the periodic table that includes the 15 elements called lanthanoids and scandium and yttrium, characterized by similar physical and chemical properties. Based on their location in the periodic table and their atomic weights, it is possible to classify these elements into light REs or LREs (lanthanum, cerium, praseodymium, neodymium, promethium and samarium, with atomic number 57–62) and heavy REs or HREs (europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium atomic no. 63–71) (Connelly, 2005). The abundance of the RE elements taken together is quite considerable. Cerium, the most common RE, is more abundant than cobalt; yttrium is more abundant than lead, whereas genuinely rare REs such as Lu and Tm are as abundant as antimony, mercury, bismuth and silver. Promethium in RE minerals is present only in amounts of < 10-19% as a result of nuclear actions (McGill, 2000).

Nowadays there is an increasing need of REs due to their usage in numerous high-technology applications such as: magnets, phosphors, metal alloys, catalysts, ceramics, glass and polishing. Furthermore, they are becoming increasingly important in the transition to a green, low-carbon economy. This is due to their essential role in permanent magnets, lamp phosphors, rechargeable NiMH batteries and catalysts (Binnemans et al., 2013). Each of these applications requires specific RE elements and they are not interchangeable (Iannicelli-Zubiani et al., 2013). Increasing demand for the different products containing REs has resulted in a restriction of supply from producing Countries, particularly China, which currently holds 60% of the reserves and produces 97% of the world's REs (Massari and Ruberti, 2013). Increased demands in modern electronics as well as simultaneous shortfall in their supply made REs metals and compounds to be considered the most critical raw materials group by the European Commission (EU, 2010).

The main objective of this study is to review the different SLE extraction systems proposed for REs separation with particular focus on the different kinds of solid sorbents used (resins, nanotubes, clays and modified clays, membranes, silica and ion-imprinted polymers) evaluating advantages and critical issues of the different systems.

This work is divided in three main parts:

- an overview about the different available methods recovery for REs;
- a focused review about SLE extraction system, evaluating in particular the different kinds of solid matrices used;
- a comparative analysis of advantages and disadvantages of the different considered systems.

2. Methods for REs recovery

Two principal types of process are used for the extraction of RE elements from mineral ores:

1. solid-liquid systems using fractional crystallization, precipitation or ion exchange.
2. liquid-liquid systems using solvent extraction (McGill, 2000).

In fractional crystallization, one or more REs in a mixture are precipitated by changing the salt concentrations in solution through evaporation or temperature control. Fractional crystallization was the first process for separating REs (McGill, 2000): it was used until the early part of the twentieth century but it revealed to be uneconomical for processing large quantities of lanthanides since many recrystallization steps were required to recover high purity products (Sabot and Maestro, 2000).

Chemical precipitation involves adding a precipitating agent to selectively remove a metal from solution. It is used mainly to operate a crude separation of the REs mixture into three groups: light, medium and heavy (Sabot and Maestro, 2000). Nowadays it is also used in recycling processes from electronic scraps, in the particular case in which the initial mixtures are not as complicated as the ones coming from ore digestion (Pietrelli et al., 2002; Innocenzi et al., 2013).

Ion exchange was proved to be effective in the separation of high purity REs, but generally involves the processing of very dilute aqueous solutions. In the 1950s, the commercial separation of the REs was dominated by ion exchange methods, but technical and economic limitations have restricted its use in industrial scale separation processes (Sabot and Maestro, 2000). Nowadays ion exchange processes are used in the production of small quantities of higher value RE elements (McGill, 2000) (generally used in electronics or analytical applications (Xie et al., 2014)) and base on the use of cation exchange resins: the H^+ cations readily exchange with other cations in solutions that percolate through a bed of the material. Mixed REs in aqueous solutions are trivalent cations and are strongly adsorbed by the resin. The REs are then recovered by elution. If a complexing agent exhibiting significantly different affinities for the various lanthanides is added to the eluent, then a separation occurs (Sabot and Maestro, 2000).

Solvent extraction is the REs separation process most extensively used in commercial and industrial scale (Iannicelli-Zubiani et al., 2012). It essentially involves selective extraction of metal value of interest from its aqueous solution into an immiscible organic phase. The immiscible organic phase consists of an extractant, a diluent and a phase modifier and is referred as the solvent phase. The selectivity of extraction is controlled by varying the chemical nature of the solvent and aqueous phase. Thus variables such as the initial acidity, metal concentration, extractant concentration play an important role. The separation process is governed by equilibrium considerations which are, in general, difficult to quantify and predict (Anitha and Singh, 2008). The solvent extraction of REs from the leach liquor presents some advantages: it not only concentrates the REs, but also separates REs from main impurities; the raffinate solution can be recycled adding some leaching agents back to leaching new ores; thus no wastewater is generated (Jun et al., 2011) and above large volumes of dilute pregnant liquors can be handled (Xie et al., 2014). Different phosphorus based extractants, tertiary and quaternary amines, sulphoxides, carboxylic acids, etc., are being employed for separation of REs (Singh et al., 2006).

5. Solid Phase Extraction

SPE is in growing development as an alternative approach to liquid-liquid extraction: SPE intends to solve, in fact, some of the limits and disadvantages of solvent extraction processes, such as:

1. the need of many process steps;
2. the consumption of large amounts of chemicals;
3. the use of large amounts of water.

The principle of SPE is similar to that of liquid-liquid extraction (LLE), involving a partitioning of solutes between two phases. However, instead of two immiscible liquid phases, as in LLE, SPE involves partitioning between a liquid (sample matrix) and a solid (sorbent) phase. This sample treatment technique enables both concentration and purification from solution by sorption on a solid sorbent. The basic approach involves passing the liquid sample through a column, a cartridge, a tube or a disk containing an adsorbent that retains the elements or species of interest. After all of the sample has been passed through the sorbent, retained materials are subsequently recovered upon elution properly changing the conditions or the solvent (Camel, 2003). This technique employs adsorbents in cartridge, disk, or membrane format and typical adsorbent materials include inorganic oxides, low-specificity sorbents (e.g., carbon, porous organic polymers etc.), organosiloxane-bonded silica materials, and class-specific sorbents (e.g. molecularly imprinted polymers (Huck and Bonn, 2000), immunosorbents, surface-bound macrocyclic ligands (Rahman et al., 2013), restricted access materials (Poole and Poole, 2012) and often the same sorbents used in liquid-liquid extraction but immobilized on solids). Recently, the use of SPE is obtaining more and more attention in the recovery of REs because of its advantages of high recovery, short extraction time, high enrichment factor, low cost and low consumption of organic solvents over liquid-liquid extraction (Li et al., 2011). In the following, different king of solid sorbents will be considered.

Extraction resins for the separation of metal ions have been under development since the mid-1970s (Park et al., 2005) and acquired great importance because they combine the advantages of high selectivities typical of solvent extraction with high efficiencies typical of chromatographic separation (Jia et al., 2004). The resins are generally porous polymeric materials modified with particular solvents that are characterized by high selectivities towards the metal ions of interest. Resins often occur in form of beads or microcapsules (Warshawsky, 1974). In fact, various new dimensions have been explored and reported in the field of metal extraction and the advantages of the use of polymeric beads extends due to large surface area, minimal use of organic solvents (environment friendly) and absence of phase separation phenomenon (Yadav et al., 2013).

In recent years, *nanostructure material* as a new adsorbent for the preconcentration/separation of substances has drawn growing attention in analytical sciences owing to its small size, large specific surface area, excellent mechanical strength, high chemical stability, and unique electrical properties. Some nanometer-sized substances have been successfully used as solid-phase extractants for preconcentration/separation of metal and nonmetal ions as well as adsorption of organic compounds (Chen et al., 2013). Since the first report in 1991, carbon nanotubes (CNTs) have shown great possibilities for a wide variety of processes and applications, which include their use as electrodes, sensors (gas, enzymatic etc.), nanoprobes, electronic materials, field emitters etc. The combination of structures, dimensions and topologies has provided physical and chemical attractive properties that are unparalleled by most known materials. Their applications have also reached the analytical chemistry field in which CNTs are being used as matrices in matrix assisted laser desorption ionization, stationary phases in either gas chromatography, high performance liquid chromatography or capillary electrochromatography, also as pseudo-stationary phases in capillary electrophoresis, etc. as well as new SPE materials. Concerning this last application the number of works has considerably increased in the last five years (Ravelo-Pérez et al., 2010).

Iannicelli-Zubiani et al. (2013) affirmed in their work that *clays* are characterized by some outstanding advantages, such as low cost, high mechanical intensity, good acid tolerance, convenient solid-liquid separation and excellent reusability. Furthermore clay minerals show a natural adsorption behaviour towards REs (Coppin et al., 2002; Moldoveanu and Papangelakis, 2012) so they are often used for their recovery, both as source both as sorbent solid-phase. Iannicelli-Zubiani et al. (2013) and Ianicelli and Zubiani (2013) modified two different clays (STx-1b and SWy-2 belonging to the smectite family) with different polymers in order to obtain new materials able to capture and release RE elements. Li et al. (2011) synthesized a new material for samarium adsorption using dry process to activate the mineral clay bentonite followed by N-(2-hydroxyethyl) ethylenediamine connecting chlorosilane coupling agent.

In the recent years, the separation of ions with very low concentration has been focused on *liquid membrane (LM) techniques*. LM can carry out simultaneous extraction and stripping processes in the same stage, and benefits a non-equilibrium mass transfer and up-hill effect, where the solute can move from low- to high concentration solutions. Main types of liquid membrane systems include supported liquid membrane (SLM), emulsion liquid membrane (ELM), bulk liquid membrane (BLM), flowing liquid membrane (FLM) and electrostatic pseudo liquid membrane (EPLM) (Wannachod et al., 2011). The LM acts generally as a solvent for a transported solute, which is governed by its solubility in the membrane. This technique likened to that of conventional solvent extraction and stripping in which a thin liquid film is used to transport the solute from the feed to the product side. Organic solvents such as D2EHPA, PC-88A and Aliquat-336 dissolved with kerosene or common sulphonated kerosene are generally the most used extractants for RE metal ions while the strippants in the receiving phase include mineral and carboxylic acids (Gaikwad, 2012; Pei et al., 2012).

Silica is an extraction support very used because of its thermal and mechanical resistance, its great resistance to organic solvents, its lack of swelling and its hydrophilic properties. Several chelating agents were immobilized on silica support according to different methods of functionalization in order to improve the selectivity, the capacity and the rate of sorption of trace metals (Bou-Maroun et al., 2006). Concerning REs, Cornejo-Ponce et al. (Cornejo-Ponce et al., 1998) described a liquid-solid extraction procedure for praseodymium, neodymium, samarium and yttrium mixtures. Zhang et al. (2008) prepared a new material starting always from silica gel and modifying it with 4-(2-morinyldiazenyl)-N-(3-(trimethylsilyl)propyl)benzamide. This new sorbent was studied for separation and preconcentration of Sc(III).

Molecular imprinting is a versatile technique for preparing polymeric materials that are capable of high molecular recognition. Molecular imprinting polymeric (MIP) materials are prepared by the copolymerization of functional and crosslinking monomers in the presence of the target analyte (the imprint molecule) that acts as a molecular template. The functional monomers initially form a complex with the imprint molecule and, following polymerization, the functional groups are held in position by the highly crosslinked polymeric structure. Subsequent removal of the imprint molecule reveals binding sites that are complementary in size and shape to the analyte. Thus, a molecular memory is introduced in to the polymer, which is now capable of binding the analyte with high specificity (Prasada Rao et al., 2004).

6. Concluding remarks

SPE is a process in growing development because of its advantages of high recovery, short extraction time, high enrichment factor, low cost and low consumption of organic solvents over liquid-liquid extraction. The separation of the particular elements REs by SPE was reviewed and the different solid sorbents used were analysed.

Extraction resins combine the advantages of high selectivities typical of solvent extraction with high efficiencies typical of chromatographic separation and are characterized by large surface area, minimal use of organic solvents (environment friendly) and absence of phase separation phenomenon. Nanostructure materials as nanotubes are advantageous for small size, large specific surface area, excellent mechanical strength, high chemical stability, and unique electrical properties.

Clays are characterized by low cost, high mechanical intensity, good acid tolerance, convenient solid-liquid separation and excellent reusability. Furthermore clay minerals show a natural adsorption behaviour towards REs so they are often used for their recovery, both as source both as sorbent solid-phase.

Liquid membrane techniques can carry out simultaneous extraction and stripping processes in the same stage, and benefit a non-equilibrium mass transfer and up-hill effect, where the solute can move from low- to high concentration solutions.

Silica is an extraction support very used because of its thermal and mechanical resistance, its great resistance to organic solvents, its lack of swelling and its hydrophilic properties. Molecular imprinting is a versatile technique for preparing polymeric materials that are capable of high molecular recognition, ensuring very high specificity.

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ANALYSIS OF SUSTAINABILITY ASSESSMENT OF BUILDING WINDOWS FOR ITALIAN RESIDENTIAL MARKET: LIFE CYCLE ANALYSIS AND LEED*

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Abstract

The policies of the products have always been aimed to create products good for their functionality, design and innovation. Actually, as energy and natural resources become scarcer and more expensive, and as climate change becomes a growing concern, companies are investing in eco-friendly products and technologies. A Life Cycle Assessment (LCA) is here applied to assess sustainability of a PVC window by relating it to the window size. Two functional units were thus considered to evaluate the quality of the environmental impacts expressed in terms of Carbon Footprint: per piece and per square meter of see-through surface. It resulted that at the change of the type of window the sustainability impact value per square meter changes considerably. We therefore propose a new criterion of the analysis to provide a reliable assessment approach that can be used in the evaluation of the environmental performance of buildings. Test has been carried out on several samples of windows to prove the soundness of the approach. The sustainability of window can also be assessed with reference to the requirements of the Leadership in Energy and Environmental Design (LEED), one of the most used Environmental Sustainability Assessment for Buildings. LEED is not an environmental label for products, but products can help the building to obtain the certification; so it is important to evaluate the performance of the windows related to the sustainability of the building and to inform consumers in order to facilitate their use in projects spreading environmental sustainability certification for buildings.

Keywords: carbon footprint environmental impact, LCA, windows

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1. Introduction

In 2012, worldwide production capacity for PVC was 54 million t an increase of 9 million tons since 2009 (Ertl et al., 2013). Most of this capacity increase occurred in China, which now has about 44 % of the world's capacity. Its current capacity of 24 million tons far exceeds the Chinese domestic demand of 14 million tons. With 37.4 million tons in 2012, PVC is in third place behind polyolefins in terms of global plastics consumption. Worldwide demand for PVC is determined largely by building construction activities. The most important applications globally are pipes and fittings (42 %), profiles and hose/tubing (18 %), rigid film and sheet (17 %) as well as cable (8 %). PVC can be combined with a number of additives to yield a wide range of end-use properties, from rigid plastics to flexible material.

This paper focuses on PVC window frames and considers the life cycle environmental impacts. Global annual consumption of PVC for window frames is estimated at around 3 million tons, or around 8% of the global PVC production (Stichnothe and Azapagic, 2013). Together with the estimated 400 million tons of PVC consumed since the 1960s, of which half is still in use in products such as window frames. This means that large volumes of PVC wastes could be available for recycling, potentially leading to a significant reduction in environmental impacts of PVC window frames (Sadat-Shojai and Bakhshandeh, 2011). There have been several LCA studies of PVC window frames, mainly aimed at comparisons of PVC with aluminum and wood frames (Italian legislation, 2013; Sinha and Kutnar, 2012). No LCA studies have been found in literature so far on the sensitivity of the LCA study to the size of the PVC windows. The impact category utilized for the paper is the Global Warming Potential in the 100 years.

2. Material and methods: Life Cycle Assessment and Carbon Footprint

According to the standardization (ISO) 14040, a Life Cycle Assessment (LCA) is the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, EN 4040, 2006; Milutinović et al., 2014; Simion et al., 2013). The life cycle of a building window includes: raw material extraction, manufacture of raw materials, distribution of materials between extraction and assembly, assembly of materials into windows, utilization and maintenance of windows, window disposal. A LCA consist of four stages (Ghinea et al., 2012):

1. Goal and scope definition: defines the system boundary and a functional unit.
2. Inventory analysis: the collection of data as defined by the study goals.
3. Impact assessment: translates environmental consequences into quantifiable environmental impacts.
4. Interpretation of the life cycle impact assessment.

The Carbon Footprint utilized for the present analysis is calculated as the total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in equivalent tons of carbon dioxide (CO_2).

3. Experimental: Inventory analysis

The company addressed by the study is voluntary committed for the evaluation of the environmental footprint and for the reduction of the GHG emissions according to the Italian environmental regulations and the Kyoto Protocol as well as the "Climate and Energy package" adopted by the Council of the European Union in 2008. To this aim, the objective of this analysis is to perform a quantitative assessment of the amount of resources required and the emissions produced to manufacture a PVC window, in the standard version node. This study has been carried on the basis of the GWP100 impact.

The purpose of calculating the GWP100 is to adopt policies and strategies to reduce and hopefully to offset the emissions to withstand the international market for carbon credits. The Italian company believes that the assessment of the environmental impacts is a necessity, to witness its commitment to sustainable business development in the long term. The measurement of consumption and environmental impacts, allows to take action and improve continuously its products and processes either from a technological point of view as well as from the environmental one, and thus it is an assumption of social responsibility in respect of all the stakeholders. Recipients of the results of this LCA were customers, suppliers, shareholders, employees, local authorities and the social community.

The products objects of study are the fixtures in colored-PVC extruded mass, with metal reinforcement. A total of 4 products to be analyzed. According to the following settings: fixed window (1200x1200 mm equaled-through surface), two-wings window (900x1200 mm see-through surface), one-wing window (1300x1200 mm see-through surface) and three-wings window (1700x1200 mm see-through surface). The functional units were of two types: the piece and the see-through surface of a PVC window for a life time of 30 years.

Table 1 shows the calculation of the surfaces, with information relating to the thermal transmittance and the total weight.

Table 1. Characteristics of the windows

Typology	*Thermal transmittance, U, W/m² K*	*Total weight, kg*
Fixed window, standard node DG00	1.63	34.95
One-wing window, standard node DG00	1.62	33.89
Two-wings window, standard node DG00	1.67	50.25
Three-wings window, standard node DG00	1.69	70.07

This study considers the entire life cycle up to the point of use (energy requirements of window installed in a particular building) starting from the upstream processes. At the boundaries of the system were considered:

- production of raw materials;
- transportation of raw materials and processes within the company;
- transportation, distribution and installation;
- the use phase.

The end of life was excluded from the characterization of the impacts, because the company was not responsible for replacement of the frame building.

The selection of the boundary of the system was consistent with the objective of the study. They were considered as the so-called temporal boundaries, geographic and technological. The study refers to the entire year 2013 and therefore the primary data are relevant to that period. Secondary data came from the database contained in the LCA software, SimaPro 8.0.3, as well as from other LCA studies related to the specific raw materials. The most recent data available were selected adopting mainly a qualitative criterion, i.e. choosing substances or processes as similar as possible to those really adopted by the company. The geographical boundaries include Europe, mostly in Italy, since the raw materials came from different countries, and the production site was in the South of Italy.

Regarding the technological boundaries, all the activities described below for product manufacturing were considered, including production of raw materials, the primary and secondary packaging, the installation as well as the use.

In particular, for the use phase it was necessary to define a reference scenario to calculate the energy requirement in the window's use. To do so it was established a location area of the building where the window were installed, since the energy consumption also depends on the weather conditions. For the transportation information concerning the number of units distributed in 2013 were collected broken down by province by referring to the weighted mean. As a representative location area of buildings the city of Matera was considered for data input, where the company had the largest number of customers.

The following assumptions were necessary for the study:

- all the stages from the extraction of raw materials to the production and use for the production and use of materials were included in the system;
- in the case of transportation, the study considered all the necessary supply of semi-finished products and supplies. It is considered as a unit of the ton per km;
- internal transport occurred by means of electric forklifts, the consumption of which has already been considered in the overall energy balance;
- to include the methods of treatment of waste, with the exception of recycling, which was considered only the transport up to the recovery;
- the production plant uses electricity mix which is made up of 41% from solar energy;
- to include the transport of the frame by the plant to the building site, installation the window frame in the building, energy use for air conditioning (theoretical calculation of the energy needs for the winter).

The environmental impacts that were excluded from the study were associated with:

- the use of the platforms and interlayer metal, because they are continually re-used;
- the maintenance of the facilities, consisting of a limited number of annual broken bits and blades that are regenerated every three months and not replaced;
- the processes of infrastructure, machinery and molds;
- the travel business from the staff and members of the workforce to go to the place of work;
- the cleaning of the windows.

When there is an outgoing flow of material to be recycled, the transport of material takes place at the point where the recycle is included. The window, at the end of its useful life, can be disassembled or crushed for the recovery of metal parts and plastics. The material for recycling and the flow out of the system of product and all related impacts to the process of recycling and processing as well as the subsequent use were considered as a part of the next life cycle and thus were outside the boundaries of the system. For the materials used in various waste recycling treatments, transportation from the production site to waste stabilization or destruction place was considered, while impacts related to this latter were not included, excluding benefits such as revenue energy - say from incineration-, being this part of the life cycle of the next recycling cycle.

The kind of data considered into this study were:

- specific data: data from the site where the process takes place;
- selected generic data: data from the database equivalent of a technological point of view (Ecoinvent 3.1). In particular, the processes considered representative of the geographic and technologically equivalent;
- other generic data: data from other sources or processes where Ecoinvent database was not representative.

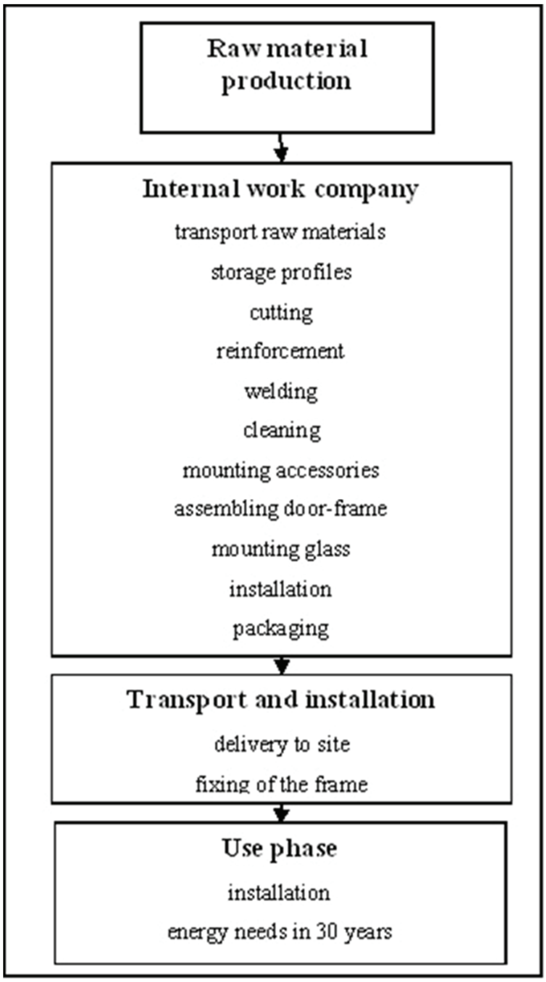

Fig. 1. System boundary

For activities within the production site, specific data directly measured from the field were used. As concerns the processes of the life cycle of the upstream company, specific information were collected from producers; in the case of unavailability reference was made to data from literature or the Ecoinvent database. The impact assessment method adopted was according the Intergovernmental Panel on Climate Change, with a timeframe of 100 years.

For the cut-off it was excluded the adhesive tape in the packaging step. The use of the allocation systems was adopted only for the waste components and the electrical energy respectively, depending on the weight of the sections and reinforcements in the first case and in function of the product unit in the second case. For the quantification of industrial waste allocated to the finished product, it reckoned by dividing the total quantity of waste of plastic products for the total weight of PVC profiles (as a function of linear measure of profile length purchased) and then multiplying this factor by the weight of each type of profile. The same procedure was used for evaluating the metal reinforcements. The results was a rejection rate of 9.6% for PVC profiles and of 3.5% for metal reinforcement. In order to consider all energy consumption and allocate them on the products properly, the “per unit of production” criterion was adopted (Table 2).

Table. 2. Electricity use for each product

Typology	*Matching unit number*	*Electricity consumption in kWh per piece*
fixed window	0.5	5.74
one wing window	1	11.48
two wings window	2	22.95
three wings window	3	34.43

In order to quantify correctly all stages of the life cycle of the product namely raw materials, energy consumption and waste were quantified (Table 3). The assembly process is made as follows. The frame and sash of the windows considered are made using PVC profiles and metal reinforcements of an average length of 6500 mm, cut according to the required size.

Table 3. Inventory for each window

Typology	*Fixed Window*	*One Wing Window*	*Two Wings Window*	*Three Wings Window*
Steel accessories [kg]	1.669	1.76	3.03	0
Zama accessories [kg]	0.184	0.278	0.516	0
Nylon accessories [kg]	0.009	0.021	0.03	0
PVC profile [kg]	11.667	18.86	26.48	6.19
Metal reinforcements [kg]	6.69	10.55	15.96	4.06
Glass [kg]	14.13	19.44	23.91	24.55
PVC glazing bead [kg]	0.7481	1.3	1.84	0.935
Silicone [lt]	0.18	0.4	0.78	0.2
Polyurethane foam [lt]	0.169	0.2	0.23	0.19
Cover-wires [m]	8.45	10	11.648	9.648
Fixing screw [kg]	12	12	16	12
Transport waste and input in [ton /km]	37.65	55.63	75.97	39.94

Reinforcements are fixed to PVC profiles by means of screws of 1 gram weight. The hardware is inserted in plastic, steel and zinc alloy. The glass is mounted on the leaf by using shims and silicone. The glazing bead used by the company is equal to the length of the profile used for the swing subtracted of 0.12 m per side. Finally packaging the entire window requires four angular shaped cartons, from a single weight of 20 g and 10 g of LDPE films. The overall window is mounted on pallets made of iron that are reused internally. The distribution transportation path is 522 km. As already stated above, it was supposed that the installation of the window was in a yard site located in Matera. For the laying of the window the following material was assumed:

- silicone, equal to 20 mL per meter of the frame;
- polyurethane foam, equal to 20 mL per meter of the frame;
- 1 m cover-wires per meter of the frame;
- fixing screws.

In the calculations of the impacts related to the use phase, the main parameter considered was the thermal transmittance of the window frames, which strongly influences the heat loss, while for the final analysis It was the energy consumption. To estimate the energy consumption in the use phase a standard room for analysis has been considered with the window located on an exterior wall.

To simplify the analysis, it was assumed that the outer wall where the window was mounted was the only heat loss point; that is, it was assumed that there is no flow of energy through the interior walls, floor or even from ceiling. As regards the use phase, the following factors were taken into account:

- the technical performance of the material;
- the duration of the frame, which coincides with the length of the structure in which it is used.

For the use phase it was important to estimate the energy needs. The assumption made concerning the insulation of the building was that it was proportional to the external climatic conditions and accordingly to the needs of indoor thermal comfort. Increases in the thermal performance of the window corresponds to a decrease in the cost of heating and cooling. The heat loss of an external wall is given by Eq. (1).

$$q = U(T_b - T_o)[J] \quad (1)$$

where U is the heat exchange coefficient, T_b is the base temperature and T_o is the average daily temperatures. The dispersion of annual heat per unit see-through surface, can be determined using the degree days HDD (Eq. 2).

$$q_A = 86400\, HDD\, U\ [J] \quad (2)$$

The annual energy requirement can be calculated by dividing the heat dissipation efficiency of the heating system η_s (Eq. 3).

$$E_{A,H} = \frac{86400\ HDD\, U}{\eta_s}\ [J] \quad (3)$$

Similarly, the cooling load can be determined by a similar expression, with CDD cooling degree-days and COP - coefficient of performance of the cooling system (Eq. 4).

$$E_{A,C} = \frac{86400\ CDD\, U}{COP}\ [J] \quad (4)$$

In this study, the annual cooling load has been neglected because in summer the influence of the window in the reduction of energy consumption is much lower than in winter. The degree days for the municipality of Matera extracted from the DPR 412/93 are reported in Annex A. For the overall efficiency of the heating system fueled with natural gas is was assumed to be 0.9.

5. Results and discussion: Impact assessment

Table 4 illustrates what are the impacts in terms of *CF*. For future analysis, we evaluated the stages of the life cycle environmental impact. The phase is the most impactful use phase comprising a time span of 30 years.

Table 4. Carbon Footprint results

Typology	*CF per piece*	*CF per m²*
fixed window	848.68	684.42
one wing window	653.19	725.76
two wings window	1032.85	737.75
three wings window	1365.57	762.89

Table 5. Carbon Footprint results for each phase

Typology	*Fixed window*	*One wing window*	*Two wings window*	*Three wings window*
Raw materials %	10.28	14.89	13.87	15.53
Transport raw materials and machining inside %	1.1	1.74	1.86	2.01
Transportation distribution and installation phase of use%	1.29	1.53	1.28	1.51
Use phase %	87.32	81.84	83	81.23

Neglecting the energy consumption of the use phase it resulted that glass and PVC profiles are the most impactful followed by metal reinforcements. The model analyzed in the present study assumes that the component parts of the fixtures are retained at the end of life for recycling, ways to open recycle if the material falls into the the process stream different from the original. In the case of open recycling, and in the particular case of Italian company considered, the window is withdrawn from customers and taken at the production site to be dismantled and sent to recyclers.

The study conducted by Stichnothe and Azapagic (2013) estimated that one window without glass weights 1430 kg, where 1000 kg are obtained for PVC granules with a consumption of energy equal to 1,100 MJ and fuel consumption equal to 3 MJ. In the case of a one-wing window DG00, the total weight is 33.58 kg, with 19.44 kg without glass, from which 13.597 kg become recycled PVC with a consumption of electricity equal to 21 MJ and 0.06 MJ of diesel.

Following the conclusions drawn from the present study, the company is considering the opportunity of replacing the current profiles in PVC reinforced with steel with PVC profiles with thermal reinforcements. The reinforced side frame is covered with a rigid PVC exterior with inside cellular PVC with integrated steel cables. The side door reinforcement is performed by means of continuous glass fiber within the walls of the profile. Ores results in fewer environmental impacts, especially in the use phase because it improves the thermal performance of the window.

6. Concluding remarks

The Carbon Footprint performed in this paper is based on a Life Cycle Assessment (LCA), where the choices taken can affect the conclusions results.

These are related to the use of the functional unit that is specific to the dimensional characteristics of the window. The value of the CFP per square meter can still well represents the range of products. A sensitivity analysis of the Life Cycle Assessment (LCA) as a function of the windows size was performed for a case of an Italian company manufacturing PVC windows. To this aim, two functional units were considered namely: per piece and per square meter of surface see-through.

This study therefore proposes the results of the analysis for several samples of windows in order to offer reliable data that can be used later in the evaluation of the environmental performance of buildings. It was found that by changing the type of window, the impact per square meter changes considerably.

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CONSERVATION OF PIPE WORKS AND MEMBRANES WITH ENERGY EFFICIENT WATER TREATMENT*

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Abstract

Cooling circuits are one of the most important parts in industrial production lines. However, when using water for cooling applications it is very important to take care of pipework surfaces. The change of material properties increases undesired side effects. For example microbial growth (e.g. fouling), scale deposits as well as corrosion can significantly compromise cooling effects with regard to dwell time and COC (cycles of concentration). Furthermore, increasing surface roughness and hydrophobicity require more pumping power, higher water flow rate, and ultimately higher costs of operation.
This paper is reporting on energy efficient water treatment in compliance with water quality regulations along with reducing the risk of bio-contamination for example from Legionella. The paper will address bacteria proliferation, microbial capacity in pipe works, and technological strategies for reducing the microbiological population capacity in pipe works without increasing maintenance efforts.

Keywords: biofilm elimination, catalysis, catalytic water treatment, energy efficient, MOLLIK

1. Bacteria and biofilm in technical water circuits

Free bacteria are normally no technical problem, as long as biofilm formation is prevented. Biofilm formation is a complex process. In literature is described (Freitag et al., 2012) that residues of bacterial cell walls are in particular phospholipids and fatty acids, which are playing a key role in this case. However, adenosine triphosphate (ATP), which is ubiquitous in all living things, can play an important role. Such residues are known to be available when bacteria die and cannot be reused immediately substantially.

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On the walls of heat exchangers bacteria are exposed to elevated temperatures leading to their death. If bacteria are retained in filters and concentrated, while the nutrients can pass through the filter unit, then a part of the concentrated bacteria "starves" to the point where bacteria count and nutrients coincide again. In case of dead bacteria are not removed residues from their cell walls serve to develop a biofilm.

Hydrogen bonds play an important role for the formation and development of biofilms. The proton permanently oscillates between two partially negatively charged partners without bonding to either one of them. Consequently, it is relatively easy to replace one of the partners without chemical changes. An equilibrium at the boundary of the material surface is achieved between removal of phospholipid and ATP and substances replacing them. Ideally, these substances are able to mask surfaces in such a way that the reattachment of biofilms becomes considerably more difficult.

2. The natural power of water molecule and return to use by catalysis

In liquid water, the proton oscillates - driven by infrared radiation of the sun - constantly at a rate of several hundred m/s (more than 1 000 km/h) between different partners. Preferred "partners" are the partially negatively charged oxygen atoms of the water. However, the proton energy is also sufficient to degrade other dissolved matter that causes aging and corrosion on surfaces. While this self-cleansing function of water occurs permanently, the process is too slow for technological use and requires a suitable catalyst in order to speed it up and achieve relevant removal rates. A requirement is that these catalysts have structures, which are able to convert the kinetic energy of the protons into usable chemical energy without destroying at the end.

On the surface of special alloys built from nickel, chromium, iron and containing mineral-metal-catalysts, it is possible to selectively and efficiently support the self-cleaning effect from the protons. Another key factor in this process are hydroxyl radicals, which are homolytically linked to the surface of the alloy. They are thermodynamically stabilized and due to their surface charge attract biomolecules. By using visible light they can be activated and lead to the decomposition of the biomolecules describing the technology as "light-induced catalysis". Currently technological embodiments so called MOLLIK-catalyst modules (Fig. 1).

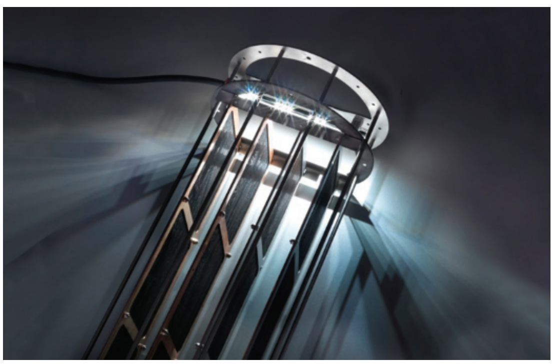

Fig. 1. MOLLIK-catalyst module with integrated LED unit (visible light spectrum)

3. Biocide-free removal of biofilm

In the presence of MOLLIK-catalyst modules ATP and other components or metabolites of living and/or dead bacteria are converted – under action of water and modicum of visible light – into biosurfactants. These are products, which are not able reducing any living harmful organisms and/or asset impair the vitality, but they are adapted to exchange binding partner of hydrogen bonds.

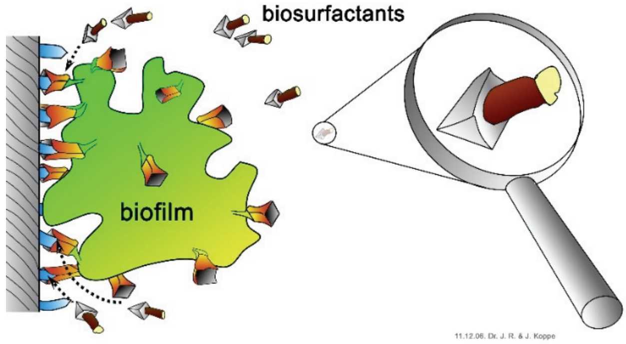

Fig. 2. Principle of biofilm removal by biosurfactans

Providing suitable alternative structures – instead of the material surface – on the hydrogen bonding may interact with these substances by receiving a new hydrogen bond. The biofilm is not chemical modified by this purely physical process. However, he loses contact with the material surface and can discharge easily from water. Here occurs no biocidal effect on the biosurfactants, too.

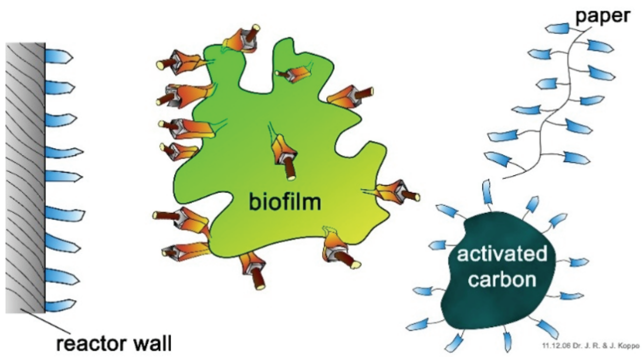

Fig. 3. Detached biofilm

Under technical conditions the concentration of biosurfactants is wet chemically inaccessible in the water, cause of the fact that their concentration is very low and biosurfactans are adsorbed on the pipe work surface and filter materials. Because of this adsorption the hydrophilicity of the surfaces increases, which inter alia results in saving pump energy. At the same time biosurfactant adsorption prevents the formation of biofilms and existing biofilms are removed.

In the presence of MOLLIK the biofilm detachment occurs as a purely physical process, where free bacteria and other living organisms are neither destroyed nor quenched or otherwise made harmless. A biocidal effect does not exist. That is preservation by adsorptive coating of surfaces at the molecular level. This adsorption is a reversible process, so a permanent use of MOLLIK technology is recommended for ensuring the facility performance.

4. Technical examples of energy-efficient catalytic water treatment

Typical technological applications are:

a) Integration of MOLLIK-modules in technical circuits,
for example, in cooling circuits, in swimming pools and pretreatment tanks.

b) Integration of MOLLIK-modules at once through applications,
for example in feed water lines of RO-plants, industry complexes and power plants.

Due to the action of biosurfactants formed far from the place of origin, it is possible to use the MOLLIK for partial flow treatment (about 20% of the total water flow).

- Catalytic water treatment at cooling circuit of a pharmaceutical company in Bitterfeld/Germany (Körner et al., 2015), means an *open cooling circuit,* with the following characteristics: system volume: 3.5 m³; circulation rate: 100 m³/h; COC: 3.0 till 4.0; make-up: portable water; 1x MOLLIK-module: weight: 4.9 kg, size: ∅ 250 / L: 600 mm, power consumption: 60 Watt*h/day (12 V DC) (Fig. 4).

Fig. 4. MOLLIK-module installed at cooling basn (Körner et al., 2015)

- Working at cooling circuit of refinery (Fig. 5), **(**Ernhofer, 2014) means an *open cooling circuit,* with the following characteristics: volume: 2000 m³; circulation: 3500 m³/h; COC: 3.0 till 4.0; make-up: well water (partial-softened); 2x MOLLIK-module: weight: 85 kg, size: (L x B x H), 1200 x 800 x 910 mm; power consumption: 350 Watt*h/day (12 V DC).

- Catalytic water treatment at public swimming pool (Fig. 6) (Maurer et al., 2013) means a *hot whirlpool* with the following characteristics: temperature: 36°C; pool volume: 10 m³; circulation: 100 m³/h; make-up: portable water; 1x MOLLIK-module: weight: 4.9 kg, size: ∅ 250 / L: 600 mm, power consumption: 60 Watt*h/day (12 V DC)

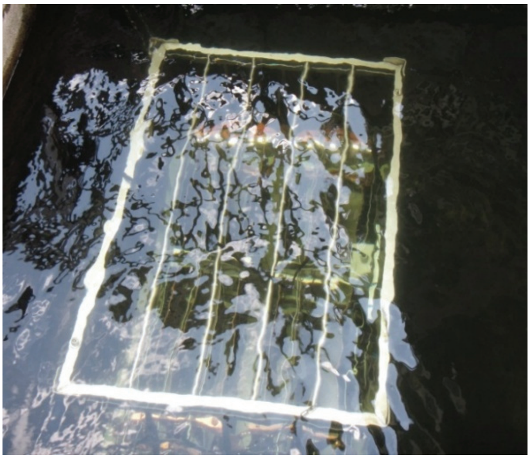

Fig. 5. MOLLIK-module installed at cooling basin

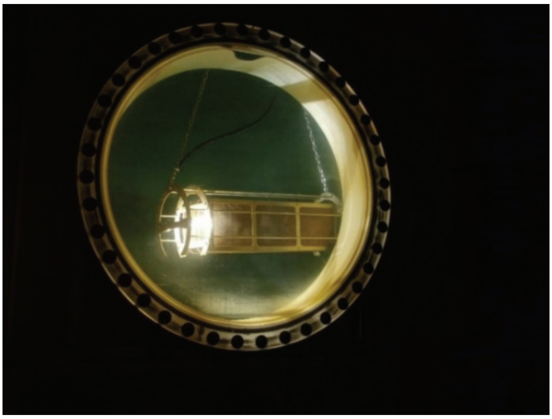

Fig. 6. MOLLIK-module installed at storage water tank of whirlpool

- Application at pretreatment of automotive painting lines (Fig. 7) (Klimkewitz et al., 2014). At VBH 10 (*clear water tank after bonderizing)* there is only a bypassing flow of 15 % main flow treated by MOLLIK, with the following characteristics: temperature: RT; volume: 50 m^3; circulation: 80 m^3/h; make-up: demineralized water; 1x MOLLIK-vessel at bypass: weight: 90 kg, size: ∅ 360/L: 1500 mm, power consumption: 100 Watt*h/day (12 V DC), bypassing flow: 12 m^3/h.

- Usage at storage water tanks for fouling prevention (Fig. 8) (Koppe et al., 2011), means an *UF-permeate storage tank,* with the following characteristics: volume: 10 m^3; flow rate: 30 m^3/h; make-up: bank filtration; 1x MOLLIK-module: weight: 3.9 kg; size: ∅ 250 / L: 370 mm; power consumption: 60 Watt*h/day (12 V DC).

Fig. 7. MOLLIK-Module with stainless steel vessel

Fig. 8. MOLLIK-module during installation at feed water tank of RO

- Once-though application at make-up of a power plant (Fig. 9) (Hagen et al., 2015). *Make-up supply (installation point before filtration unit)* has the following characteristics: tank volume: 50 m³; flow rate: ≤ 1000 m³/h; make-up: seawater; 2x MOLLIK: weight: 60 kg, size: (L x W x H):1200 x 800 x 910 mm, power consumption: 350 Watt*h/d (12 V DC).

Fig. 9. MOLLIK-module at make-up supply of power plant

5. Concluding remarks

In evidence to numerous technical applications in cooling and process water systems, catalytic water treatment with energy efficient MOLLIK-technology is removing biofilms on pipe works, container walls and even on activated carbon in filter units. Based on the degradation of these microbiological shelters, the aerobic colony units according to Drinking Water Ordinance and for pathogens – such as Legionella – reduced significantly.

Finally, microbiological concentration is sustainably falling below the intervention value of the relevant technical regulations. As a result the heat transfer performance of the cooling circuit is rising. Furthermore availability and lifetime of the facility are increased.

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BIOHYDROGEN PRODUCTION THROUGH BIOWASTE FERMENTATION*

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Abstract

Dark anaerobic fermentation is one of the most promising processes for the bio-hydrogen production. Moreover, when the organic waste is used as substrate, the biofuel production get together with the management and valorization of organic wastes. In this work, a demonstrative plant was developed in order to produce purified hydrogen gas with the aim to fuel a near zero emission hybrid-electric vehicle. The H_2 producing bacteria were selected by pretreating the digested sludge, coming from the anaerobic digestion plant of ACEA Pinerolese Industriale, with HCl for 24h. The organic fraction of the municipal solid wastes was used as substrate and the biogas production started after a lag time of 4 h. The maximum production rate was 360 L/h and the gas mainly consist of hydrogen and carbon dioxide. The maximum H2 production yield was 9 L for liter of fed biomass. In addition it must be considered that the pre-digested biomass, downstream of this process presents optimal characteristics to be used for bio-methane production.

Keywords: anaerobic bacteria, biohydrogen, dark fermentation, organic waste

1. Introduction

Hydrogen is one of the most promising fuel because of its high energy content per unit of weight. Gaseous blend, currently tested at 30%v/v H_2, could results in a reduction in CO2 emissions if used as a fuel for combustion engines in automotive sector. Moreover in NG (natural gas) vehicles the pollutant emissions and engine efficiency could take advantages from the use of biohydrogen and biomethane blend. Hydrogen could be produced by steam reforming, electrolysis, gasification and biological process. Nowadays, the hydrogen bio

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production has gained attention due to its greater sustainability. Above all, among the biological processes, dark anaerobic fermentation is recognized as the most promising especially when organic wastes is used as substrate (Levin et al., 2004). This process is carried out by anaerobic bacteria belonging to *Clostridia* species, highly concentrated in anaerobic digested sludge. *Clostridium spp.* are able to convert sugar in carbon dioxide and hydrogen by acetate-butyrate pathways during the acidogenic step of fermentative process (Fang et al., 2002). However, during this process, methanogenic or sulphate-reducing bacteria consume hydrogen to form methane; In order to inhibit the hydrogen consumers in the mixed microflora, digested sludge is usually pre-treated using thermal shock or acid-basic treatment (Mohan et al., 2007).

This work was carried out within the project Biomethair, founded under the Piedmont Region Automotive Platform that aims to develop an innovative system for a complete approach to the urban mobility. The project has the purpose of realize a near zero emission hybrid-electric vehicle powered with a self-produced biohydrogen/ biomethane fuel. ACEA Pinerolese Industriale and Environment Park SpA worked together in order to produce the bio fuel in a pilot scale plant using biomass wastes as substrate. In particular, the collaboration concerns the plant realization and the optimization of the process parameters (WP5 e WP6).

The aim of this work is to develop a solution for the urban mobility powering a zero-emission automobile with self-produced bio fuel. Moreover, the purpose is to install the plant where biomass are available in order to combine the high sustainable hydrogen production with treatment and valorization of organic wastes.

2. Demonstrative plant description

The plant for the bio-hydrogen production consists of a 500L anaerobic reactor and a 500 L supply tanks for feeding the biomass. The plant is divided into three different zones:

- ***Zone 1: Shredding of the biomass***

The biomass is fed into the plant through a hopper tank in polyethylene with a capacity of 700 liters, equipped with a butterfly valve to discharge the content. Downstream of the hopper is positioned a blades shredder. After this system there's a second shredder of industrial type (model ROTOCUT Vogelsang), and a centrifugal pump that allows to recirculate the biomass into the tank for obtain a pulp easily processable within the system.

After the grinding, through the centrifugal pump, the biomass is fed into the storage tank in AISI316 with a capacity of 500L.

- ***Zone 2: Storage biomass***

The storage tank in AISI316 and has the following technical characteristics:

- capacity: 500 liters;
- inspection hatch on the cover;
- three-legged support;
- input for nitrogen to realize the anaerobic conditions;
- inputs and attacks: biomass coming from the centrifugal pump, agitator mounted on the top cover, a pressure switch as indicator for maximum and minimum level, a temperature probe, a probe for measuring the pH
- a vent
- drain.

The shredded biomass, after reaching the correct pH value, is sent to the digester through the opening of a 3-way valve and the use of a peristaltic pump.

- ***Zone 3: Anaerobic fermenter***

The anaerobic fermenter for the bio-hydrogen production is in AISI 316 and has the following technical characteristics:
• capacity: 500 liters;
• rounded bottom;
• external jacket for temperature control;
• three-legged support;
• inputs for feeding the biomass and for corrective solutions of acid and base;
• input for nitrogen to realize the anaerobic conditions;
• pH and temperature probes;
• level pressure switch;
• pressure gauge (0-100 mbar, r)
• mixing with peristaltic pump
• a vent valve in the head of the reactor to maintain the internal pressure in the range of 20-60 mbar,
• drain
• heater to heat the water inside the reactor jacket

- ***Control System of the plant***

The plant has been implemented in order to operate automatically through a control system. This system is able to perform the functions of management of the flows in continuous mode (downloading and uploading of the flow of biomass), the process of correction of the pH, the monitoring of the level in the reactors and the temperature control in the anaerobic fermenter.

- ***Gas purification system***

The produced biogas is sent continuously to a gas purification system with a compressor.

The purification stage consists of:
• a column of washing with water, dispersed through a sprinkler and filled with Rashig rings to eliminate the most of CO_2 content;
• a column to reduce the moisture content of the gas stream, which is saturated with water vapor at the previous stages. The dehumidification is realized with silica gel;
• a column of active carbons for the purification of H_2S.

3. Materials and methods

The demostrative plant (Fig. 1) was planned by implementing the pilot scale plant located at the Green Chemistry of the Environment Park, Torino and is localized at the Polo Ecologico Integrato of ACEA Pinerolese Industriale (Pinerolo). Environment Park did all the preliminary tests in order to determine the optimal process parameters for a continuous production of biohydrogen from organic wastes.

The inoculum used (10% v/v) was a digested sludge coming from the anaerobic digestion plant of ACEA Pinerolese Industriale, that was chemically pre-treated with HCl for 24 h in order to inhibit the methane forming bacteria. The biomass used as substrate was the organic fraction of municipal solid wastes initially basified with NaOH. The substrate was mashed and mixed using two shredders and a centrifugal pump in order to obtain a fragmentation of 2 mm of diameter. After mashing, the biomass was pumped in a homogenization reactor of 500L for the hydrogen production, equipped with pH and temperature control system, two parameters that strongly influence the process.

The pH was regulated by introducing sulfuric acid (H_2SO_4, 10% v/v) or sodium hydroxide (NaOH, 30% w/v), through two peristaltic pumps. Temperature (37°C) was maintained by flushing hot water in the heating jacket. To avoid stratification, the biomass was recirculated through to an external recirculating system using a peristaltic pump.
In order to guarantee a correct carbon/nitrogen ratio and an optimal micronutrient supply, a micronutrient medium containing inorganic salt and yeast extract was added along with the first inoculum. During the process samples were taken in order to measure the total solids (TS), the volatile solids (VS), the sugar concentration and the COD.

At the beginning of the fermentation process, nitrogen was insufflated at the bottom of the reactor to obtain anaerobic condition. Inside the reactor, the pressure was set at 55 mbar by regulating a relief valve. The gauge pressure allowed the maintenance of anaerobiosis conditions and the prevention of product inhibition. For the entire process, the biomass inside the reactor was recirculated with a peristaltic pump and samples were taken in order to measure the concentration of suspended total solid (TSS) and suspended volatile solid (VSS).

The gas composition was measured by collecting the gas in gas sampling bags and then analysing through a micro gas chromatograph. The volume of gas produced was continuously measured with a volumetric gas counter and it was collected in a tank of 200L. From this tank a compressor pressurized the stored gas into the purifying system with an automatic control that maintain the set pressure. The gas then flow through a purification system composed by a washing column that remove the CO_2, a column filled with silica gel that lower the moisture content and a column filled with activated carbon that remove H2S. After the purification step, the biohydrogen is collected in the final tank (1000L) ready to be used for an house-hold system for car refueling.

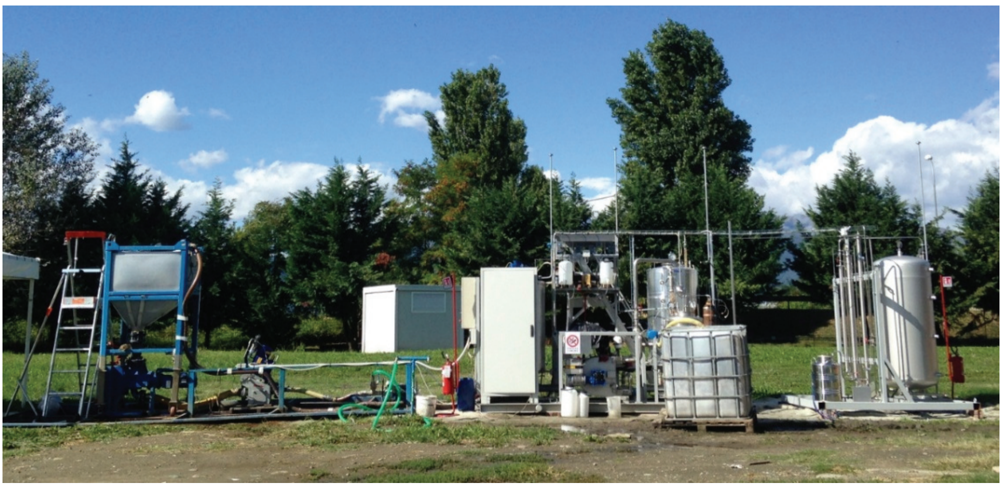

Fig. 1. View of pilot scale plant

4. Results and discussion

After an initial batch phase of 4 h the plant operated in continuous. The gas production increased exponentially for 24 h and the gas flow assessed its value in a range of 110 L/h to 360 L/h (Fig. 2).

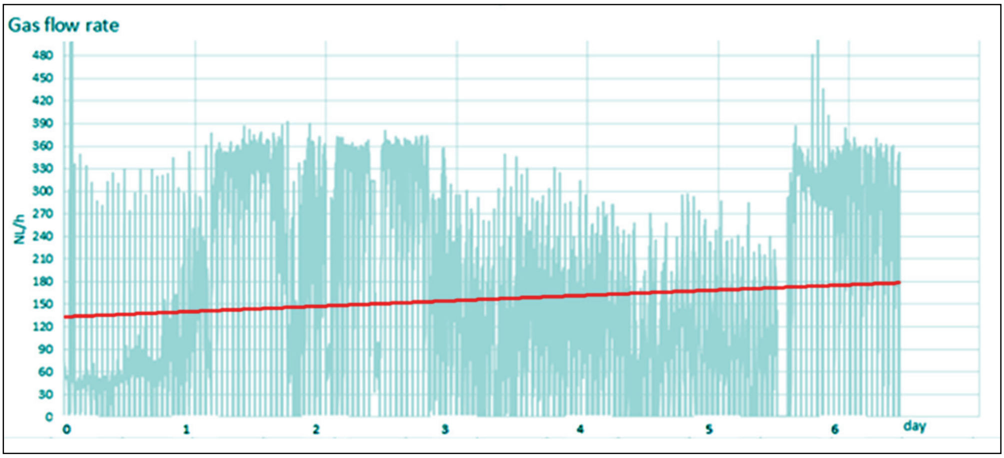

Fig. 2. Biohydrogen production through biowaste fermentation: total gas production rate (the red line show a polynomial trendline)

The analysis of gas composition evidence that the gas was mainly composed by hydrogen and carbon dioxide. No methane production was detected, confirming the efficient inhibition of methanogenic bacteria. Hydrogen percentage ranged between 21% and 36%, with an average value of 30% during the entire process. The average of hydrogen production rate was 1300 L/h and the maximum production yield was 112 L/L of fed biomass.

During the lag phase the pH quickly decreased from pH 6.5 to 4.8 and then it settled around pH 5.3 (Fig. 3). Such decrease of pH was due to the production of Volatile Fatty Acids during the fermentation, mainly acetate and butyrate, which are strictly connected to H_2 production (La Licata et al., 2011). In Fig. 4, the trend of temperature during process is shown.

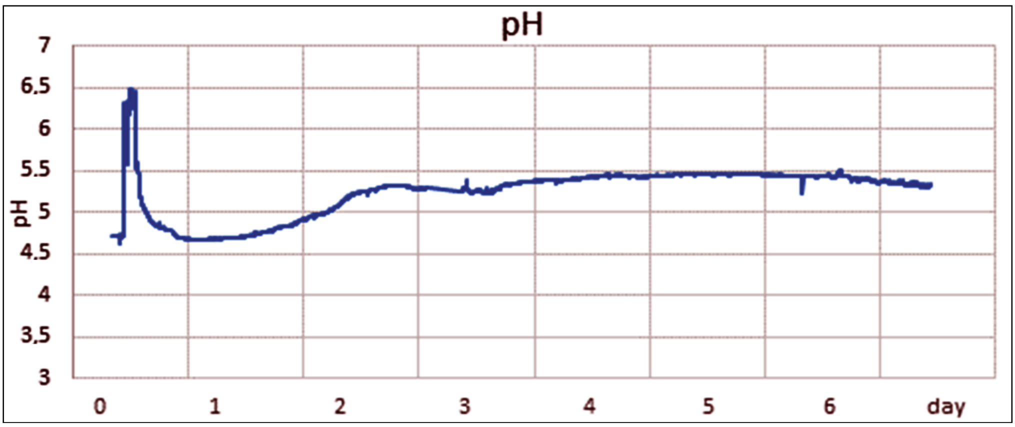

Fig. 3. pH trend during the process

5. Conclusions

In this work it was confirmed at demonstrative scale the feasibility of bio-hydrogen production using organic wastes as substrate. The pilot scale data already available regarding the bio-hydrogen production from organic wastes tested in Environment Park laboratories was almost confirmed, with an increased value of productivity in terms of rate and a slightly lower value in terms of H_2 percentage in the biogas.

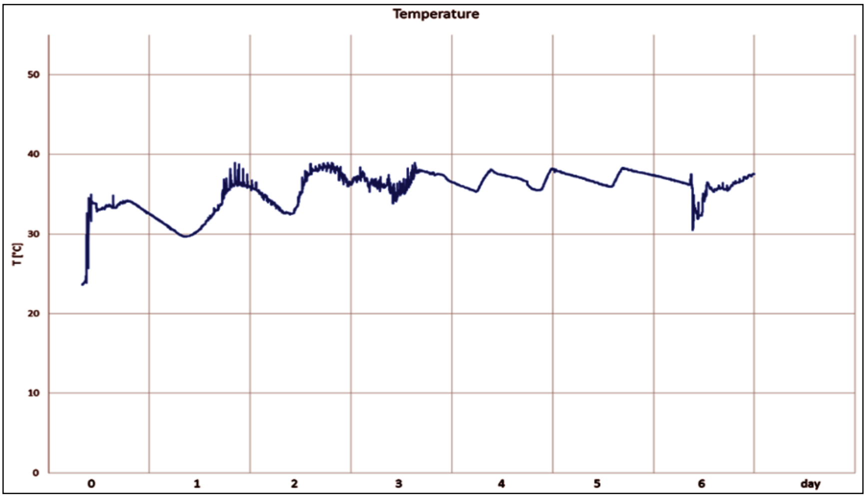

Fig. 4. Temperature trend during the process

After a quick (4 h) lag time, the gas production yield was assessed at an average value of 9NL for Liter of fed biomass. The analysis of gas composition revealed an average of 30 % of hydrogen and a maximum percentage of 36%. Moreover, the result shown a maximum production yield of 11.4 L H_2/g of volatile solid.

In addition the downstream derived from the first stage of anaerobic digestion for hydrogen production could be used as substrate for the biogas production with increasing of the overall energy efficiency of the process. The obtained results could open the possible scenario of industrial refuelling system for NG vehicles with self-producing methane/hydrogen blends from organic wastes. The utilization of biomethane and biohydrogen blends in NG vehicles represent a significant opportunity to make the H2 carrier enter in the transportation sector.

The outlook to combine bio-methane and bio-hydrogen production by fermentation in a double exploitation of organic fraction of municipal solid wastes could represents a significant complementary step to meet the European target of use of renewables energy sources in the transportation sector.

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INTEGRATION OF ANAEROBIC-AEROBIC DIGESTION OF ORGANIC WASTES: GHG EMISSION IMPACTS AT MICRO AND MACRO SCALE*

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Abstract

We estimate the Greenhouse Gas (GHG) emissions from two process configurations: the aerobic composting and the integrated anaerobic-aerobic digestion with production of electricity, heat and high quality fertilizer. The reference case study is an existing composting plant, operating in aerobic conditions in the Province of Siena (Tuscany, central Italy) from 2009 to 2011. We hypothesize to install an anaerobic digester inside the existing composting plant in order to recycle the anaerobic digestates. We evaluate the climate impacts of these two different waste management practices at technological and regional scale. The integration of anaerobic-aerobic digestion of organic wastes could determine a yearly reduction of the GHG emissions equal to almost 23% of those from the existing composting plant. Moreover, the electricity production from biogas obtained by the anaerobic technologycould avoid the release of 5% of the annual GHG emissions from the waste disposal plants, operating in the integrated management system of the Province of Siena. At the same time, the provincial area could benefit from the production of electricity obtained by waste incineration and biogas (anaerobic digestion and landfills), reducing the territorial net carbon balance of almost 1.8% per year. The estimated GHG emissions, calculated according to the "2006 IPCC Guidelines for National Greenhouse Gas Inventories", can provide useful information and management suggestions to waste operators and policy makers.

Keywords: compost, anaerobic digestion, GHG emissions, organic wastes

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1. Introduction

The role of the aerobic composting has been strengthened over time and simultaneously the anaerobic digestion has obtained greater technological attention for the organic waste management (Gunaseelan, 1997). The composting practice aims at producing high quality fertilizer, while the anaerobic digestion is a biological process in which the organic matter is transformed into biogas and digestates (Bustamante et al., 2013). The latter can be recycled by aerobic composting in order to improve the quality of the obtained fertilizer for agriculture (CRPA, 2006).

In fact, some undesirable characteristics of the digestates, such as odor, viscosity, high humidity and high content in volatile fatty acids may restrict its application to agricultural soils without treatment (Abdullahi et al. 2008; Walker et al., 2009). Anaerobic digestates require a "purification" to enhance their fertilizer value and applicability as a soil conditioner. For this reason, the digestate can be separate into a liquid and a solid fraction, which is composted with green wastes in order to obtain marketable compost for agriculture (Holm-Nielsen et al., 2009). The biogas generated in the anaerobic digestion can be directed to a co-generator to produce energy: electricity, heat and upgrading to bio-methane that is introduced in the national grid or used for vehicle traction. During the last decades, engineers worked on the possible integrations of the anaerobic-aerobic digestion with the aim of optimizing their strengths and minimize the disadvantages.

The main objective of this study is to compare the climate impacts from two process configurations: the aerobic composting and the integrated anaerobic-aerobic digestion with production of electricity, heat and high quality fertilizer. For this reason, the greenhouse gas (GHG) emissions due to these waste management technologies are estimated in order to evaluate the impacts at plant and regional scale.

The proposed analysis could provide useful suggestions for reducing GHG emissions from the waste sector, in particular the management of solid organic wastes, which provides marketable end-products (i.e. biogas, electricity, heat and compost).

This work is divided into three main parts:

- selection of an aerobic composting plant, operating in the integrated management system of the Province of Siena (Tuscany, central Italy) as reference case study;
- evaluation of the GHG emissions due to the aerobic composting of solid organic wastes compared with those from the integration of anaerobic-aerobic practices, in order to estimate over time (2009-2011) the climate impacts at plant, sector and territorial scale;
- analysis of results, drawing conclusions and recommendations for decision makers.

2. Materials and methods

The GHG emissions of the composting plant under study, named Le Cortine and located in the Province of Siena, were calculated for all the performed activities according to the "2006 IPCC Guidelines for National Greenhouse Gas Inventories". Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) released from the disposal plant were estimated, multiplying the activity data by the related emission factors. The GHG emissions of the composting plant were estimated into direct and indirect from 2009 to 2011.

The direct emissions take place within the boundaries of the considered waste management plant, assessing the climate impacts of bio-degradation of green residues and Organic Fraction of Municipal Solid Waste (OFMSW), as well as the use of fossil fuels for heating, working machineries, transport of materials and energy production within the plant. On the other hand, the indirect impacts occur outside the analyzed plant with the consumption of the electricity imported from the national grid and the combustion of fossil fuels for the transport of the production cycle wastes to other disposal facilities (Marchi et al., 2014, 2015).

We have also estimated the direct and indirect GHG emissions of a hypothetical anaerobic digester located inside the existing composting plant, where on average 3585 t green wastes and 13,129 t OFMSW were managed (Siena Ambiente S.p.A., 2012). The obtained biogas was calculated considering a production equal to 70 Nm^3 biogas/t of green residues and 130 Nm^3/t of OFMSW (CRPA, 2006a; Siena Ambiente S.p.A., 2011). As in Reichhalter et al. (2011), we have assumed that 1% of the produced biogas was accidentally released to the atmosphere, thus, we have calculated the CH_4 emissions that contribute to the greenhouse effect, considering that 60% of the biogas is constituted by methane.

The quantity of electricity produced from the biogas obtained by the anaerobic digestion is equal to almost 1.98 kWh/Nm^3 of biogas (CRPA, 2006b; Siena Ambiente S.p.A., 2011). The amount of the anaerobic digestates is estimated, considering a weight loss equal to almost 15% of organic wastes in input to the plant (Siena Ambiente S.p.A., 2011). On average, 2950 t of green wastes per year are added to the anaerobic digestates, obtained by the digestion of organic matter (Siena Ambiente S.p.A., 2011). The composting process of this material releases GHG emissions due to the bio-oxidation of the semi-stabilized organic matter previously treated in the digester; thus, we have considered that they emitted 0.03 g CH_4/kg of waste and 0.06 g N_2O/kg of waste (ANPA CTN-ACE, 2002; IPCC, 2006).

The electricity and thermal energy used in the hypothetical anaerobic digester are estimated, considering an annual consumption of 12 kWh/t of waste and 38 kWh/t of waste, respectively. The consumption of fossil fuels in the anaerobic digester is one half of that used in the aerobic composting plant, consuming mainly for the material movement within the boundaries of the system. We have also hypothesized that the combustion of fossil fuels for the transport of the production cycle wastes (coming from the anaerobic digestion) is equal to that of the existing composting plant.

The GHG emissions due to the combustion of fossil fuels were estimated considering the specific emission factors, proposed in the handbook of national emissions factors (ANPA CTN-ACE, 2002).The emissions due to the consumption of electricity and those avoided by virtue of the use of energy produced by renewable resources were calculated, considering an emission factor determined from the production of electricity at national scale and that locally produced. All GHG emissions other than carbon dioxide (CO_2) were converted into CO_2 equivalent (CO_2-eq), using Global Warming Potentials at 100 year horizon (IPCC, 2007).

The GHG emissions due to the aerobic composting and the integration of anaerobic-aerobic technologies were compared from 2009 to 2011, quantifying the climate impacts at plant and regional scale (e.g. the integrated waste management system and the territory of the Province of Siena).

5. Results and discussion

The combination of anaerobic-aerobic technologies determines some advantages on the greenhouse effect, showing a reduction of almost 1/3 of the direct GHG emissions due to the degradation of organic wastes in a traditional aerobic composting plant (Table 1).

The electricity produced by the biogas extracted during the anaerobic phase decreases GHG emissions, avoiding the consumption of energy obtained from fossil fuels. This positive aspect brings the integrated processes to a surplus of emission credits. The carbon credits from the cooperation of the two technological configurations are estimated by the difference between the total GHG emissions and the avoided ones, showing lower climate impacts than those of the aerobic composting (Table 1).

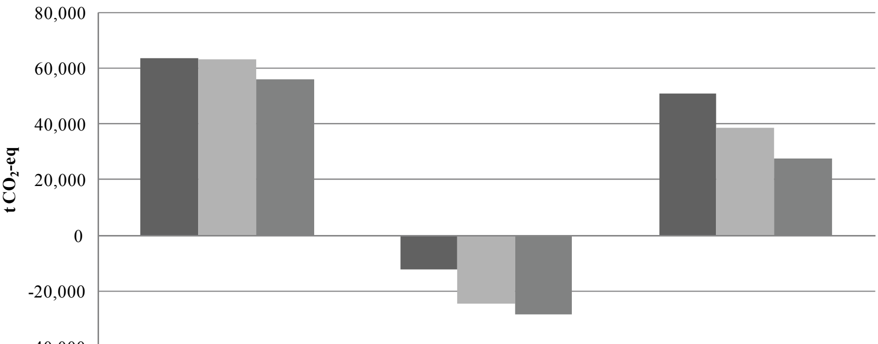
The integration of the two processes (anaerobic-aerobic digestion) determines considerable advantages:

- produces compost, that can be applied in agriculture (stocking the carbon and nitrogen in soil), and biogas with a potential generation of electricity and heat;
- improves the energetic balance of the waste disposal site because in the anaerobic phase there is a surplus of energy production compared to the energy needs of the overall plant;
- the olfactory problems can be better controlled, considering that the more odorous phases are managed in closed reactors (the digestate is a material already semi-stabilized) and the used up air is represented by biogas;
- there is a lower use of the available spacefor the aerobic treatment, considering the same quantity of disposed waste; in fact, the time of the aerobic phase passes from 90 to 60 days. Moreover, the recycled anaerobic digestates occupies a lower volume than the wastes managed in the composting plant;
- it has a better effectiveness to treat wastes with higher water content than solid matter;
- recycling of anaerobic digestates by composting allows to acquire legal and commercial requirements for a product that is a fertilizer (End of waste);
- it increases the production of the electricity obtained by biomass and other renewable resources (e.g. covering the roofs, backyard and car parking with solar cells).

Table 1. Comparison between the GHG emissions due to the composting of organic wastes, as well as the anaerobic digestion and the integration of these two management practices

Activity	*2009*	*2010*	*2011*
	t CO_2-eq	*t CO_2-eq*	*t CO_2-eq*
Aerobic composting plant			
Aerobic compost production (direct emissions)	1,467.55	1,583.43	1,494.38
Consumption of fossil fuels and electricity (direct and indirect emissions)	593.93	539.61	599.66
Avoided emissions from the local production of electricity	0	0	0
Total	2,061.48	2,123.04	2,094.04
Anaerobic digester			
Anaerobic digestion (direct emissions)	201.81	220.77	209.42
Consumption of fossil fuels and electricity (direct and indirect emissions)	462.43	485.01	467.28
Avoided emissions from the local production of electricity	-1,799.32	-1,895.01	-1,830.30
Total	-1,135.08	-1,189.23	-1,153.60
% variation between the hypothetical anaerobic digester and the existing composting plant	-155%	-156%	-155%
Integration of anaerobic-aerobic technologies			
Integrated anaerobic and aerobic digestion (direct emissions)	511.40	554.80	524.67
Consumption of fossil fuels and electricity (direct and indirect emissions)	1,056.36	1,024.62	1,066.94
Avoided emissions from the local production of electricity	-1,799.32	-1,895.01	-1,830.30
Total	-231.56	-315.58	-238.70
% variation between the hypothetical integrated anaerobic-aerobic digestion and the existing composting plant	-111%	-115%	-111%

The climate benefits due to the degradation of the organic wastes in the integrated anaerobic-aerobic digestion are higher than those of a traditional composting plant and an anaerobic digester, working alone. Considering the advantages listed above, the integration of these two technologies is the best practice to obtain energy, high quality compost and lower amount of GHG emissions, considering the same quantity of treated organic wastes. For this reason, we have hypothesized to install an integrated anaerobic-aerobic plant in the waste management system of the Province of Siena in order to evaluate the potential advantages at micro and macro scale. The integration of anaerobic-aerobic practices could determine an annual reduction of the GHG emissions equal to almost 23% of that from the existing composting plant. The avoided GHG emissions due to the electricity production from the biogas obtained by the anaerobic digester (Table 1), summed to those produced by the biogas captured from landfills (1273 t CO_2-eq on average) and the waste incineration (16,418 t CO_2-eq on average), could be equal to 21,891 t CO_2-eq on average over time (Marchi et al., 2014, 2015). The electricity production from the biogas obtained by the anaerobic digestion could avoid 5% of the annual GHG emissions due to the waste disposal plants, operating in the integrated waste management system. The net GHG emissions could decrease during the years, passing from almost 50,810 t CO_2-eq in 2009 to 27,212t CO_2-eq in 2011 (Fig. 1).



	Total emissions due to the disposal plants of the integrated waste mangemnt system, considering the integration of anaerobic-aerobic digestion	Avoided emissions due to the local electricity production	Net emissions
2009	63,351.17	-12,540.79	50,810.39
2010	63,059.58	-24,691.07	38,368.51
2011	55,652.91	-28,441.37	27,211.55

Fig. 1. Total emissions of the plants operating in the integrated waste management system of the Province of Siena (considering the integrated anaerobic-aerobic digestion), avoided emissions due to the electricity production and net GHG emissions

The production of electricity from the biogas obtained by the integrated anaerobic-aerobic digestion and from other waste treatment plants (landfills and incinerator) could determine a decrease of the GHG emissions of the Province of Siena equal to almost 1.8%, considering all the anthropogenic activities performed in the area. Thus, the integration of anaerobic-aerobic practices could contribute to the total GHG emission reduction of the Province of Siena, which became carbon neutral in the year 2011 (Progetto REGES, 2008-2013).

The GHG inventory is a management tool able to identify the main GHG emitters and suggest the best environmental policies in order to reduce the climate impacts (Bastianoni et al., 2014). By the observations emerging from this study, we can state that the introduction of the integrated anaerobic-aerobic digestion is profitable because it could provide the opportunity to improve the environmental performances at plant, sector and regional scale. This practice can be considered an environmental policy to be applied in the program "Siena Carbon Free", a project aimed to maintain the net GHG balance of the Province of Siena equal to zero t CO_2-eq.

6. Concluding remarks

The integration of anaerobic-aerobic digestion determines a number of management advantages at plant, waste sector and regional scale, for what concern the climate impacts.

The combination of these two technologies facilitates the production of high quality compost and biogas, which is used to obtain electricity and heat. The GHG emissions from anaerobic-aerobic degradation of the organic wastes are lower than those released by composting; moreover, the electricity produced by renewable resources (in this case biogas) determines a reduction in the anthropogenic greenhouse effect due to the avoided use of energy from fossil fuels.

The proposed analysis, coupled to the GHG inventory of all the waste disposal plants operating in the integrated management system (Marchi et al., 2014, 2015), can provide useful information at planning level, giving environmental suggestions to waste operators and policy makers.

The anaerobic-aerobic digestion method could be applied in order to evaluate further technological developments, such as the bio-methane production and its use in the vehicle traction or its introduction in the national grid. The bio-methane production and use is a new interesting research subject and a very intriguing solution to achieve the European 20-20-20 targets (Tasios et al., 2013).

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BUILDING PRODUCTS AND INDOOR AIR QUALITY: THE USER DEMAND AND THE MARKET SUPPLY*

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Abstract

Environmentally friendly, or "green", it is no longer a fashionable term, but is gaining importance as a factor of choice for consumers, when they have to make decisions related to the purchase of a products. In the United States, where attention to the green building is high, periodic surveys show high percentages of consumers who are increasingly aware and sensitive about choices that can have significant impacts on their living environment, in terms of health and safety. The major concern is related to Indoor Air Quality and the factors that may affect health.
At European level, a yearlong survey, released in 2013, shows that most Europeans would be prepared to change their consumption habits, buying products that are more environmentally friendly, healthier and safer, requiring, however, guarantee about the authenticity of the declared performance. In Italy, a survey carried out by Eurisko, in 2012, showed that for consumers one of the main expectation is the possibility to buy products that are not harmful to health. If the consumer requests are specific and constantly growing, on the supply front, the attitude appears to be a little ambiguous: on the one hand, many manufacturers are already able to provide environmentally friendly products with less impact on the indoor air quality too, on the other hand the green products on shelves are not so available.
Manufacturers and consumers are obstructed providing and purchasing these goods. In many cases these obstacles arise from the ambiguity related to what in effect is an environmentally friendly product. In addition, for the consumer, to do informed choices is often difficult due to a lack of information and transparency in communication about product performance.

Keywords: building products, IAQ, manufacturer, user

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1. Introduction

In the past two decades, in the decision-making spheres, where the health goals and strategies are established and updated, it appears that the key issue is shifting from the health issues related to the urban environment to the issue of human exposure to indoor air pollution. It is estimated that people spend at least 90% of their time indoors, rising to 100% when the focus is on some of the most vulnerable populations, such as elderly, children, sick people, who need maximum protection. The awareness of the correlation between indoor air quality and health of occupants took place in the Seventies. Thanks to studies of the Anglo-Saxon scientific community, in 1987 the World Health Organization (WHO) coined the term Sick Building Syndrome to briefly outline the symptoms detected in groups of workers employed mainly in large buildings.

Scientific studies have shown the relationship between the occurrence of certain symptoms or illnesses, and the working environment, but also the complexity of the problem due to multiple variables related to people, to the characteristics of the physical environment and to the microclimate conditions. The achievement of this awareness and the recognition of the problem by the WHO have been an important stimulus to continue research and broaden the object up to the home environment that, in the collective, is associated with the idea of safety and health, even though the data contradict that. A study, to date still the most complete and detailed, conducted in 1998 by IEMB (Indoor Environment Management Branch) of the EPA (Environmental Protection Agency), intended to compare Indoor / Outdoor concentrations and exposures in relation to hazard air pollutants. The data analysis has supported the hypothesis that indoor concentrations of most pollutants considerably exceed outdoor ones (and that indoor exposures exceed outdoor ones). The revealed indoor concentrations were generally from 1 to 5 times greater and indoor exposures were 10 to 50 times higher than outdoor exposures (EPA, 1998). Indoor air quality has been, then, finally recognized as an essential goal of an integrated strategy for air pollution as a whole.

A fundamental act of the long process of study and research on the issues of air quality, health and comfort of people in buildings is represented by the document “The Right to Healthy Indoor Air” published by World Health Organization in 2000 (WHO, 2000). It contains nine principles on the human right to health, the first of which states unequivocally the right of every person to breathe clean air inside buildings.

Subsequently, in 2003, the European Commission adopted the document “A European Environment and Health Strategy” (COM (2003) 338), which sets the reduction of the adverse health effects due to environmental factors (including respiratory disorders, asthma and allergies associated to air pollution, both external and internal) among the priority objectives. The updated air quality guidelines (WHO, 2006) make explicit reference to the need for specific indoor air pollution guidelines.

The first significant step in this direction was the publication of the indoor air quality guidelines, in relation to dampness and mould (WHO, 2009). The document contains an analysis of the scientific evidence of health problems associated with the presence of dampness and biological contaminants in the indoor environment and provides recommendations and control measures. The most recent guidelines (WHO, 2010) focus on some pollutants, whose concentrations, particularly high in the living environment, cause serious health effects. Therefore, since the indoor pollution originates from either external or internal, it is understandable as the only measures related to the reduction of external concentrations are not sufficient to ensure good indoor air quality and that, therefore, the action should be synergistic.

It’s good that the knowledge gained in the scientific community is also spreading in the society. This makes people more sensitive and aware about the issue of health and, at the same time, incites to adopt solutions to make their living environments healthier.

The choice of green building products goes in this direction (Oberti, 2014), considering the close relationship between the emission of pollutants from building materials and finishing products and the deterioration of the indoor air quality (the scientific literature about this topic is extended and widespread, since the Eighties) (Levin, 1989; Mølhave, 1982).

2. Materials and methods

The main objective of this study is to analyze the user demand and the market supply about the green building products, in particular focusing on the Indoor Air Quality aspects. The research was developed collecting information and data from sources at different levels: scientific articles, economic reports of the building sector, legislative texts, information from manufacturers, informative articles.

3. Results and discussion

3.1. User demand

The results of surveys carried out periodically in the United States, where attention is substantial to the issue of the green building, containing data with high percentages of consumers who are increasingly sensitive and aware of decisions that can have a significant impact not only on the environment, but also on their living environments, in terms of health and safety. The greatest concern is related to the Indoor Air Quality: that emerges from the market surveys about green building. The continued growth of this market, especially in the US, is already a sign of precise will and sensitivity of the user. The findings in the Smart Market Report (McGraw Hill Construction, 2014) demonstrate that green building is increasingly important in the single family and multifamily sectors:

- 62% of those are building new family homes report that they are doing more than 15% of their projects green. By 2018, that percentage increases to 84%.
- 54% of those are building new multifamily homes report that they are doing more than 15% of their projects green. There is also growth expected, with that percentage rising to 79% by 2018.
- 73% of single family builders (up from 61% since the last report) (McGraw Hill Construction, 2012) and 68% of multifamily builders say consumers will pay more for green homes.

Greater consumer interest has contributed to the ongoing growth, leading the experts to anticipate that by 2016 the green single family housing market alone will represent 26%-33% of the market (McGraw Hill Construction, 2014). In the sixth edition of Green Building Market Barometer (Turner Construction Company, 2014), the data demonstrate that commitment to green construction remains high, with a greater attention on the benefits of improving the health, wellbeing and indoor air quality (Fig. 1). Additional important facts come to light from the U.S. market for green building materials: it reached nearly $40.0 billion and $43.8 billion in 2013 and 2014, respectively. This market is expected to grow at a compound annual growth rate (CAGR) of 9.5% to nearly $69.0 billion over the period 2014-2019 (BCC Research, 2015).

In Europe, according to a widespread survey (EC, 2013), lasted one year and announced in 2013, it is emerged that the most Europeans would be prepared to change their purchasing habits and buy more environmentally-friendly, healthier and safer products, but many feel they lack information and distrust manufacturers' environmental claims. The survey indicates that more than three-quarters of respondents are willing to pay more for green products if they were confident that the products are truly green (77%). However, only slightly more than half of EU citizens feel informed (55%) about the environmental impacts of the products they buy and use.

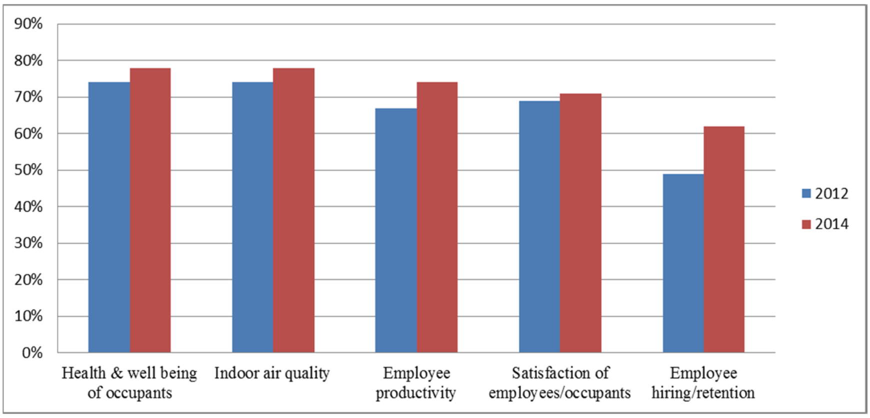

Fig. 1. Importance when evaluating Health and financial benefits of green features. Percentage extremely or very important in 2014 and 2012

From the Italian point of view, an interesting survey about the evolution of the socio-cultural aspects and the consumption of Italians over 14 years, carried out annually by Eurisko, highlighted as the main expectation of the consumers is the possibility to have on the market products not harmful to health and safe (Fig. 2).

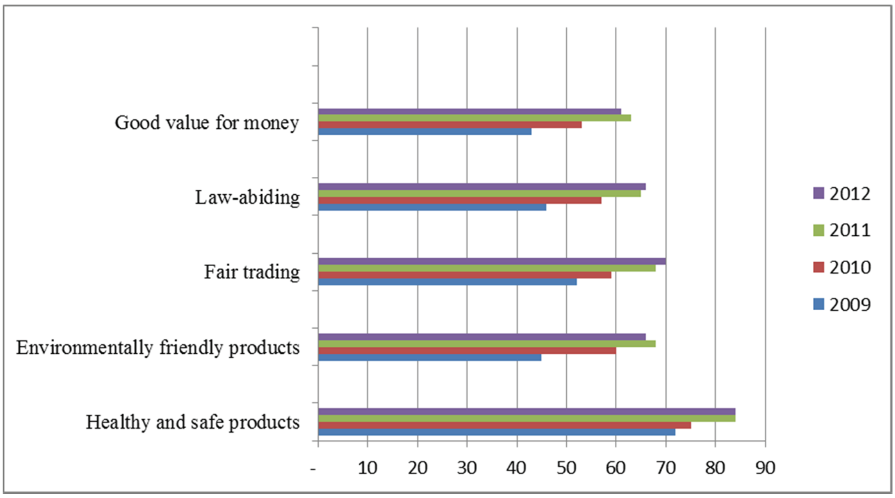

Fig. 2. The increasing expectations of the users about products (Eurisko Sinottica 2009-2012)

The emerging trend from these investigations is the growing consumer awareness of having to direct their purchase choices towards products that are environmentally friendly, healthy and safe. This tendency clashes, however, with an offer of the market not yet completely mature.

3.2. Market supply

Referring to the European survey previously mentioned (EC, 2013), it is interesting to relate the comments on the results of the investigation expressed by EU Environment

Commissioner Janez Potočnik: "Of course we all want to see more green products on shelves, but this survey shows that most of us are confused by green claims and don't trust them. That is not good for consumers, and it is not rewarding those companies that are really making an effort. We are working with companies and other stakeholders to develop the credible information consumers are looking for when they buy products. This will help develop markets and open up opportunities for innovation and investment in the green economy."

These words reveal the serious problem related to the market for green products: the poor transparency and clarity of the information provided to the consumers. Inadequate communication can be misleading or liable to create confusion to the addressees of the message, it can obstruct the decision-making process and could undermine confidence in the self-declared environmental claims.

These are the reasons why it becomes necessary to refer to a set of principles to be applied when communicating information about the products performances, as indeed also emphasized by the European Commission in the Communication "Building the single market for green products. Facilitating better information on the environmental performance of products and organisations" (COM (2013) 196). The EU action aims to reduce the current uncertainty on what constitutes a green product and a green organisation. It is a step towards a more integrated internal market, where products and organisations that are genuinely green are recognised by consumers.

Of note, in this direction, also the work in ISO (International Standard Organization) area: within the technical committee ISO/TC 207 "Environmental management", whose task is the development of legislation on the management of environmental issues, there is a subcommittee SC3 "Environmental labelling", which deals with the issue of labeling and environmental product declarations and processed the series of standards 14020:2002 Environmental labels and declarations - General principles. In them, guidelines are traced for proper environmental communication on products, offering different types of schemes, joined by the term "environmental claims".

Such statements, expressed in terms of labels or logos, symbols, declaration, etc., regardless of the form they take, they must respect the basic principles:

- be verifiable, accurate, not misleading and communicated in a non-misleading way;
- to ensure transparency, both to make available, on request of the stakeholders, information about the labelling environmental, and in promoting an open consultation process among stakeholders exactly in the development phase of labeling programs;
- be based on scientific methodologies that allow the accuracy, reproducibility and comparability of results;
- be related to the aspects of the life cycle of the product.

Another critical aspect is related to the cost of green products not yet competitive compared to the traditional (this is especially true in Europe), although over time the gap has been gradually reduced. Among the causes of a higher cost, there are a limited production, the cost of development manufacturing and, in some cases, a specialized distribution (Malin, 2000).

Despite the difficulties, we note the efforts of several manufacturers to provide an adequate response to consumer demands. Wiser and competitive manufacturers are working to change the production process, in order to offer products whose pollutants emission levels are negligible. Some categories of manufacturers are particularly active, such as those of the finishing products. As an example, considering that the main pollutants from building products are VOC (Volatile Organic Compounds) and that the greatest responsibility of air concentrations is due to solvents, the most important producers of paints and adhesives, products in which these substances were present in large measure, proposed in recent years alternative products, with reduced amount of solvents. This was possible thanks to significant investment in research by the manufacturers: the result is the transition from the old formulations containing polymers in solution to formulations aqueous-based polymeric dispersions or based reactive resin (epoxy, polyurethane) solvents-free.

4. Conclusions

The picture resulting from this work highlights that demand and supply are still far. If on the one hand the consumer appears to have reached a good awareness on the issues of health and safety within the living spaces and consequently requests building products with specific features, on the other hand the market responses are not be able to completely satisfy the needs of the consumer. More research and investments by the manufacturers together with regulatory measures can be the drives so that it is possible matching supply with demand as soon as possible.

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WHICH THERMOCHEMICAL CONVERSION PROCESS FOR AGRICULTURAL WASTE? PHYSICAL AND CHEMICAL ANALYSES TO GUIDE THE CHOICE*

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Abstract

This study investigates how physical and chemical analyses may lead the choice of the more suitable thermochemical energy conversion process for agricultural wastes. Four different case study are presented: corn cobs, digestate pellets from anaerobic digestion, wood biomass from river maintenance and seed cake from vegetable oil production. For all the cases analyzed the physical as well as the chemical characterization of the feedstocks are presented and discussed.
Outputs of these analyses are: chemical composition, moisture content, ash content, ash softening point and particle size. These outputs, together with logistic considerations about availability and pre-conditioning of the biomasses allow to properly define the optimal process for each biomass. Three thermochemical processes are taken into account: pyrolysis, gasification and direct combustion.

Keywords: gasification, combustion, pyrolysis, waste biomass

1. Introduction

Literature suggests that the possible ways to convert biomasses into energy or in a suitable fuel for power generation can be divided into two major groups: thermal conversion and biochemical conversion. The first group includes combustion, pyrolysis and gasification where the heat is the key factor of the processes (Allesina, 2013a; Basu, 2010). Depending on the desired effect and the desired products of the conversion, the thermochemical processes are dived in: pyrolysis that transforms biomass into char, gaseous and liquid compounds, the process can be obtained directly with under-stoichiometric combustion of biomass or

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indirectly if the heat is supplied externally instead of being generated from partial combustion of the fuel (Allesina, 2013a). The process temperatures are commonly set between 400 and 800°C. At increased temperature and/or oxidant content, gasification occurs: a thermal process that occurs at peak temperatures between 800-1000°C. The gas produced through gasification can be used as engine fuel, for synthesis of more complex fuels or burned in order to produce high temperature heat (Basu, 2010).

However, an internal combustion (IC) engine can not be coupled with a gasifier if the syngas is not adequately cleaned (FAO, 1986; Reed and Das, 1988). Furthermore, this filtering process decreases the heating value of the syngas due to the reduction of its tar content. For this purpose a downdraft gasifier is the best choice due to the low tar and oil content in the produced syngas (FAO, 1986; Reed and Das, 1988). Finally, biomass combustion has as main product heat. In this process the biomass is completely oxidized. Combustion is commonly used for heating, i.e. in stoves, boilers and district heating plants; but it can also be used for power generation (Allesina et al., 2012). In fact, the direct combustion also avoids problems related to the char and tar disposal from the gasification plant. The thermal energy obtained in such a way will be easily exploited in an organic rankine cycle (ORC) power plant, in an external firing gas turbine (EFGT), in a Stirling engine or in a gas turbine plant (Duvia and Gaia, 2004; Martelli et al., 2000; Naso, 1991; Souleymane, 2012),

In an ORC power plant heat is supplied externally to a closed cycle, the cycle uses organic siloxanes as working fluid, which operates between lower temperature heat sources if compared with the conventional steam Rankine cycle (Duvia and Gaia, 2004). A modified version of the Brayton cycle is the EFGT, which expands a hot air flow that is heated in a radiant boiler (Martelli et al., 2000). The Stirling engine is an external combustion reciprocating engine with a higher ideal thermodynamic efficiency; however, thermal and mechanical losses decrease its performance (Naso, 1991).

The physical and chemical properties of the biomasses can narrow the range of possible solutions in terms of process, temperature and reactor choice. In this work four different agricultural wastes are analyzed in order to explain and discuss the major rules that lead the process choice. The first biomass investigated are the corn cobs, a by-product of the edible maize supply chain. Corn cobs are normally left in the field after the harvesting process, but theirs high cellulose and hemicellulose contents suggest their use as fuel in biomass power generation system (Allesina et al., 2015; Biagini et al., 2014; Groeneveld et al., 1979; Mavukwana et al., 2014).

The second waste investigated is the digestate from anaerobic digestion power plants. Digestate is a by-product of biogas power plants and it is composed of a solid and a liquid part. The solid part can be pelletized and used as fuel in heat power generation system (Pedrazzi et al., 2015). A further biomass investigated consists of sunflower seed pellets normally used as animal feed. Previous studies suggest that this feedstock can fuel a thermochemical conversion system (Allesina et al., 2014). Finally, the last feedstock investigated is soft wood chips from river maintenance operation. All these waste biomasses where chemically and physically analyzed and for each of them the right thermochemical conversion process was outlined and discusses.

2. Materials and methods

2.1. Physical analyses

The first step to take for the correct evaluation of biomasses energy conversion potential is to completely characterize feedstock physically. Average dimensions of biomass particles were evaluated with caliper measurements. The true density of the pellets ρ_{true} [kg/m^3] was estimated by a Micromeritics^{TM} helium pycnometer, model "AccuPyc 1330". While the apparent density of the pellets ρ_{app} [kg/m^3] was evaluated using a Micrometrics^{TM} mercury intrusion porosimeter, model "AutoPore IV 9500". The void fraction of the pellets is calculated by Eq. (1) (Basu, 2010).

$$\varepsilon_v = \frac{\rho_{true} - \rho_{app}}{\rho_{true}} \quad (1)$$

2.2. Chemical analyses

In order to obtain the average dry-ash-free (daf) composition of the biomasses, the samples were tested in an EA 1110 CHNS-O analyzer. In addition, the samples were reduced to ash by heating them in a stove at 550 °C for 4 h (ASTM, 1995) to estimate the ash content ASH [%]. The average "as-received" (ar) composition of the biomasses was then calculated using Eqs. (2)–(7) (Basu, 2010). The moisture of the samples M[%] was evaluated weighing the samples before and after 24 hour of drying at 85 °C in an oven.

$$C_{ar} + H_{ar} + N_{ar} + S_{ar} + O_{ar} + M + ASH = 100 \quad (2)$$

$$C_{ar} = \frac{C_{daf}(100 - M - ASH)}{100} \quad (3)$$

$$H_{ar} = \frac{H_{daf}(100 - M - ASH)}{100} \quad (4)$$

$$N_{ar} = \frac{N_{daf}(100 - M - ASH)}{100} \quad (5)$$

$$C_{ar} = \frac{C_{daf}(100 - M - ASH)}{100} \quad (6)$$

$$O_{ar} = \frac{(100 - C_{daf} - H_{daf} - N_{daf} - S_{daf})(100 - M - ASH)}{100} \quad (7)$$

where C_{ar}, H_{ar}, N_{ar}, S_{ar}, O_{ar}, M and ASH are the mass percentage of carbon, hydrogen, nitrogen, sulfur, oxygen, moisture and ashes in the biomass considering "as-received" conditions; C_{daf}, H_{daf}, N_{daf}, and S_{daf} are the mass percentage of carbon, hydrogen, nitrogen and sulfur in the biomass considering "daf" conditions.

2.3. Combustion analyses

The higher heating value of biomass samples was estimated using a Mahler bomb calorimeter (ASTM, 2007). In this device, a sample of fuel of known mass is burned into a closed vessel filled with oxygen at 20–25 bar in order to assure the complete combustion of the sample.

The isochoric combustion generates a thermal energy amount equal to the increase of the internal energy of the system ΔU [J]. The heat of combustion H_{comb} is calculated by Eq. (8).

$$\Delta H_{comb} = \Delta U + \Delta nRT \quad (8)$$

where Δn [mol] is the mole variation of the gas inside the "bomb", R [J mol^{-1} K^{-1}] is the universal gas constant and T [K] is the temperature.

The difference between ΔH_{comb} and ΔU is small for solid fuel such as biomass (about 0.1%), so the ΔH_{comb} is considered equal to ΔU.

The method to evaluate ΔU is to soak the "bomb" into a quasi-adiabatic vessel filled with a known amount of water. The combustion increases the water temperature with a specific trend and a graphical method, discussed in ASTM, 2007, allows us to calculate the average ΔT of the water. The ΔU of water is assumed equal to the ΔH_{comb} and it is evaluated using Eq. (9).

$$\Delta H_{comb} = \Delta U_{water} = k\Delta T \quad (9)$$

where the calorimeter constant k [J/K] was previously calculated through a calibration process described in ASTM, 2007.

2.4. Ash analysis

The high amount of low-melting-point ash into the digestate pellets creates some agglomerations during the combustion. In order to understand this phenomenon of agglomeration, some biomass pellets were heated in a kiln for 4 h at 550°C to reduce it to ash. The ash sintering behavior was then investigated testing a parallelepiped of pressed ash into an optical vertical dilatometer. The dilatometer was heated up to 1500°C before the ash sample was added (flash test mode as suggested by Paganelli and Sighinolfi, 2009). The temperature in the instrument rose to 1500°C at a rate of 80°C/min and then the heaters were turned off, letting the sample cool down. The apparatus detects the ash sintering temperature T_{sin} [°C] and the ash melting temperature T_{melt} [°C].

3. Results

Physical, chemical and combustion analyses results are summarized in Table 1 for each waste investigated. The choice of the best thermochemical process for a waste biomass mainly depends on the following biomass parameters: ash amount, ash melting point and particle dimensions. In fact, moisture needs to be reduced under 20% wt. in order to avoid biomass fermentation. This moisture value is acceptable for all the thermochemical processes considered.

Several rules can be applied using a specific algorithm in order to reduce the complexity of the systems and, consequently, the cost. These rules assure a good fitting of the biomass with the technology selected. Figure 1 depicts the selection algorithm proposed. Some assumption was been taken: maximum particles dimension < 100 mm, fixed bed biomass gasification, traveling grate biomass combustor and batch pyrolysis systems. The first rule applied takes into account the ash amount of the biomasses. As shown in Fig. 1, the limit value for gasification is 6%, this value is reported by Basu (2010) for downdraft gasifiers. In fact, a high ash amount forces a continuous disposal of the char bed inside the gasifier reactor.

Table 1. Biomasses characterization

Properties	*Corn cobs*	*Digestate pellets*	*Sunflower seed pellets*	*Wood from river*
True density ρ_{true} [kg/m^3]	1360	1510	1790	1450
Apparent density ρ_{app} [kg/m^3]	107.2	1260	931	218
Void fraction εv [-]	0.92	0.16	0.48	0.86
Particle diameter [mm]	20.9	6	8.5	10
Particle length [mm]	56.1	24.6	9	30
Carbon amount C_{ar} [% wt.]	39.1	32.2	39.9	40.8
Hydrogen amount H_{ar} [% wt.]	5.0	4.8	5.8	5.9
Nitrogen amount N_{ar} [% wt.]	2.7	1.3	0.7	0.46
Sulfur amount S_{ar} [% wt.]	0	0	0	0
Oxygen amount O_{ar} [% wt.]	48.7	48.7	39.2	42.4
Moisture M [%. wt]	9.4	0	10.8	10
Ash amount ASH [%. wt]	1.53	13	3.82	0.5
Ash melting temp. T_{melt} [°C]	1020[a]	300[b]	1020[c]	1335[d]
Higher heating value [MJ/kg]	15.9	14	16.11	16.53

[a] Osman and Gross, 1983; [b] Pedrazzi et al., 2015; [c]Magasine and de Kock, 1987; [d]AIEL, 2008.

Thus reducing the efficiency of the gasifier and increase the tar production. The second rules applied imposes the limit value of ash melting point at 1000 °C. If the biomass has a lower value of ash melting point, issues related of ash sintering and klinker formation can occurs on the gasifier or combustor grates. These agglomerations may occlude the ash disposal in gasifiers and stop the traveling grate in boilers and furnaces. Finally, biomass particle dimensions lower than 5 mm creates bridging issues and channeling phenomena inside gasifier reactor beds (Allesina et al., 2013b). In addition, combustion of fine particle is unstable as result of the not homogeneous distribution of the combustion air.

The algorithm reported in Fig. 1 was applied to all the feedstocks here discussed. Corn cobs are suitable for gasification, in addition theirs composition and higher heating value is similar to the value of the wood. In fact, several works suggest corn cobs gasification as reported in the introduction section. Digestate pellets are suitable only for pyrolysis as result of their low ash melting point. Digestate pellets combustion was investigated by Pedrazzi et al., 2015 and several ash sintering agglomerations was reported. To overcome this issue, dried digestate particles were mixed with wood sawdust in order to reduce the ash content of the blend and in order thus reducing the risk of ash sinterization.

About sunflower seed pellets, the algorithm suggests that they are suitable for gasification. This result is confirmed by literature, in fact Allesina et al. (2014) produced high quality biochar and syngas by the gasification of sunflower seed pellets. Finally, wood chips from river maintenance result suitable for gasification as result of its low ash content, good dimensions and high temperature ash melting point.

4. Concluding remarks

This paper describe a method to guide the choice of the best thermochemical conversion technology for a biomass waste. Gasification, combustion and pyrolysis are considered. The choosing algorithm uses the following biomass properties: ash amount, ash melting temperature and particle dimensions.

Four biomasses samples were tested: corn cobs, wood chips from river maintenance, sunflower seed pellets which results good for gasification and digestate pellets which results suitable for pyrolysis.

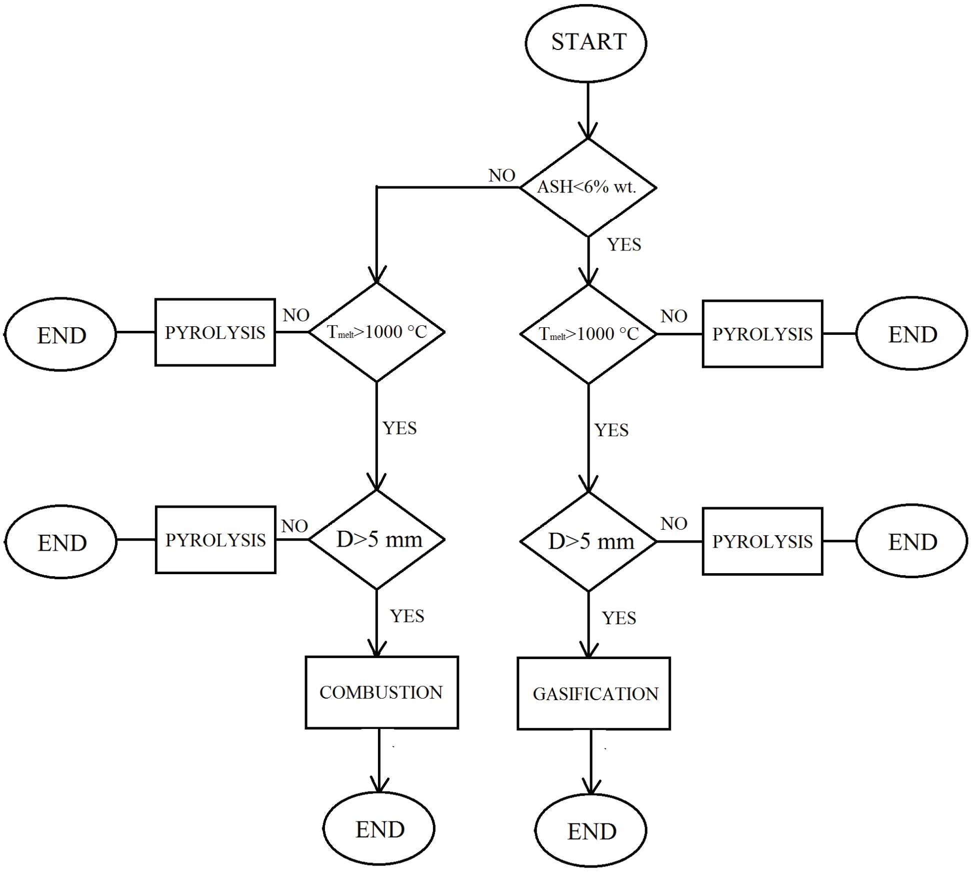

Fig. 1. Termochemical process selection algorithm

The good agreement with literature confirms that the present algorithm is a useful tool for the selection of the right technology starting from biomass physical and chemical characterization.

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WATERNOMICS (ICT FOR WATER RESOURCE MANAGEMENT) METHODOLOGY AND WATER INFORMATION PLATFORM*

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Abstract

WATERNOMICS is a three years EU funded research project and responded to the call FP7-ICT-2013-11. The partners variously specialize in ICT & Automation systems development, water sensors development, business model development, water system design, open source based platform, energy and sustainable management, exploitation, dissemination and communication activities. WATERNOMICS will provide personalized and actionable information on water consumption and water availability to individual households, companies and cities in an intuitive & effective manner at relevant time-scales for decision-making. Key project objectives include: to introduce demand response and accountability principles in the water sector; to engage consumers in new interactive and personalized ways that bring water efficiency to the forefront and leads to changes in water behaviors; to provide decision makers with the actionable information they need to get started in the implementation of a water management program.

WATERNOMICS will develop a water information system that aims to raise awareness about efficient water management and it focuses on water efficiency at household, municipality and corporate level through the change behaviors of the end users to achieve reduced water usage and improved operation and maintenance by utilities. The innovative water information system, through its water platform and a standards based methodology, is the main instrument through which WATERNOMICS aims to change consumption behavior and effect changes in water resource management as it will provide a personalized and customizable solution and application to stakeholders.

Keywords: ICT, raising awareness, water management, water information platform, water consumption

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1. Introduction

Significant part of Europe suffers from water stress. Furthermore, the cumulative impacts of economic development and climate change are likely to aggravate the situation. ICT offers an untapped potential to improve the management of water resources by integrating real-time knowledge about water consumption (Curry et al., 2014). Into this challenge and opportunity, WATERNOMICS (ICT for water resources management) brings together ICT and water stakeholders in joint research to deliver this un-tapped potential via real-life testing and demonstration experiments. The WATERNOMICS project aims to reduce the water consumption of municipalities, corporations and domestic users by providing water managers and consumers alike with timely and actionable information about water usage and water availability (Clifford et al., 2014; Kouroupetroglou et al., 2015a, b). Understanding the social, economic and environmental drivers for introducing the necessary smart water technologies helps shaping the architecture of a water information system. To get a better understanding of these drivers, WATERNOMICS conducted workshops and interviews with various stakeholders from industry and municipalities in Greece, Italy, Ireland and the Netherlands. The results showed a wide range of ways in which water was managed and water conservation programs where implemented. From the research, the WATERNOMICS water information system will be designed, developed and validated and will create a common process to lead water management (WATERNOMICS, 2015).

Currently, the limited information available from the water services ecosystem is not interoperable or not presented effectively to stakeholders. Waternomics overcomes this problem by implementing a new level of smart meter and sensor technology associated with a simple water information platform and a standard based methodology. These decision support services are enabled by smart water technology, which (i) enables the detailed and real-time measurement of water flows and usage, (ii) informs analysis of water consumption patterns and (iii) provides key recommendations on how to increase water efficiency in a holistic context that includes governance, standards and local area policies and environmental conditions.

Project results will be validated and demonstrated in three high impact pilots (WATERNOMICS, 2015):

1. Domestic: Households in the municipality of Thermi, Greece.
2. Corporate: Operator from Linate Airport in Italy.
3. Municipal: University and public school in Galway, Ireland.

Figure 1 provides an overview of the structure of the Waternomics project.

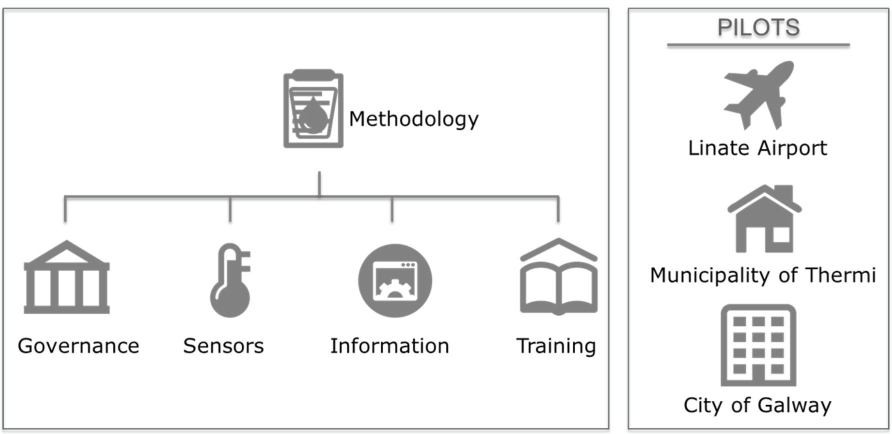

Fig. 1. Structure of WATERNOMICS project

The main objective of the WATERNOMICS project is to provide personalized and actionable information about water consumption and water availability to individual households, companies and cities in an intuitive and effective manner at a time-scale relevant for decision-making. Access to this information will increase end-user awareness and improve the quality of the decisions from decision makers regarding water management and water government. WATERNOMICS will accomplish this by:

- combining water usage related information from various sources and domains to offer water information services to end-users (Fig. 2)
- making water usage related information accessible across devices and locations
- supporting personalized interaction with water information services (Fig. 2)
- conducting knowledge transfer from energy management systems to water management systems
- enabling sharing of water information services across communities of users

WATERNOMICS will use both new and state of the art sensors and water meters to provide new services (applications) and add new features like leakage detection, fault detection and water awareness games. These services will be bundled into the *WATERNOMICS Water Information Services Platform*, or short name, *WATERNOMICS Platform.* This software platform will be able to integrate (convergence layer) on top of existing water infrastructures or be employed using dedicated sensors fielded using the project methodology for water management system design (WATERNOMICS, 2015).

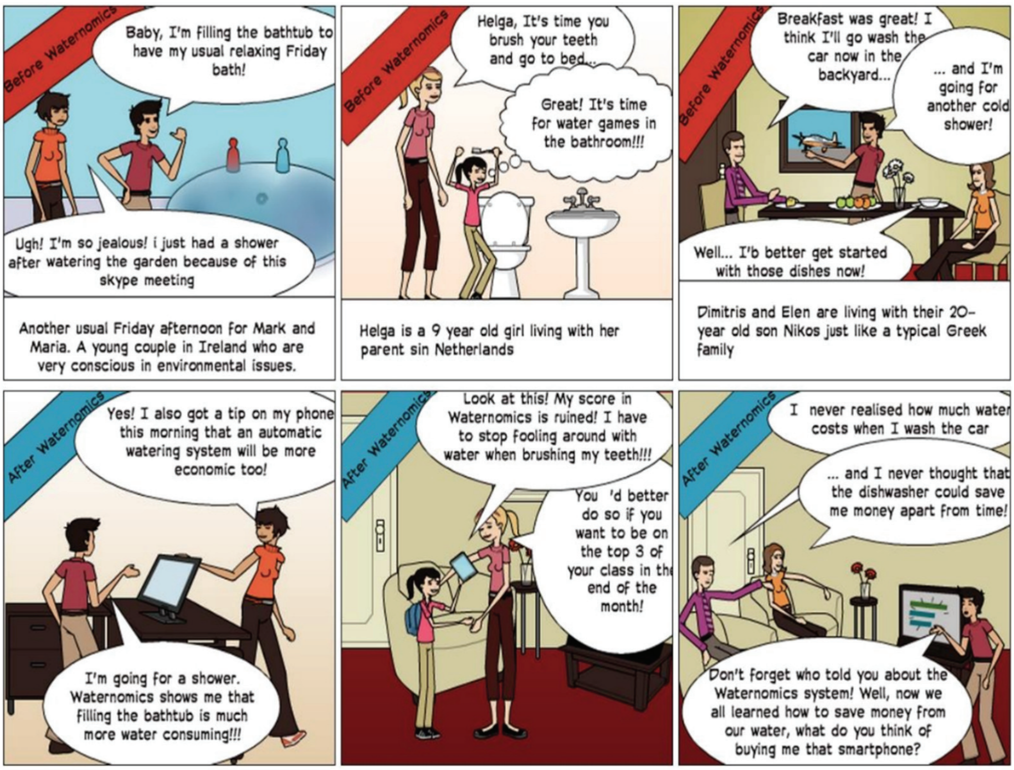

Fig. 2. Example of supporting water utilities to engage end-users in a new ICT-enabled way: technical concept & architecture of the WATERNOMICS Platform

3. Outline of the work

The two main outcomes of The Waternomics Project are: (i) the Standards based Methodology adopted to guide the project phases, (ii) the aforementioned Waternomics Platform.

- *Waternomics Methodology*: a standards-based methodology developed "*ad hoc*" for the development and implementation of ICT-enabled water management programs. This methodology will, given constraints, standards, corporate preferences, and key performance indicators (KPIs), provide decision makers and designers with a systematic way to select technologies, measurement points, data collection methods, and data management techniques for ICT-based water management systems.
- *Waternomics Platform*: the information platform of WATERNOMICS is an instrument that focuses mainly on water efficiency at household, municipality and corporate level through the change behaviours of the end users to achieve reduced water usage and improved operation and maintenance by utilities. Of course it is the main instrument through which WATERNOMICS aims to change water consumption behaviour and it will provide a personalized and customizable solution and application to end-users and doing so it will be able to help in changing water consumption behaviours and policies.

4. Materials and methods

The developed methodology, which in itself is a new development for the water sector, has five phases: Assess, Plan, Do, Check, Act. These phases are intentionally similar (with the exception of Assess being added as a first step to engage users) to those of ISO50001 (Energy Management Systems). In this way, environmental managers and the organizations, staff and service providers that work with them will immediately recognize the correlation between energy efficiency and the desired outcome of water efficiency. Other standards that many stakeholders will recognize include ISO50002 (Energy Audit), IPMVP (measurement and verification planning), and ISO14046 (Water Footprint). In this way, a comprehensive and holistic standards-based approach is established (WATERNOMICS, 2015).

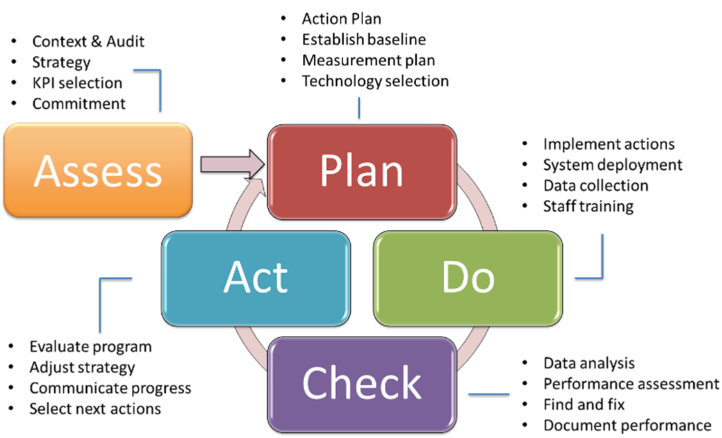

Fig. 3. WATERNOMICS methodology overview

In order to identify and describe key features that a Waternomics Information Platform should include during its first months, WATERNOMICS followed an eight steps method to provide a final set of three scenarios. In the last stages of this method a cycle of iteration in the development process begun including user tests using paper prototypes of the potential applications of the platform. Overall, scenario development has been based on three sets of guidelines and criteria. The set of final scenarios should:

- be based on end-user perceived value,
- be based on business value,
- cover all target functionality of the WATERNOMICS project, i.e., be compatible with the Description of Work (DoW) document,
- be technically innovative.

To achieve that, we used a zoom-in method, and as such the process was mainly bottom-up. By this we mean that we started by collecting a large set of functionalities and features as basis for the WATERNOMICS scenarios. Then we filtered these features, based on the criteria mentioned above, in a step-by-step way. The final results have been integrated in three scenarios that each covers a part of the WATERNOMICS project from a different perspective and together cover the complete scope of the project (WATERNOMICS, 2015).

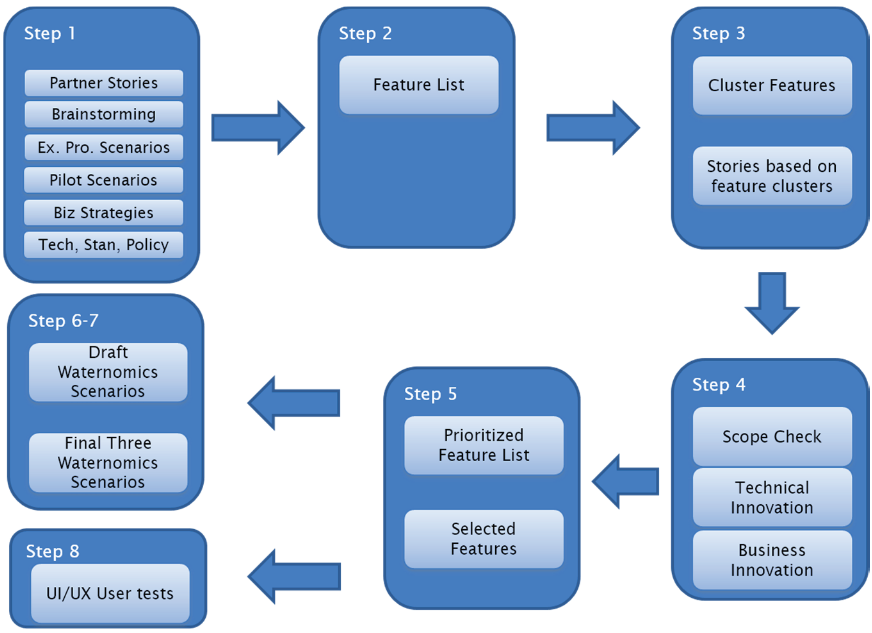

Fig. 4. Scenario development methodology

5. Results and discussion

WATERNOMICS leads to the project methodology which creates a common standards-based methodology for the design and implementation of ICT enabled water management systems. It should be noted that such a methodology is sorely lacking in the water sector and thus this document is an important step in ensuring water efficiency measures can be implemented in a similar way that energy efficiency measures have been. The culmination of the methodology work is a 5 phase methodology (Assess, Plan, Do, Check, Act). The methodology draws strong inferences from and integrates the principles of ISO50001 (Energy Management Programs), ISO 50002 (Energy Audits/Diagnosis), IPMVP (International Performance Measurement & Verification Protocol) and ISO14046 (Water footprint) into a holistic framework. This is coupled with project activities toward the development of a water information system, directed at the challenge of water resource management.

Several of the associated standards are recent (ISO50002 and ISO14046) and furthermore the focus of several is energy (ISO50001 and ISO50002). The application and adaptation of such standards in a holistic framework is innovative and new. It should be noted that the authors did not confine their research to just energy and water based standards but also looked across other disciplines. However, the energy-based standards were found to be most relevant and applicable to this sector. Added to the PDCA cycle is an initial "Assess" phase. Because end users may be less aware of water efficiency, water scarcity and how/why it affects them, the Assess Phase in the Waternomics methodology is a deliberate attempt to engage and educate the end user.

In assembling relevant standards and in constructing the Waternomics methodology, it is noted that many standards have overlapping aspects and as such a direct overlay of each of the steps from the standards would produce redunancies. It is also true that terminology is not yet completely harmonized across the various standards and that some propose themselves as an umbrella to group other availablestandards. Regardless of any sticking points, we instead found it most useful to look at what each standard was trying do to and then to assemble those intents in a logical way from initial consideration of the problem to its definitive conclusion and/or iterative loop. The result is a logical process (the five phases) where it was not constrained to have a one-to-one mapping between a standard and phases (e.g. each phase does not correspond to only one standard). Figure 5 shows a more refined and full view of the Waternomics methodology. In specific, the activities, desired outcome, and related standards are shown for each phase.

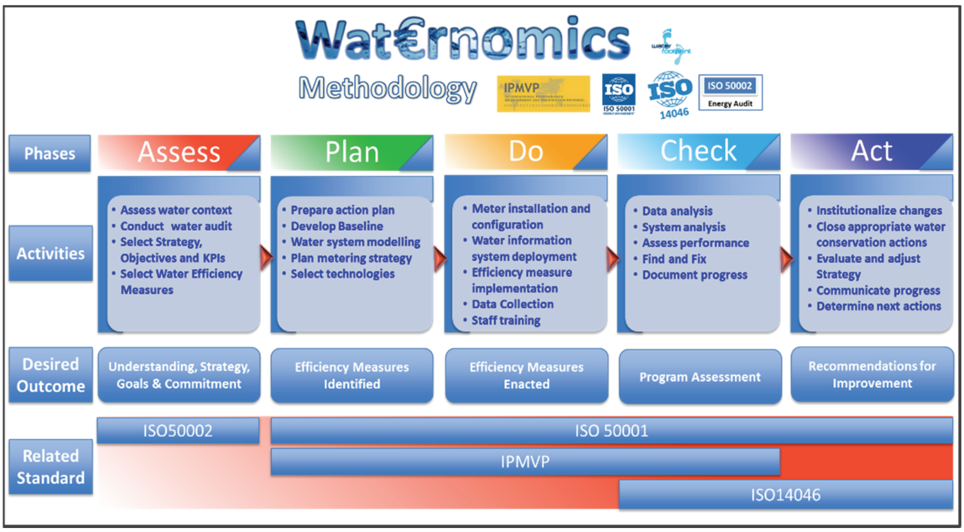

Fig. 5. The WATERNOMICS Methodology (full view) which includes activities, outcomes and its relation to the assembled standards

Each of the five phases has approximately roughly five activities which are the steps and methods associated with each phase. The approach is general enough to applicable to the different targeted stakeholders (domestic, municipal, corporate) but also detailed enough to be useful and actionable. Deliberately and by design, the methodology is based on standards so that the approach overall has a higher likelihood of adoption, uptake and replication. The use of ICT is the second cornerstone of the methodology and overall the methodology is branded as a “Standards based approach for the implementation of an ICT-enabled water management program.”

WATERNOMICS leads to develop an integrated information platform for water use means as an instrument that can be immediately understood by operational decision makers to achieve the water efficiency and use reduction. Indeed as almost always happens, a mere graph of the probability density function is usually not immediately understood by decision makers, so the aim of the WATERNOMICS platform is to collect all the available data dealing with water consumption. The platform will be designed in order to satisfy the main needs and preferences of tits end-users. The users needs have been explored by conducting user tests based on face-to-face interviews and paper prototypes. In particular there were 3 applications which include

- A monitoring dashboard
- A news portal
- A simulation tool

In addition to these 3 applications a set of home pages for the platform was designed. Fig. 6 and Fig. 7 present some options for a home designed for the WATERNOMICS platform.

Fig. 5. Example of the home page

Fig. 6. Example of monitoring dashboard

The development of the WATERNOMICS Platform is an ongoing work, WATERNOMICS project is in its first year of operation and the total duration is three years.

6. Concluding remarks

This paper presents and discusses some important results in terms of outputs of the WATERNOMICS project: the water information platform and the standard based methodology.

With respect to the WATERNOMICS methodology and developed content, the research and interaction with stakeholders have shown a clear need for this project development. WATERNOMICS is developing tools, references and resources to assist in the construct and implementation of water management programs and the execution of water efficiency measures. WATERNOMICS standards-based methodology offers an innovative way of merging together the main standards of the water and energy sector and by providing the end users a step-to step guide to follow in implementing their water saving programs.

With respect to the WATERNOMICS Information platform, the research and interaction with stakeholders highlighted a clear need for a simple ICT tool that can provide useful information about end users water consumption, water saving, water consumption prediction and new ways to raise people awareness. All the WATERNOMICS Team strongly believes in the potential of this project and is investing heavily in the development of this new ICT technology. In the following months we will develop the Waternomics Information platform and the applications to provide the water information to the end users.

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Books:
Faber K., (2000), *Biotransformations in Organic Chemistry - A Textbook*, vol.VIII, 4th Edition, Springer, Berlin-Heidelberg-New York.

Handbook, (1951), *Handbook of Chemical Engineer*, vol. II, (in Romanian), Technical Press, Bucharest, Romania.

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Masutti D.C., Borgognoni A., Scardovi F., Vaccari C., Setti L., (2014), *Production of Lignocellulosic Enzymes from Different Agro-Food Wastes by Solid State Fermentation*, Proc. of 5^{th} International Conference on Engineering for Waste and Biomass Valorisation - Rio de Janeiro, September 6th-8th, Brazil.

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JRC European Commission, (2011), *Supporting Environmentally Sound Decisions for Construction and Demolition (C&D) Waste Management*, A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA), On line at: http://lct.jrc.ec.europa.eu/pdf-directory/ReqNo-JRC65850-LB-NA-24916-EN-N.pdf.

EC Directive, (2010), Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (Integrated Pollution Prevention and Control), *Official Journal of the European Union*, **L334**, 17-119.

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