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Procedia Environmental Science, Engineering and Management

22nd International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 6th-9th November, 2018, Rimini, Italy

Selected papers (3)

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Volume 5, Issue 3, 2018

Procedia

Environmental Science, Engineering and Management

Editor-in-Chief: **Maria Gavrilescu**

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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. He has about 140 papers on medium/high IF peer-reviewed international journals of industrial and environmental biotechnology, sectors in which he coordinated the FP7 projects NAMASTE and BIOCLEAN and participated in other 7 FP7 collaborative projects. He is vice-chairman of the "Environmental Biotechnology" section of the European Federation of Biotechnology (EFB). He is the Italian Representative in the "Working Party on Biotechnology, Nanotechnology and Converging Technologies" at OECD (Organization for Economic Co-operation and Development), Paris, in the "European Strategy for the Adriatic and Ionian Region" (EUSAIR) and in the "Western Mediterranean Initiative" (WEST MED). He is member of the "Expert Group on Biobased Products" (DG GROW, European Commission, EC) and is the Italian Representative in the a) Horizon2020 Programming Committee "European Bioeconomy Challenges: Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research" (SC2, DG RTD, EC), b) "States Representatives Group" of the "Public Private Partnership BioBased Industry" (BBI JU)(DG RTD, EC) and c) BLUEMED Strategic Board (DG RTD and DG MARE, EC). Finally, he is the scientific coordinator of the International Exhibition on green and circular economy ECOMONDO held yearly in Rimini (Italy).

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

She worked at the R&D Centre of Basell Polyolefins in Ferrara for 2 years in the frame of a project addressed to the development of a novel methodology for qualitative and quantitative analysis of additives in polymers. She also worked at ARPA, Regional Agency for Environment in Ferrara, division Water Analysis.

Then she started working at the school of Engineering of the University of Bologna for a Ph.D. in Materials Engineering (2007-2010). After that, she had a scholarship "Spinner 2013" in cooperation with Reagens spa (San Giorgio di Piano) on novel PVC nanocomposites. Now she is post doc fellow at the same school on new polymer-based nanocomposites from renewable sources and inorganic fillers. She also worked at the laboratoire de Chimie et Biochimie Pharmacologique et Toxicologique (Université Réné Descartes) in Paris in 2001 and was visiting professor at the Ecole Nationale Superieure de Chimie (Université Blaise Pascal, Clermont Ferrand, FR) in 2012 and 2015. Dr. Totaro has about 25 scientific papers and several participations at conferences and scientific schools. She collaborates on Ecomondo from 2013.

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ECONOMIC AND ENVIRONMENTAL ANALYSIS OF HYDROPOWER PLANTS IN SICILY*

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Abstract

Renewable energy sources are a central issue in people's daily life. These sources of energy are called "renewable" as they do not run out like traditional ones, such as oil, entailing lower emission levels and better environmental conditions. In recent years' governments have taken care of issues such as "sustainable development": a development which is possible thanks to the satisfaction of both present and future generation's needs. As renewable energy sources are infinite, they can be exploited in different ways, with an approach that respects the main features of circular economy. It has been shown that global shares of energy sources changed in the last 20 years, with an increasing influence of REs. Hydroelectric power is one of the elder renewable energy sources: hydropower technologies are used for both storage and production of energy, using the potential energy of water to create electricity. The aim of this work is to contemplate the main financial and environmental advantages and disadvantages and to analyze costs and revenues coming from the implementation of hydropower plants in Sicily, which is an infinite source of environmentally-friendly resources. Sicilian potential is certainly underestimated: it contributes to the total amount of Italian energy production with very few quantities of energy, but it could be one of the leading Italian regions as far as it concerns electricity. The presence of hydropower plants in Sicily would lead to the increase of energy production, the increase of Sicilian independence in terms of energy needs, better environmental conditions (reduction of CO_2, NOx and particulate matters emissions together with other environmental benefits), better healthy standards and the reduction of the current very high levels of deaths due to pollution.

Keywords: air pollution, circular economy, hydropower plant, Renewable energy, sources sustainable economy

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1. Introduction

Hydropower is part of the group of the so called “RE”, together with photovoltaic energy, biomasses and many others. It is the most spread renewable resource used and plays an essential role in many regions. As a result, it is an important renewable energy resource worldwide and one of the eldest too. As a matter of fact, Man has always been trying to use as many sources of energy as possible, apart from his own muscles. The use of electricity, on the other hand, has entailed the development of more and more advanced energy production systems until the current state of technology. Indeed, until 70s, in Italian rural areas, it was normal to find water mills based on traditional technologies. But, in the last century, the levels of awareness of water potential are improved and have entailed the use of this resource at almost its potential. Nowadays the success of this way to produce energy is due to the fact that it does not depend on periods of crisis, on prices, political choices, cartels and so on, but only on the presence of water in a certain area. Water is contemplated as one of the most environmental-friendly sources of energy (so, hydropower has an ethical value too) and is seen as a mean to reach aims in a global, general, view.

The ten-year strategy “Europe 2020” (European Commission, 2010), in 2010, fixed the following well-known objectives to be reached within 2020:

- reduction of greenhouse gases by 20%;
- reduction of energy consumption by 20%;
- fulfilment of 20% energetic needs through renewable sources.

These aims have been translated in Italy in: gaining 13.4% in terms of energetic efficiency and reliability on renewable energy sources that should produce at least the 17% of the total amount of energy. In these circumstances, hydropower plants play an important role, in order to efficiently reach the previously pointed out objectives, and governments have started to offer incentives to this form of energy production.

The production of hydropower can be based on many different sources, such as natural streams and rivers, irrigation and remediation canals (with little differences of heights and low impacts on the environment), aqueduct (with minimum or zero environmental impact), waste water, industrial discharges and so on (Autonomous Region of Friuli-Venezia Giulia, 2007). However, what matters is the presence of two different heights (the so-called “head”) and the flow rate. The former is the difference in terms of height between the surface where water is and the section of the water flow where water falls and it is strictly related to the territory, the latter is the volume of water that crosses a certain sector of the water flow in a unit of time. Hydroelectric plants can be classified into: Small Hydro Power (SHP) (with a power lower than 10 MW), mini (2MW) and micro hydro plants (100kW) (Sanson and Giuffrida, 2017). Another possible classification is: run-of-the-river plants, basin plants, pumping plants and hydric conducts plants. The former uses the instantaneous flow rate until the limit of the plant, usually with low heads and high powers. The aim of this paper is to start with the description of Sicily in terms of climatic conditions, territory structure and overall economic feature to understand the level of Sicilian adaptability to hydropower. In this chapter the energetic demand and supply are analyzed, together with costs and revenues coming from hydropower plants.

2. Materials and method

Sicily is one of the so-called “autonomous Statut” regions of Italy, with a surface of 25.711 km^2 and a population of 5074261 people: it is one of the most populated regions of Italy and the biggest isle of the Mediterranean. The territory is mainly mountainous and hilly, with few plains near the coasts. The highest picks are situated in the Eastern zone in correspondence of the Etna Vulcan (which is a sort of continuation of the Apennines situated in Calabria). The Sicilian Apennine is divided into three groups: Peloritani, Nebrodi and Madonie, which are 1374 m, 1847 m and 1979 m high, respectively. The most extended plain is situated in the eastern coast too, in the area of Catania, which is a plain created thanks to alluvial deposits from the river Simeto and its tributaries. The south-eastern area is characterized by the presence of the Iblei mounts, of which the highest pick is 986 metres high. The other areas are more or less hilly or flat. Rivers in Sicily are torrential with very low flow rates in summer and periods of sudden overflows. The main rivers are:

Simeto (with its tributaries as Salso, Dittaino, Gornalunga and Caltagirone), Alcantara, Anapo, Tellaro, flowing into the Ionio Sea; Torto and San Leonardo, flowing into the Tirreno Sea; Belice, Platani, Imera Meridionale, Irminio, flowing into the Mediterranean Sea. There is, unfortunately, only one natural lake (called Pergusa, near Enna) whereas the others are artificial or are classified as morasses (the great Lake of Lentini deserves special mention as its 15 km^2-surface had been dried out between the '40s and the '50s and was then re-flooded again 30 years ago).

The climate is Mediterranean, of course, with hot and dry summers and mild and rainy winters. Nonetheless, there are different climates and temperatures according to the areas (depending on the altitude, the vicinity to the sea or the vicinity to a mount): near the coasts the average temperature is more likely to be around 19°C, which is higher than the internal temperatures. Moreover, the southern part of Sicily reaches higher picks of temperature in summer due to the presence of African hot winds (temperatures nearby 42°C) and having less climatic excursions. As far as it concerns rainfalls, they are quite relevant in the areas of Etna, Iblei mounts and Sicilian Apennine with more than 1000 mm of rain per year. Whereas, the areas of Catania and Gela (the plains) and the southern coasts are concerned with lower levels of rainfalls (less than 600 mm of rain per year).

The territory is full of natural reserves as is characterized by so many different landscapes and fauna and flora species that it is now considered relevant for the entire world (most Sicilian landscapes and cities are part of UNESCO) to preserve Sicilian biodiversity and variety of sceneries. Unfortunately, Sicily is not able to manage his resources and still tries to improve tourism, but most of times it has no adequate structures to welcome tourists. As a result, even though Sicily could live only thanks to tourism, 8.3% population works in the agricultural sector (a rate that is higher than the Italian average rage) but with a very low productivity. Manufacturing, on the other hand, is only the 20.7% of the total workforce, specialised in: energetic, building, extractive industries. The tertiary sector represents the remaining percentage of workforce, with more advanced services in the areas around Catania and Palermo. The most relevant industrial districts are the ones concerning electronics, microelectronics and communication in Catania whereas there are many other areas famous for artisan production (such as the well-known Caltagirone's pottery) (www.sapere.it).

3. Energy demand and supply in Sicily

As already mentioned, Sicilian potentiality is not well exploited and the following data support this statement in Table 1 (GSE, 2016). As for any other good, there is a demand and there is a supply of hydropower and they are certainly related to the territory in a certain period. Studying the demand and the supply of a good is fundamental to understand whether there is the need for that good or not. Moreover, the analysis of the demand and supply of a good is essential to provide the demand with what is asked, in the right quantities and moments.

Table 1. Sicilian RE production related to Italian RE production in 2016
(Energy Services Manager, 2016)

Renewable Energy	***Number of plants***	***Installed power (MW)***	***Sicilian power/ Total Italian power (%)***
Hydropower	19	741.8	0.71
Wind energy	524	1.795.2	19.07
Solar energy	47.072	1.344.0	6.97
Geothermal energy	-	-	0.00
Bioenergy	33	74.1	1.80

As far as it concerns supply, it has been calculated that, between 2010 and 2015, hydropower annual production decreased from 616 million kWh to 475 million kWh, together with the reduction of the thermo-electrical production (from 21.393 million kWh to 17.989 million kWh). These values refer to gross production and show that hydropower is not so relevant in Sicily and, consequently, Sicilian hydropower production is not great if compared to the total Italian production. There are in Sicily 21.983 producers (a number that has considerably increased in the last few years, while the total energy production decreased) (Giambone, 2016).

Hydropower supply in Sicily is mainly represented by plants, located in many areas of the region. These plants are (Regione Sicilia, 2016; Regione Sicilia, 2004):

- Anapo (SR), with a power equal to 500 MW (4 plants);
- Casuzze (PA), with a power equal to 9.0 MW;
- Guadalami (PA), with a power equal to 80.0 MW;
- San Carlo – Burgio (AG), with a power equal to 6.0 MW;
- Favara – Caltabellotta (AG), with a power equal to 1.0 MW;
- Poggiodiana – Caltabellotta (AG), with a power equal to 4.3 MW;
- Alcantara – Castiglione di Sicilia (CT), with a power equal to 2.6 MW;
- Alcantara (ME), with a power equal to 4.2 MW;
- Troina (EN), with a power equal to 42.0 MW;
- Grottafumata (CT), with a power equal to 22.8 MW;
- Regalbuto (EN), with a power equal to 6.4 MW;
- Contrasto (CT), with a power equal to 35.0 MW;
- Paternò (CT), with a power equal to 12.8 MW;
- Barca (CT), with a power equal to 9.4 MW;
- Petino (SR), with a power equal to 4.1 MW;
- Cassibile (SR), with a power equal to 2.2 MW.

With regard to the demand, it is quite lower than the production, allowing Sicily to refurnish other Italian regions too. Between 2010 and 2015 the demand for agricultural needs passed from 405 million kWh to 385 million kWh, the one for the secondary sector decreased from 7.158 to 5.689, the one for the tertiary sector has slightly reduced from 5.676 million kWh to 5.668 million kWh. Nonetheless, it is necessary to take into account the demand for domestic use: it has decreased too, from 5.848 million kWh to 5.614 million kWh. To sum up, the total demand for electricity passed from 19.087 million kWh to 17.356 million kWh between 2010 and 2015: a reduction that reflects the decline of supply too (Tables 2 - 6). However, as Sicily is divided into 9 provinces, it could be useful to better satisfy the demand to illustrate the previously mentioned values separately for each province as follows (Miotto et al., 2008)

Table 2. Energy demand in 2015 in Sicily (Giambone, 2016)

Province	***Primary sector consumption (million kWh)***	***Secondary sector consumption (million kWh)***	***Tertiary sector consumption (million kWh)***	***Domestic consumption (million kWh)***	***Total consumption (million kWh)***
Agrigento	26	129	410	479	1043
Caltanissetta	16	120	265	272	673
Catania	84	1035	1332	1168	3619
Enna	10	56	152	160	378
Messina	20	987	765	724	2496
Palermo	30	376	1312	1432	3150
Ragusa	102	479	376	369	1325
Siracusa	71	2293	459	480	3303
Trapani	27	214	456	532	1229

These data, when compared to the first ones reported in the first lines of this paragraph, show that there is a potential and that this potential can be filled by new possibilities, new horizons and that there are amazing perspectives for Sicily: the implementation of a hydropower plant to increase production, to make Sicily increase its relevance and reduce emissions and, more in general, pollution with good consequences on people's health.

3. Case study: economic and environmental analysis of hydropower plants

The advantages and disadvantages of hydropower plants have already been displayed in the previous chapter and are valid for Sicily too, but with a specification: as Sicilian availability of water is low, it will be necessary to find solutions able to exploit the already existing resources, taking into account the scarcity of water and how precious it is. Therefore, the suggestion is to develop new plants filling new buckets in order not to use potable water or to use aqueducts. When making a cost-benefits analysis, revenues must be analysed. Fortunately, in recent years, new incentives have been available for producers, allowing them to know in advance their future revenues.

The most important incentives are two:

Green certificates, since 2001 there is the obligation for energy producers and importers to place on the market the 2% of revenues due to renewable energy (with annual increases of the 0,35%) for the part that exceeds 100 GWh. A green certificate is a fully-fledged title, attesting the production of 50 MWh of renewable energy, with a 2-years bankability.

Guaranteed prices, which are the prices of sold energy. Any energy producer must sell its energy to the nation (if the power is higher than 20 kW) through direct agreements establishing a price (the guaranteed price) or different prices for three different times of the day. For small plants (with a power lower than 20 kW) the producer obtains only the difference between produced energy and the consumed one.

On the other hand, for smaller plants (up to 500 kW) there are not prices related to the hour but there are "minimum prices" that change every year. In 2018 minimum guaranteed prices are (Regulatory Authority, 2018):

Power ≤ 250.000 kWh → 154.7 €/MWh;

Power between 250.000 kWh and 500.000 kWh → 106.3€/ MWh;

Power between 500.000 kWh and 1.000.000 kWh → 67.1/MWh;
Power ≥ 1.000.000 kWh → 58.1/MWh.

Table 3. Prices at different time slots (Miotto et al., 2008)

Time slot	***Price (c€/KWh)***
F1 (on Monday-Friday, from 8 a.m. to 7 p.m.)	9.7799
F2 (on Monday-Friday, from 7 a.m. to 8 a.m. and from 7 p.m. to 11 p.m. + on Saturday from 7 a.m. to 11 p.m.)	7.9971
F3 (on Monday-Friday from 11 p.m. to 7 a.m. + on Monday, all day long)	5.3259

As a result, when estimating revenues, it can be stated that: gross revenues (according to average market values) are 75€/MWh, needing to be added to the value of incentives, which can be estimated as 105 €/MWh for plants with a lower power (<1MW) and 145€/MWh for more powerful plants (>1MW). To sum up, a hydropower plant with a power <1MW would entail net revenues amounting to 180 €/MWh, a hydropower plant with a major power would sell green certificates with final net revenues amounting to 220 €/MWh.

As far as it concerns costs, they are represented by the needed capital for the realization of the opera and by the resources needed for the maintenance of it.

Investment costs depend on the kind of plant that is realized, however it is possible to generalize this information. Generally, these costs are elevated because it is necessary to produce not only the machineries, the turbines, the generators, the control systems and others but the charge basin, the ducts, the central building and so on. The reason why investment costs are different according to the installed power can be found in the fact that in small plants the collecting, channeling and recovery devices are not numerous and are really simple, whereas in larger plants the impact of these instrument on total costs amounts to 60-70% (and it is minor than 30-40% in smaller plants). To sum up, costs depend on: differences in height (the so-called “head”); payload; power; regulation times.

According to Federidroelettrica, costs can be classified into two different ways: taking into account the power or the “head”. Tables 3-6 express costs in these two different ways (Politecnico di Milano, 2013). The data can be represented as in Fig. 1.

Table 4. Hydropower plants’ annual costs classified according to the power (Politecnico di Milano, 2013)

Plant (KW)	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900
Leases	2988	5863	6315	8908	10580	16361	11150	29074	27293
Monitoring	20000	23311	26991	28602	32125	44000	50577	60000	60000
Insurance	1307	5139	5773	6714	6560	4830	6207	7309	14415
Other exercise costs	1871	6702	7880	16985	8103	6184	4909	3652	15389
Ordinary manutention	1634	9226	6735	8338	15232	13379	22135	14187	24468
Extraordinary manutention	1155	10968	10991	4434	16403	8661	3691	3992	16348
Administration costs	35781	25051	28227	43218	41796	44000	51341	62263	60000
Other costs	-	3638	9931	7766	13195	5081	100643	34590	6426
Total costs	64736	89898	102843	124965	143994	142496	250653	215067	224429

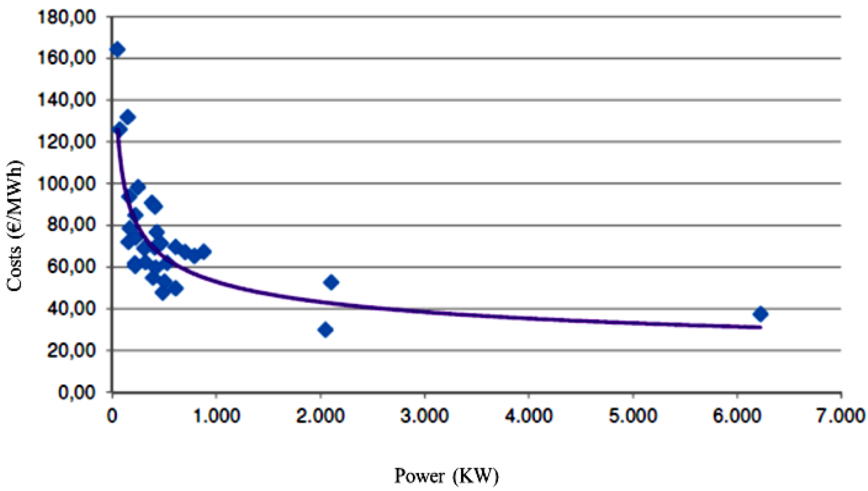

Fig 1. Total costs in relation to the power (Politecnico di Milano, 2013)

The other type of classification considers the differentiation of plants in terms of "head" (High Head, HH, > 1000 metres or Low Head, LH, < 1000 metres), which means (De Carli, 2010).

Table 5. Ordinary costs for plants maintenance with a power up to 1 MW, classified according to the differences in height (Politecnico di Milano, 2013)

KW	*50*		*100*		*200*		*400*		*1000*	
Type	*HH*	*LH*	*HH*	*LH*	*HH*	*LH*	*HH*	*LH*	*HH*	*LH*
Raw materials	2850	3400	3050	3500	4400	4400	5000	5000	11000	10000
Services	42210	55898	69067	81980	94582	104280	109000	131400	147040	182130
Workforce	5000	5000	7500	7500	12000	12000	39000	43000	68000	68000
Other costs	5342	6186	8968	10553	15426	18475	37578	35206	85506	79601
Funds	5083	6625	10167	14000	16750	19625	25500	29042	37833	48250
Total costs	60485	77090	98752	117510	143160	158780	216080	243650	349380	387980

As far as it concerns tax burdens, they increased in the last few years leading to a general increase of costs (both investment and maintenance ones). The hypothetical income statement could be imagined, for different sizes of plants, as in Table 6.

Table 6. Hypothetical income statement (De Carli, 2010)

Power of plant	>10 MW	1-10 MW	<1 MW
Production per year (GWh/year)	31	6	1
Revenues (€/MWh)	180	180	220
Total costs (€/MWh)	96	106	174
Unitarian margins (€/MWh)	84	74	46
Total margins (€/year)	2.604.000	444.000	46.000

The business considered in this paper is called “Azienda agricola Verzì Liberto” located in eastern Sicily, a region in southern Italy. The business operates in the production and transformation sectors of mushrooms and vegetables, since 1989. The production site extends for 50 hectares and the transformation unit features a 6.000 m^2 area split in about 2.000 m^2 dedicated to mushrooms cleaning and packaging, the rest used for the packaging of vegetables. Both product lines have an innovative transformation and packaging system able to guarantee traceability along all production phases, from seeding to distribution so to evaluate possible microbiological changes in the product. In case of anomalies which differ from the qualitative standard, compliant with the ISO 9001:2008 standards, corrective action will be taken to restore products to their standards.

The company is specialized in the production of a variety of fresh mushrooms, such as Pleurotus Ostreatus and Agaricus Bisporus more commonly known as oyster and champignon mushrooms, respectively. Mushrooms are farmed in controlled temperature and humidity greenhouses to ensure the optimal conditions in which mycelium will grow in all-natural antiparasitic-free substrate bases. A drip irrigation system allows for the conservation of an optimal level of humidity of the mushroom substrate bases as well as the avoidance of redundant or excessive consumption of water.

The company believes in an eco-friendly production; indeed, it uses inhouse electric energy produced with solar panels to power the greenhouses and the transformation unit. The need to differentiate its business has brought “Azienda agricola Verzì Liberto” to look at the future with a vision of circular economy that will bring benefits to the company itself, the environment and above all local consumers.

4. Results and discussion

It is possible to say that the implementation of hydropower plants is possible in Sicily, with a long term for the recovery of initial investment costs (between 15 and 20 years). Moreover, apart from the economic feasibility, social and environmental impacts on Sicily are considerable: these plants will reduce the mentioned high mortality rates due to pollution, both for humans and fauna, it will reduce the production of pollutants such as CO2 and particulate matters as Sicily will not need to produce energy by old-fashioned ways. Sicily suffers because of the scarcity of water, nevertheless hydropower plants are possible ways to embrace renewable energy, exploiting the periods of fluctuation of flow rates. With such plants, Sicily could reach as high standards as the ones already reached by several Italian regions: Sicilians will not be considered anymore negatively as they are in this moment, but they will show to have the right strength to be proactive and able to adapt to the modern world. Moreover, the building of hydropower plants, could be a good way to monitor at any time the flows of Sicilian rivers, their fauna and flora, the presence of algae and the balance of a variety of micro-ecosystems. In this way, the production of green energy would not only entail the use of rivers and water sources that are not used nowadays, but it could be a good way to monitor the quality of Sicilian waters and try to reduce the levels of pollution in the water too.

Moreover, in the future, further projects could help Sicily to recover from the diseases caused by the lack of attention towards the issues of circular economy, green economy, renewable sources of energy and similar. There is a lot of trust in Sicilians capability of taking care of this region and its limitless resources and possibilities. Unfortunately, Italians governments have been seeing Sicily as a weight over time and the situation now has not changed: Sicilian universities, firms, organizations of any kind must always work using their own strengths, because of the lack of organization, because of corruption, lack of democracy and meritocracy and mainly because of mentality.

There is not awareness about the richness of this isle, people do not believe in renewable energy, in the need to protect the environment and to reduce pollution. Sicily is a kind of treasure trunk, the only thing to be done is to open this trunk, discovering the wonders that Sicily can offer to future generations, for a better living, higher living standards and better preservation of Sicilian amazing environment.

5. Conclusions

This study has illustrated the advantages and backwards of hydropower plants, with specific reference to Sicily. It has been demonstrated that investments are worth it, that there is a demand and there is a supply for energy and that they can match with ease. The cost-benefit analysis has led to the consideration that hydropower plants are a good idea to help Sicily earn a primary role in Italian energetic overview. Though the current situation is not desirable, there are plenty of room for manoeuvre for the development of green energy in Sicily. Therefore, it should be considered that renewable energy sources have been seen for a very long time as something marginal, far from people's daily life and the environmental and health problems caused by polluting factors were not so relevant. Still today there are people who believe that the hole in the ozone layer, the global warming, the melting of glaciers, tumours, ictus, cardiopathies, chronic respiratory diseases, airways infections and others are not due to pollution. But now the protection of the environment has become a common issue, everybody is interested in it, understanding the relevance of green energy. As a result, it should be underlined that not only hydropower, but other REs can be applied in Sicily: there are regional and governmental (even European) incentives to produce green energy, independently from the kind of renewable energy source that is used. As a matter of fact, Sicily has many sources to be exploited and it should be the Italian government's priority to encourage local development of RE sources, first of all in a region that has so much to offer.

Apart from hydropower plants, Sicilian energy production could experiment the effects of photovoltaic production: it is known that southern Italian regions have a Mediterranean climate, with summers lasting more than winters and with the constant presence of the sun. Consequently, modern photovoltaic cells (that follow the sun's path) could be perfect for Sicilian climate, considering the high productivity of these cells (useful for both electricity and heat production). Unfortunately, methods to recycle or to manage old photovoltaic cells after their life cycle are still in phase of refinement. However, technology nowadays makes great strides towards solving current problems and there is the certainty that Sicily will become independent.

The same considerations can be made referring to other renewable energy sources too: the power of wind is infinite and it should be exploited. The only backward refers to the dimension of the pales but, fortunately, as already said, technologies will soon be found to make pales smaller, with no bad consequences for Sicilian wonderful landscapes nor for birds (which could now be in danger because of the high speed that can be reached by these huge pales).

To sum up, Sicily's future can be represented by renewable energy sources, such as hydropower, photovoltaic and wind energy. Man can imagine that the world in 2050 will be totally different: humans will live in harmony with the environment, without the need to build nuclear centrals nor to process large amounts of fuels, encouraging the exploitation of the resources owned by a country. There will be a very big difference between the world of today and the future world: each country, each region or area will just use the resources that have been given to that land, to produce electricity, to warm houses and offices, to give power to machines. Sicily will finally redeem itself, always improving its production to reach one unique aim: green energy production.

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COMPOST STREAM AS A POTENTIAL BIOMASS FOR HUMIC ACID PRODUCTION: FOCUS ON COMPOST SEASONAL AND GEOGRAPHICAL VARIABILITY*

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Abstract

Compost is a voluminous stream rich in humic and fulvic acids, which may be recovered as high-added value compounds. These soluble bio-based lignin-like polymeric substances (SBO) can be extracted through a completely green process developed at pilot scale, whose main core is the hydrolytic route in aqueous solutions at relatively mild temperature (< 140 °C) at ACEA Pinerolese Industriale premises. Due to their chemical-physical properties, the SBO compounds can be used with advantage for myriads of industrial applications, from the formulation of detergents to the production of agriculture bio-stimulants, answering the increasing demand for bio-compound utilization. In view of LIFECAB project (LIFE16 ENV/IT/000179), the characterization of starting materials and the derived compost has been performed over four seasons and over three European countries (Italy, Greece ad Cyprus). In view of establishing a relationship between SBO molecules and compost properties, this work is a challenging opportunity for assessing the compost variability and its temporal evolution during the composting process. Analyses of pH, salinity, total carbon, total nitrogen and C/N ratio, critically assessed by means of a statistical approach, provide important information about compost composition according to the season and to the local environmental conditions.

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Keywords: bio-stimulants, compost, hydrolysis, humic acids

1. Introduction

Compost is rich in humic compounds, which can be extracted with success through a hydrolytic process (Montoneri, 2017). Therefore, compost represents an important source of soluble new bio-based products (SBO), which have potential use in several fields, from the chemical industry to agriculture and animal husbandry. The SBO specific feature is the possibility of replacing fossil derived products, whose production has a significant environmental burden in terms of resource depletion, emissions and water pollutants. In fact, SBO can be efficaciously extracted by compost derived from both municipal biowaste and green residue, fulfilling the guidelines reported in the Directive 2008/98/CE (EU, 2008) concerning the proper management of waste flows in accordance with the circular economy (Kirchherr et al., 2017).

In addition, new findings in SBO knowledge have witnessed the SBO capacity in reducing the ammonia content in the anaerobic digestate of municipal solid waste (MSW) (Francavilla et al., 2017) if added in small amounts (0.05-2 % w/w) to the organic fraction of the fermentation slurry. This property is expected to be validated on an industrial scale in view of the EU supported Lifecab project (LIFE16 ENV/IT/000179), which involves the production of compost and the subsequent hydrolytic extraction of SBO, together with the analytical characterization of all the investigated biological streams.

This work addresses the collection of analytical data in order to monitor the seasonal and geographical variability of the compost. This activity results preparatory to the following phases of the European research project LIFECAB since the properties of the compost significantly affect not only the yield of the SBO extraction project but also the quality of SBO. After the selection of the parameters to be investigated, the analytical methods have been carefully discussed and designed. More specifically, the plants in charge of producing compost from feedstocks locally available were: the Italian ACEA Pinerolese Industriale (ACEA), the Greek Organohumik Thrakis (OT) and the Cypriot Sewerage Board of Limassol (SBLA). Analyses have been performed on the starting materials (i.e. green residue and digestate) and on the stable compost, highlighting the temporal evolution by monitoring physical and chemical parameters.

This work is divided in three main parts:

- collection of the materials involved in the analyses, taking into account the different materials used for compost production;
- description of the methodology employed for sampling and analytical measurements;
- analysis of the results, drawing conclusions through a statistical approach.

2. Materials and methods

2.1. Compost production

ACEA, SBLA and OT produce compost from different raw materials: ACEA utilizes gardening residue (GR) and digestate (D), while both OT and SBLA utilizes only GR. Regarding OT, a mixture of mixture of olive mill solid wastes, dried municipal wastes, leaves, saw dust, and wood chips is employed, while SBLA uses a mixture of leaves, pruning, grass, soil and saw dust.

2.2. Sampling and analytical measurements

The selected compost sampling approach was the composite sampling (ANPA, 2001). Therefore, a composite sample constitutes a single sample for laboratory analysis composed of sub-samples uniformly distributed throughout the entire volume that, after mixing, accurately represents an average or median value of the property for a batch or general mass. For the specific case, the compost sampling was fixed once per week during the first month interested by an intense oxidation phase and once per month during the following two months of the curing phase.

After the sampling procedure, all samples were stored in suitable packages and placed at -20 °C until the day of analysis. Before the analyses, all the samples were dried and homogenized using a laboratory blender. Analyses included the assessment of pH, salinity, moisture, volatile solids (VS) and total carbon and nitrogen. Compost sampling and analyses were carried out according to ANPA (2001), DIVAPRA (1992), APHA (1998).

Data collected for this work regard four seasons and three European countries, and triplicate analyses for all samples were conducted for allowing application of statistical analysis and assessment of results' significance. For each parameter, the significance of the differences between the average values has been determined by one-way ANOVA analysis and Tuckey test. In conclusion, four experimental campaigns for raw materials and compost analyses were simultaneously conducted at ACEA, OT and SBLA site in September 2017, November 2017, February 2018 and April 2018.

3. Results and discussion

3.1. Compost evolution during the composting process

For each composting plants, we have monitored the evolution of compost during the composting process and Table 1 summaries the properties of starting materials and compost during the first season started in September 2017 for ACEA site.

Table 1. Properties (mean±SD) of the composting material during the first season started on 04/09/2017 at ACEA site. Different letter, within the columns, indicates that the values are significantly different ($P < 0.01$)

Time, weeks	*Material*	*pH*	*Salinity, meq/100g*	*VS, % TS*	*C, % TS*	*N, % TS*	*C/N*
0	GR	7.5±0.15a	18.2±0.84a	72.4±1.43a	39.3±1.86a	1.9±0.10a	21.1±1.23a
0	D	8.2±0.05b	73.7±6.95b	57.6±1.31b	33.1±3.19b	3.2±0.14b	10.1±0.52b
1	compost	8.1±0.03b	39.2±5.36a	62.0±0.10c	31.6±2.41bc	2.4±0.08c	12.9±0.55c
2	compost	8.3±0.07bc	32.4±2.75a	56.4±2.37b	27.6±1.36c	2.2±0.07ac	12.6±0.80c
3	compost	8.6±0.06c	37.4±17.97a	56.5±0.48b	28.9±0.72bc	2.1±0.11ac	13.1±0.42c
4	compost	8.4±0.04bc	22.9±3.73a	53.7±0.74b	27.7±1.71c	2.3±0.18c	11.7±0.20b
8	compost	8.4±0.14bc	36.6±11.59a	54.6±0.56b	30.0±0.72bc	2.3±0.12c	12.7±0.87c
12	compost	8.2±0.08b	20.9±3.03a	53.8±0.14b	28.9±0.13c	3.0±0.08b	9.3±0.26bc

The main characteristics of the composts do not point out relevant variations during composting. The most significant differences are between the two starting materials (GR and D): the digestate exhibits higher pH, salinity, and N content than the gardening residues, which are richer in organic carbon and volatile substances. These results are in agreement with the nature of the materials.

3.2. Compost seasonal variation

The analyses carried out in September 2017 were repeated in order to assess the seasonal variability for each composting plants. The comparison between the composts obtained during the three completed seasons pointed out some significant differences as far as the carbon and nitrogen content were concerned. For example, for ACEA premises (Fig. 1), the observed trend is an increase of C and a decrease of N from season 1 to season 3, reflecting an increase of the C/N ratio. No significant differences have been noticed for pH, salinity and VS.

The data of season 4 (to be completed) will be useful for confirming such trend.

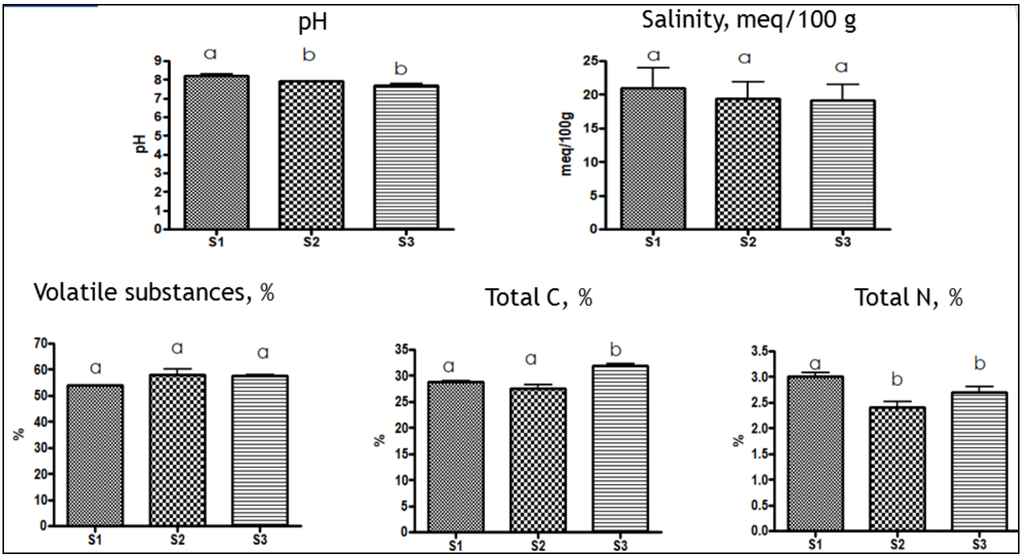

Fig. 1. Comparison of the stable compost properties (at the end of the composting process) for samples deriving from ACAE site. The parameters investigated were pH, salinity, volatile substances, total carbon and total nitrogen. S1: first season (started in September 2017), S2: second season (started in November 2017), S3: third season (started in February 2018)

3.3. Effect of the sampling time on the properties of the starting materials

The raw materials used as a feedstock for compost production have been analysed for each composting site at the beginning of the process. The most significant differences were noticed at ACEA site where both digestate and green residue were used for the compost production. In this case, the seasonal variability affects the content of both total nitrogen and total carbon. Furthermore, as far as the ACEA GR is concerned, the variations in nitrogen content could be due to the differences of protein content of the lignocellulosic material and to the maturation of the pile, while the different carbon content is related to the partial maturation of the green wastes during the storage which leads to a loss of carbon as CO_2. Similarly, the digestate strongly depends on seasonal variability as well, because of the seasonal variability of the food wastes used for feeding the digestor.

3.4. Compost geographical variation (Italy. Greece and Cyprus)

Finally, compost samples collected simultaneously from Italy, Greece and Cyprus were compared for evaluating the geographical variability (Fig. 2). Significant differences in carbon and nitrogen content were noticed comparing the compost produced at ACEA site with the ones obtained at OT and SBLA premises. This behavior is mainly related to the fact that ACEA utilizes both digestate and green residue for compost mixture, whereas OT and SBLA obtains their compost only from green residue (please, see Section 5.1 for the differences between D and GR).

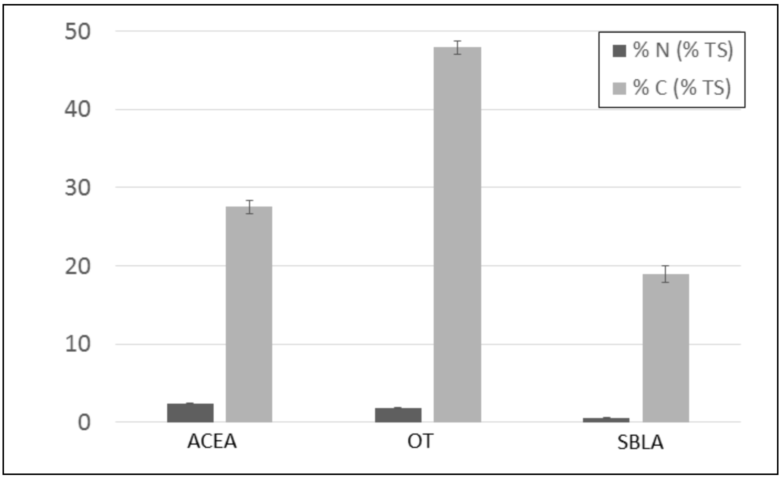

Fig. 2. Comparison of the stable compost (compost at the end of the process) obtained at ACEA, OT and SBLA sites. More specifically, the figure takes into account the analyses of total carbon and total nitrogen for season 2 (started in November 2017)

4. Concluding remarks

The properties of the compost vary according to the season and to the local environmental conditions. Therefore, in this extensive study different compost samples collected throughout four seasons and in three European countries have been analyzed, in order to identify the best period of the year as well as location to produce compost for the subsequent SBO extraction. In the future framework, after the extraction of SBO compounds from compost, correlations will be provided for drawing relationships between hydrolysis process parameters, nature of the starting materials and SBO yield and quality.

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THE USE OF SPENT MUSHROOM SUBSTRATE IN THE PRODUCTION OF THERMAL ENERGY IN TERMS OF A CIRCULAR ECONOMY *

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Abstract

Over the past few years, the growing attention to some steps in the chain of production has brought an increasingly important vision of the circular economy, as well as the use of production waste as an input for further production to reduce environmental impact and, ultimately, safeguard the planet. In this case, the Spent Mushroom Substrate (SMS) was studied, a product used by firms to cultivate mushrooms. The business examined in this paper is “Verzì Liberto”, located in Contrada Scalilli – Paternò (CT). It has operated in the sector of cultivation and transformation of mushrooms and vegetables since 1989. In particular, the Spent Mushroom Substrate is used for the farming of Pleurotus Ostreatus and Agaricus Bisporus, more commonly known as the oyster and the Champignon mushroom. The aim of this paper is to find a suitable solution to the large quantity of SMS waste available in this sector with the aim of transforming it into a source of energy which respects the environment.

Keywords: circular economy, spent mushroom substrate, sustainable agriculture, thermal energy, waste

1. Introduction

The term “circular economy” is a generic term for the reducing, reusing and recycling activities conducted in the process of production, circulation and consumption (Naustdalsild, 2017). This entire process starts thanks to the incessant and pressing demand that society makes on firms to reduce their environmental impact. Firms have the possibility

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to achieve competitive advantages by the use of waste materials in subsequent production and consumption cycles, maximizing their utility. Bioenergy is able to sustainably meet the future demand of energy, because it has a significant potential for expansion in relation both to electric and heat production, but also to the transport sector (Di Mario et al., 2011).

During the last decade, the concept of biomasses, used to indicate organic material originated by fauna or flora organisms, has gained importance as source of bioenergy, because it has helped energy production through renewable sources all over the world. It is necessary to clarify that the kind of energy which will be analyzed in this paper is thermal energy, which refers to energy used in the district heating network. In this specific area, during the decade 2004-2013, a significant increase has been noticed in the percentage of renewable energy sources used: in Europe there has been an increase from 10% to 21%, while Italy has seen an important growth from 4% to 16% (Bianchini et al., 2016).

As can be imagined, there are different processes that can be implemented to transform biomass into thermal energy and one of these is combustion. The simple act of burning biomass to obtain heat is one of the oldest biomass conversion processes known to humankind (Klass, 1998). Complete combustion of biomass consists of the rapid chemical reaction known as oxidation and the release of energy, the amount of which is a function of the enthalpy of combustion of the biomass. Different elements used within the entire combustion process, will burn in different conditions based on both their physical and chemical composition and also on the conditions of the environment where they are used. Applying this entire process to the agricultural sector, firms will be able to benefit from significant advantages thanks to innovative waste materials managements systems.

"Azienda Agricola Verzì Liberto" (n.d.) is specialized in the production of mushrooms ("Pleurotus ostreatus" and "Agaricus bisporus"), adheres to ISO 9001:2008. Thanks to its collaboration, it will be possible to understand the feasibility of the study carried out in this paper, that is the possibility of creating a plant that produces thermal energy through the combustion of biomass – SMS, waste material that the firm produces. The analysis of the firm will include a detailed study of the different machines that could be used within the process of thermal energy production, so that an optimal decision can be made by considering the economic and environmental impact point of views. The possible need to add another element to the SMS will also be analyzed due to its high burning capacity. The study will end with considerations about the advantages that the firm will be able to achieve. It can be observed that, in 2030, biomass, if used properly, could represent 60% of renewable energy consumption, covering 20% of World's energy consumption. 40% of biomass could be made up of waste and agricultural residues (Manuelli, 2015).

2. Materials and methods

This analysis has been divided up into paragraphs concerning the different topics, the explanation of which is fundamental in order to ensure a clear understanding of the research carried out. The Spent Mushroom Substrate plays an important role in this study, because it outlines both the problems dealing with the disposal costs and environmental impact, but it is also considered an opportunity. It is important to describe the actual production process that creates the spent mushroom substrate, in fact reference is made to the mushroom production process. These kinds of organisms grow in a variety of different elements, such as straw, poultry manure, peat, soil and calcium carbonate which is used to pH adjustments. These components are mixed into specific containers and, afterwards, these containers are brought into rooms which temperature and humidity are carefully controlled in order to ease the growth of the mushrooms. Only after having obtained the main product, that are mushrooms, the mixture in which they have grown can be defined as SMS.

The spent mushroom substrate (also known as spent mushroom compost or SMC) is a residual material similar to the soil. Its composition can vary based on the needs of the firm's production and, according to the containers used, various amounts of water will be needed (Williams et al., 2001). The compost has high capacities in terms of organic material production; this makes it extremely desirable as a factor of chemical soil balance or as a soil conditioner (Beyer, n.d.).

As mentioned above, the SMS will be used to produce thermal energy and, for the creation of a diet of residual materials that will be used into the machine adopted by the firm for the implementation of this project, it has been possible to set up Table 1, containing the physical and chemical properties of the SMS coming from "Azienda Agricola Verzì Liberto" (n.d.).

Table 1. Laboratory analysis of SMS

	H2O (%)	*SS (%)*	*NDF (%)*	*ADF (%)*	*ADL (%)*	*Ashes (%)*
Pleurotus	49.6	50.4	51.40	35.87	12.42	7.93
Champignon	57.1	42.9	32.37	24.80	14.69	9.34

The data that must be considered in this analysis are the humidity and the ash rates. The compost's humidity is very high, but it is possible to remedy this problem by incorporating another agricultural waste material to the SMS with a high burning capacity, so reference is made to pruning products. With regard to the ash, the critical issue in this case is that these residues have a particular composition, occupy a volume, have a considerable weight, have a particular behavior at high temperatures, but most importantly, they need to be managed as waste materials. It should be remembered that, from an agronomic point of view, the ashes contain minerals and substances that the plants have extracted from the soil, so their regeneration and reuse as a soil improver would also allow the inorganic loop to be almost completely closed (BIOCEN). After appropriate treatments which aim to obtain a proper composition suited for the soil, the use of ashes would adjust the soil's pH bringing the values to more basic ones. Considering the presence of polluting components, the reuse should preferably be in appropriate doses.

The thermal energy of an object is that contained in the movement and oscillation of its molecules and the friction between them generates heat. The heat could be employed later in the most appropriate and efficient way so not to waste this new energy source, reusable internally in the industrial process in the form of electrical energy.

Environmentally speaking thermal energy is a form of renewable energy, in fact it is self-generated. Within the mid-21st century the production of electricity coming from renewable sources will account for about three-fifths of the global requirements (Thomas, 1993). However, according to a recent evaluation just 15-16% of the global energy was produced from renewable sources, of which four-fifth from hydro-electrical energy (Jonhstone, 2009). Actions taken by the world's governments will determine the future of renewable energy sources. Denmark has recently established that by 2030 the amount of energy produced for domestic purposes will need to be about 50% from renewable sources and by 2050 the country domestic demand will be entirely satisfied with renewable energy. At this stage the right renewable energy source is unclear (Lund, 2009).

In this paper, the waste to extract thermal energy from is represented by the spent mushroom compost, a by-product of the production of mushrooms. SMS will be employed form the production of thermal energy using an appropriate machinery with characteristics and performances suitable for the study. There are a few suitable machines, and each has unique characteristics regarding dimensions, quantity of waste input and the total energy obtainable from the recycle waste. Given the business demand a small plant easy to run and relatively cheap to maintain proves to be the best option to investigate.

The first machine investigated is known as "bubbling fluidized bed". It is a high temperature boiler where the waste is inserted with a mixture of sand which will stabilize the combustion because of its high thermal capacity. This technology which reaches temperature up to 900 °C during combustion considerably reduces emissions of nitrogen oxides (NOx) and other pollutants. A second type of machine is the "stoker fired chain grate" another kind of boiler; this technology is widely utilized with high humidity concentration wastes. A belt inside the combustion chamber uniformly distributes the SMS, mixed with a diet which increases the overall thermal capacity, to obtain a more homogeneous combustion. The result of the process are ashes that will be collected at the end of the belt in appropriate container which will be disposed later (IEA CLEAN COAL CENTRE, (2018). The only problem with this process is the slightly unstable combustion which causes small and sporadic emission of pollutants (CO, NOx and organic matter).

The variety of available machines presents different types and quantities of emissions, as shown in Table 2, from which it is clear that the fluidized bed and the stoker are some of the machines with the lowest emissions (Aureli, 2001).

Table 2. Arithmetic average of emission's levels from different biomass combustion's plants

	NO_x as NO_2 [mg/MJ]	***Particles [mg/MJ]***	***Tar [mg/MJ]***	***CO [mg/MJ]***	***UHC as CH_4 [mg/MJ]***	***VOC [mg/MJ]***	***PAH [mg/MJ]***
Cyclone furnaces	333	59	n.m	38	n.m	2.1	n.m
Fluidized bed boilers	170	2	n.m	0	1	n.m	4
Pulverized fuel burners	69	86	n.m	164	8	n.m	22
Grate plans	111	122	n.m	1846	67	n.m	4040
Stoker burners	98	59	n.m	1846	67	n.m	9
Wood boilers	101	n.m	499	4975	1330	n.m	30
Modern wood boilers	58	98	66	1730	200	n.m	26
Traditional wood stove	29	1921	1842	6956	1750	671	3445
Fireplace	n.m	6053	4211	6716	n.m	520	105

n.m = not measured

The quantity of waste required by the machine for its ordinary running depends on the dimensions of the same: the minimum required is about 4-5 tons/hour up to 650.000 tons/hour. The retrievable energy is about 15-20 MWh for large dimensions' machines. Both machines are suitable for the application proposed by the business and the acquisition and maintenance costs would be covered thanks to regional and European funds for the technological progress and the reduction of environmental impact in the sector.

3. Case study: Azienda Agricola Verzì Liberto

The business considered in this paper is called "Azienda agricola Verzì Liberto" located in eastern Sicily, a region in southern Italy. The business operates in the production and transformation sectors of mushrooms and vegetables, since 1989. The production site extends for 50 hectares and the transformation unit features a 6.000 m² area split in about 2.000 m² dedicated to mushrooms cleaning and packaging, the rest used for the packaging of vegetables. Both product lines have an innovative transformation and packaging system able to guarantee traceability along all production phases, from seeding to distribution so to evaluate possible microbiological changes in the product. In case of anomalies which differ from the qualitative standard, compliant with the ISO 9001:2008 standards, corrective action will be taken to restore products to their standards.

The company is specialized in the production of a variety of fresh mushrooms, such as Pleurotus Ostreatus and Agaricus Bisporus more commonly known as oyster and champignon mushrooms, respectively. Mushrooms are farmed in controlled temperature and humidity greenhouses to ensure the optimal conditions in which mycelium will grow in all-natural antiparasitic-free substrate bases. A drip irrigation system allows for the conservation of an optimal level of humidity of the mushroom substrate bases as well as the avoidance of redundant or excessive consumption of water.

The company believes in an eco-friendly production; indeed, it uses inhouse electric energy produced with solar panels to power the greenhouses and the transformation unit. The need to differentiate its business has brought "Azienda agricola Verzì Liberto" to look at the future with a vision of circular economy that will bring benefits to the company itself, the environment and above all local consumers.

4. Results and discussion

The analysis argues that, from an environmental point of view, it is convenient for the firm to use SMS for the production of thermal energy. The plant transforms waste produced by the firm into a resource, through combustion. The productive cycle is divided into six different phases:

- Storage: in this section of the plant, after the collection of wastes, it is possible to stock the biomass needed in the feeding system;
- Feeding system: the biomass is moved from the storage. The feeding system consists in a chain conveyor. The system is designed to work responsibly, according to the current regulations on safety;
- Boiler: the combustion chamber and the heat exchanger design the boiler section. The first one is equipped with a ventilator for the air adduction and a probe that measures and controls the relevant parameters;
- Combustion grill: the material is poured into the grill for the combustion;
- Filtering;
- Chimney: The filtered smoke produced by the combustion, is pushed by the ventilator and released into the atmosphere through the chimney.

Focusing on the substrate, mushroom wastes are not essential for the correct and efficient usage of the plant. This is mainly caused by the divergences between the proprieties of the SMS analyzed, such as humidity, and the characteristics of the plant. In particular, it is necessary to insert about 22,000 tons/year of SMS and other wastes of agricultural origin, such as corncobs, residues of vine pruning and fruit tree pruning, husks, shells or kernels.

In order to obtain a successful result, it is strongly recommended to balance the high humidity of SMS with dry agricultural waste materials. The firm might obtain different benefits from the implementation of this innovation. Dealing with the economic aspect, the cost of the plant, its management and maintenance might appear high, but in a long-term perspective it definitely represents an economic advantage, like the cost reduction concerning the usual consumption of thermal energy and the recurring disposal of produced wastes. Additionally, the firm will be able to demonstrate its eco-friendly nature, that can be considered as a good advertising. From an environmental point of view, the implementation of the conversion system will permit a reduction on the thermal energy consumption, that will imply a significant reduction in terms of environmental impact.

Nevertheless, apart the high initial cost for the firm required for the purchase of the plant, it is important to consider the implementation timing that requires long bureaucratic and logistic procedures. Finally, the necessity to integrate dry agricultural waste material might represent a cost, unless the firm decides to stipulate agreements with other local suppliers.

5. Conclusions

The new perspective that has proposed the implementation of Circular Economy, especially concerning a firm that operates in an extremely polluting sector, could represent a possible breakthrough.

The project previously analyzed could receive positive feedbacks from the growing agricultural sector. The firm "Azienda Agricola Verzì Liberto" that has worked on the drawing up of the draft, after having understood the feasibility of the project, would play the role of pioneer in the management of waste materials, creating a domino effect within the sector in which it operates.

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METHANE OXIDATION EFFICIENCY AND NMVOCs REDUCTION IN A FULL-SCALE PASSIVE BIOIFLTRATION SYSTEM FOR THE TREATMENT OF RESIDUAL LANDFILL GAS *

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Abstract

The aim of this study is to assess the abatement of Non-Methane Volatile Organic Compounds (NMVOCs) in a full-scale prototype (biowindow) constructed for the passive biofiltration of low levels of Landfill Gas (LFG). The prototype was built on an emissive hot spot of the capping layer at Le Fornaci di Monticiano Landfill (SI), an aftercare landfill site. NMVOCs emissions from landfills can cause unpleasant odors, can be toxic for human health and cause an important impact on the environment. As such, is important to characterize the LFG and evaluate the abatement efficiency of the technique adopted for the treatment of LFG. In this study, the composition of the LFG inlet the prototype was characterized in terms of NMVOCs and the dynamic chamber method was used to assess the concentration of NMVOCs emitted at the surface of the biowindow. Three monitoring campaigns were performed, and the methodology applied have permitted to evaluate the NMVOCs abatement and methane (CH_4) oxidation efficiency. Regarding CH_4 oxidation efficiency the results show an average maximum value greater than 95%, while NMVOCs efficiency abatement depends on the functional group of each compound, but the average efficiency is more than 90%.

Keywords: biofiltration, NMVOCs, oxidation efficiency, residual landfill gas

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1. Introduction

The management of low levels of Landfill Gas (LFG) is a central issue of the scientific community in the context of the waste management sector. After the entry in force of the Landfill Directive (1999/31/CE), the amount of biodegradable waste disposed in landfills was reduced and only pre-treated waste must be disposed in landfills. As such, the generation of LFG, produced by the anaerobic decomposition of the organic fraction of the municipal solid waste (MSW) is less in quantity and quality. Accordingly, the technical measures imposed by the Landfill Directive to control emissions of LGF can become technical inefficient and the LFG is vented to the atmosphere without treatment. Moreover, in Europe there are thousands of closed landfills, without any facilities for the management of LFG.

LFG is mainly composed by CH_4 and carbon dioxide (CO_2), both greenhouse gases (GHGs), and Non-Methane Volatile Organic Compounds (NMVOCs), that account for a minor part of the total LFG, but cause human health concern, unpleasant odor emissions and toxicological effects on the environment. When the content of CH_4 in LFG is below approximately 30% v/v, the LFG can be defined LGF with low calorific value (low CV-LFG) (EPA, 2010).

Biological CH_4 oxidation represents an innovative and cost-effective process to mitigate emissions of low CV -LFG (Bogner et al., 2007). Today, biofilter, biocover, biotarp and biofiltration trench are the main technologies studied to apply for the biological methane oxidation.

Many studies focus on the evaluation of CH_4 oxidation efficiency, on the suitability of the filter media (Huber-Humer et al., 2009, Huber-Humer et al., 2011, Scheutz et al., 2009), and on the major aromatic, sulphur and odorous compounds in the raw LFG and emitted at the surface of these biofiltration systems (Kim, et al., 2006, Kim et al., 2005, Scheutz et al., 2008, Capanema et al., 2014). However, only few studies analyze the composition of low CV-LFG in terms of NMVOCs and abatement of this trace compounds in a passive and full-scale prototype for the biological CH_4 oxidation, as a biowindow.

Biowindows, proposed by Kjeldsen et al (2007) are innovative technologies for the treatment of low CV-LFG in aftercare or closed landfills in which there is not a gas collection pipe network. A biowindow is directly builds in the cover layer of a landfill and the gas migrates in the system thanks mainly to the variation of atmospheric pressure and diffusion. The main objective of this study is to assess the CH_4 oxidation efficiency and NMVOCs abatement efficiency of a biowindow built at Le Fornaci di Monticiano landfill, an aftercare landfill site.

2. Case study

The location selected as case study is Le Fornaci di Monticiano landfill. The landfill has been closed by the landfill owner in 2001, before the entry in force of the Landfill Directive. At the landfill site, the LFG management system is composed only of vertical wells and flares with manual ignition, no more functioning because of the low quality and quantity of LFG produced within the landfill. Based on the outcomes of a preliminary field survey, seven emissive hot spots were identified, and, on each point, the existing LFG passive control system has been substituted by a passive biofiltration module. Briefly, each biowindow is made of a filter volume of about 5 m^3 with a filtering section of 4 m^2. The filter bed is made of two layers: a gravel layer for the homogeneous LFG distribution and a compost layer in which the microbial process occurs. The thickness of the compost layer is approximately 120 cm while the gravel layer is about 20 cm (grain size 15-30 mm). Sand in a volume ratio 5:1 has been added to improve compost structure. A geogrid was used to separate the two layers. The filter bed is contained in metal formworks that reinforce the whole module.

In this context, one biowindow (BW8) was investigated and three monitoring campaigns were performed to characterize in terms of NMVOCs the raw LFG inlet and emitted at the surface of the prototype. At the same time the CH_4 oxidation efficiency and NMVOCs abatement efficiency were assessed.

The campaigns were made in March 2017, August 2017 and March 2018. Materials and methods applied to characterize the NMVOCs in the raw LFG and emitted at the surface of BW8 are described in detail in Pecorini et al., 2017. The methodology proposed by Lee et al., 2018 is applied to evaluate NMVOCs abatement efficiencies while CH_4 oxidation efficiency is evaluated through the methodology proposed by Gebert et al., 2011 and described in detail in Pecorini et al., 2017.

3. Results and discussion

Table 1 shows the composition of LFG inlet BW8. Regarding the three monitoring campaigns, the average composition is 15±12.2 % v/v, 16.7±12.2% v/v 7.1±6.9 % v/v respectively of CH_4, CO_2 and O_2 that is typical of a residual landfill gas. A high variability of LFG composition was observed. This is due to many factors that affect the composition of LFG such as waste composition, components of the Organic Fraction of the Municipal Solid Waste (OFMSW) (Pecorini et al., 2012) landfilled, the age of the waste and waste management systems.

Table 1. LFG composition inlet BW8

LFG composition	*March 2017*	*August 2018*	*March 2018*
CH_4 [%v/v]	29.47	9.34	7.51
CO_2 [%v/v]	15.33	29.53	5.27
O_2 [%v/v]	7.04	0.23	13.98

Fig. 1 shows the results of the characterization of NMVOCs in the LFG inlet, emitted at the surface and NMVOCs reduction efficiency of BW8. In Fig. 1 the sum of the concentration levels of compounds belonging to each NMVOCs family find in the samples is showed. Regarding the classification of NMVOCs in the inlet LFG, aliphatic compounds are the dominant one and the most abundant are cyclohexane, n-butane, propylene and n-pentane (results not shown). This result is typical of a LFG with low calorific value as indicated by Parker et al., 2002.

H_2S is classified as the second prevalent compound and the concentration level is similar of those evaluated by J.-J. Fang et al., 2012, sampled from a gas well located in an older section of one of the landfills studied. Then, was observed an abundance of organ-halogen and aromatic compounds. The authors Kim et al., 2006 and Liu et al., 2016 indicate toluene as the most abundant compound in LFG, but in this study m,p,o-Xylene and 1,3,5-. Trimethylbenzene has the higher concentration levels, while toluene is ranking only third.

The concentration levels of alcohol, terpene, nitrogen and sulphur compounds were lower than the others. Dimethyl sulphide and methyl mercaptan, malodorous components, were found at appreciable but not very high concentration, respectively 21.4 e 8.1 µg m^{-3}. High values of standard deviation indicate high differences in concentration levels of NMVOCs find in the samples. These differences suggest that the emissions of NMVOCs is not only site-specific, but also other factors such as the variation of climate conditions (ambient temperature, atmospheric pressure), CH_4 and LFG load affect the process.

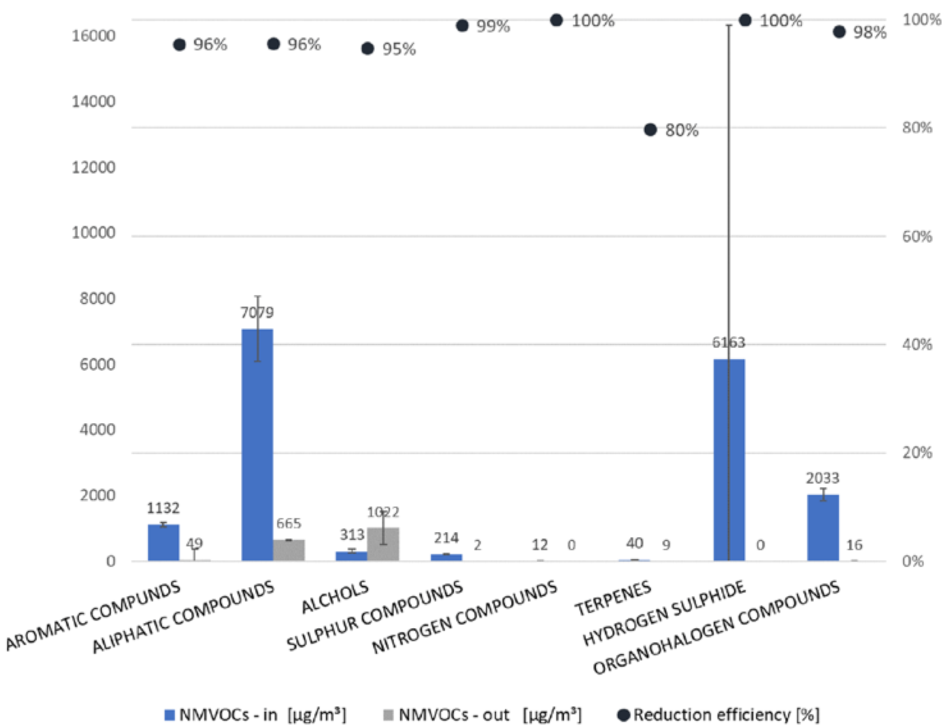

Fig. 1. Concentration levels of the NMVOCs present in the LFG samples and NMVOCs abatement efficiency of the passive biofiltration system

Concentration levels at the surface of BW8 are very low as shown in Fig. 1. NMVOCs reduction efficiency (black spots in Fig.1) is more than 80% for each family of NMVOCs. BW8 can completely remove nitrogen compounds and H_2S. Sulphur compounds are removed with an efficiency of 99%, while Capanema et al., 2014 indicates that biocovers made of sand and compost have an abatement efficiency respect to total reduce sulphur greater than 95%.

Fig. 2 illustrates the oxidation efficiency evaluated in each of the three monitoring campaigns in which was performed the NMVOCs screening. Fig. 2a) shows oxidation efficiency calculated along the gas sampling profile of BW8 in each monitoring campaign performed. At the bottom of the filter bed (130-70 cm of depth), the concentration of O_2 is too low, CH_4 oxidation process doesn't occur and CH_4 oxidation efficiency is less than 50%. Rising to the surface the concentration of O_2 increase and it is available to the methanotrophic bacteria that can oxidase CH_4 presents in LFG. As such, has been observed that CH_4 in completely oxidase at the surface of BW8. The CH_4 oxidation efficiency increases up to the maximum value of 100% in March 2017 and in March 2018. Despite of this result, during August 2017 the maximum oxidation efficiency was calculated at 30 cm of depth. This is probably due to the hot climate (over 40°C of the ambient temperature was registered during the sampling date in August, data not shown), that reduce the moisture content of the compost and minimize the bacterial activity in the upper layer. Fig. 2b) illustrate the average CH_4 oxidation efficiency regarding the three monitoring campaigns. The maximum value of oxidation efficiency is greater than 99% while the maximum standard deviation is calculated at 50 cm depth.

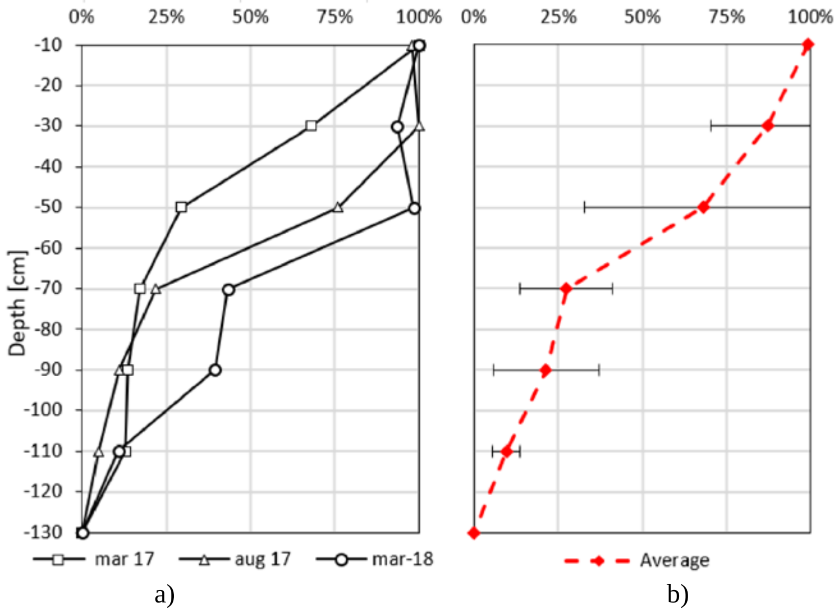

Fig. 2. CH_4 oxidation efficiency of BW8: a) of each monitoring campaign b) average of the three monitoring campaigns

4. Concluding remarks

The composition of LFG in terms of NMVOCs and abatement efficiency was investigated. The concentration levels of the NMVOCs indicates that the LFG is typical of those find in the older sections of a landfill.

Passive biofiltration systems, especially biowindows, show to be effective technique for the reduction of concentration levels of many family of NMVOCs find in LFG. High CH_4 oxidation efficiency was observed even the high variability of CH_4 load inlet BW8.

Future works should focus on the influence of climate factors on the microbiological process.

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LANDFILL MINING: A CASE STUDY ON CHARACTERIZATION OF EXCAVATED WASTE *

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Abstract

Landfilling has represented the dominant method for municipal solid waste (MSW) disposal during the recent decades. Therefore, the recovery of materials from landfills through landfill mining is proclaimed as an innovative method to address these challenges. The excavation, processing, treatment and recycling of deposited materials is mainly referred to the economic aspects and to the reduction of the re-landfilled fraction of the waste. The main objective of this work is to describe a case study of sampling and characterization of excavated waste of a potential landfill mining site in Peccioli - Pisa (Legoli Landfill). Approximately at 10 m depth, the samples were collected from two layers of waste of different ages (2001 and 2007). Manual sieving and sorting into different waste fractions was performed. All the fractions were characterized in terms of total solids and total volatile solids and Biochemical Methane Potential test. Anaerobic tests were performed to evaluate methane production coming from landfilled waste, in particular referring to the residual biodegradable fraction contained in the municipal waste. Results show that the composition of the two excavated waste analyzed are quite different due to the waste management system used in that years. This factor affects methane production that resulted respectively 115 Nm^3 CH_4/ton e 47 Nm^3 CH_4/ton for 2001 and 2007.

Keywords: biochemical methane potential, landfill mining, waste characterization

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1. Introduction

Recently, concerns about resource and land scarcity have resulted in a renewed interest in historic landfills. In this context, the new concept of "Enhanced LandFill Mining" (ELFM) proposed by Jones et al. (2013) has originated. In particular, ELFM regards landfills not as a final solution but as temporary storage facilities from which the landfilled waste will eventually be valorized by means of recycling and incineration. This will result in improved recycling, increased re-use rates and optimized energy valorization (EU Directive, 1999; Jones et al., 2013; Van Passel et al., 2013).

Essentially, ELFM includes the combined and integrated valorization of waste streams as both materials (Waste-to-Material, WtM) and energy (Waste-to-Energy, WtE), while respecting stringent ecological and social criteria (Jones et al., 2013; Bosmans et al., 2013). One of the main drivers of ELFM is the valorization of waste materials excavated from landfills. Due to the heterogeneous nature of the waste streams in landfills, separation and treatment of the different waste streams are required to enable the generation of valuable recycled materials.

The main objective of this work is to describe a case study of sampling and characterization of excavated waste of a potential landfill mining site in Peccioli - Pisa (Legoli Landfill). At the beginning, all mixed MSW was landfilled in Peccioli; however, during the 2000s source separation (biowaste, paper and cardboard, glass and metals) gradually increased in this region and since the end of that decade, only the residual fraction of MSW has been landfilled (the percentage of separate waste collection in Tuscany passed from 13% in 2000 to 60% in 2015).

The specific aim of this study was to evaluate the feasibility of sampling landfill bodies and to analyze the samples in order to characterize their properties and thus provide information for post-landfill monitoring and operation.

The objectives of the field test were to:

- analytically characterize the composition of excavated waste;
- assess the variation in composition for each specific waste type;
- investigate the impact of storage time on the composition and characteristics of the waste;
- make an assessment of the valorization potential of the materials stored in the landfill.

4. Materials and methods

Approximately at 10 m depth, the samples were collected from two layers of waste of different ages (2001 and 2007). Manual sieving and sorting into different waste fractions was performed. All the fractions are characterized in terms of total solids (TS) and total volatile solids (TVS) and Biochemical Methane Potential (BMP) test. Anaerobic tests were performed to evaluate methane production coming from landfilled waste, in particular referring to the residual biodegradable fraction contained in the municipal waste.

Sorting was based on visual inspection, and thus small particles, which could not be identified visually, were classified as fine fraction. Each category was weighed separately. For analytical purposes the samples were shredded (A11 IKA, M20 IKA) into three size fractions, except bulky materials which were not processed (e.g., metals and stones).

The sorting was done within 7 days, while the analytical sample was stored for 1–2 months at ambient temperatures (below 0 °C) prior to analysis (Sormunen et al., 2008).

The rest was sieved and sorted manually into 7 waste categories (Table 2), namely paper and cardboards (PCB or hereafter referred to as "paper"), plastic (P), wood (W), metal (M), textiles (T), inert (I) and fine fraction (<10 mm).

One of the most important parameters in USEPA estimation model is the methane generation potential (L_0) which can be determined for any degradable waste by Biochemical Methane Potential (BMP) assay, which is a commonly accepted method used for waste characterization and estimation of ultimate methane amount produced under anaerobic conditions (Sel et al., 2016; Mou et al., 2014; Pearse et al., 2018).

Anaerobic biodegradability assays were performed for at least 90 days in order to determine the biogas (gas sum GS, Cossu and Raga, 2008) and the final methane (BMP_f) production of the evaluated substrates. The analyses were conducted using a modified method of Pecorini et al. (2012) following the basic guidelines and advice included in Angelidaki et al. (2009). The test was performed in triplicate for each sample using stainless steel batch reactors (1 L, 2 bar proof pressure). The vessels were incubated in a water bath at 37 °C and tightly closed by a special cap provided with a ball valve to enable the gas sampling (Pecorini et al., 2017). In order to determine the methane production, the methane content of the gas was then measured by using an IR gas analyzer (ECOPROBE 5 – RS Dynamics) and a microGC (INFICON) for residual production. As such, the BMP was calculated as the cumulated methane production (sum of the daily methane productions), divided by the TVS content contained in each batch (Pecorini et al., 2016).

5. Results and discussion

Different compositions were found by the manual sorting (Table 1). From the sampling it has been possible to observe how the fine fraction represents the degraded part of the organic unsorted waste component. The fine fraction is higher in the 2001 sample probably because the 2007 sample is a mechanically shredded dry waste. It can be notice that in 2001 no mechanical pretreatment was realized before the landfilling. Indeed, the percentages of metal is about 3% while in 2007 sample was equal to 0% probably due to a treatment of electromagnetic separation. The presence of the inert fraction is higher in 2007 sample; this fact can be a consequent of more precautionary request of local authority in the daily cover depth.

Table 1. Compositions of excavated waste in studied years

Fraction/composition (%)	***2001***	***2007***
Fine fraction	25	17
Green waste and wood	8	3
Plastic	19	21
Textiles	10	13
Paper	23	18
Inert	12	28
Metal	3	0

In Table 2 BMP_f values are reported based on specific TVS content and tons of sample waste. The biodegradable fractions were analyzed separately and mixed together depending on their percentage composition. It can be observed that the contribution in terms of methane production of single fraction is comparable in both samples. For this reason, the BMP_f of whole samples were mainly affected by the composition.

Results show that the composition of the two excavated waste analyzed are quite different due to the waste management system used in that years. This factor affects methane production that resulted respectively 115 Nm^3 CH_4/ton e 47 Nm^3 CH_4/ton for 2001 and 2007. The mechanically shredded dry waste (2007 sample) gives a methane production which is less than 59% compared to the 2001 sample. While the fine fraction of the 2001 sample is predominantly composed by incompletely biodegradable fraction, in case of 2007 sample it is evident that the fine fraction was composed by daily cover of soil due to low BMP_f.

Table 2. Compositions of excavated waste in studied years

Fractions	***2001***		***2007***	
	BMP $_f$		***BMP $_f$***	
	[NL CH_4/kg TVS_{sub}]	***[Nm^3 CH_4/t]***	***[NL CH_4/kg TVS_{sub}]***	***[Nm^3 CH_4/t]***
Fine fraction	211	110	204	22
Green waste and wood	209	68	105	63
Textiles	151	84	169	117
Paper	237	121	289	140
Mix Sample	221	115	-	47

For the sake of brevity, in Fig. 1 and Fig. 2, the cumulative biogas and methane productions of the 2001 sample are shown, as the 2007 sample curves are similar in shape and kinetics. Fig. 1 illustrates the differences between the results in terms of BMP of all fraction which compose the 2001 sample separately and the global contribution of mixed sample (with the percentual composition report in Table 1).

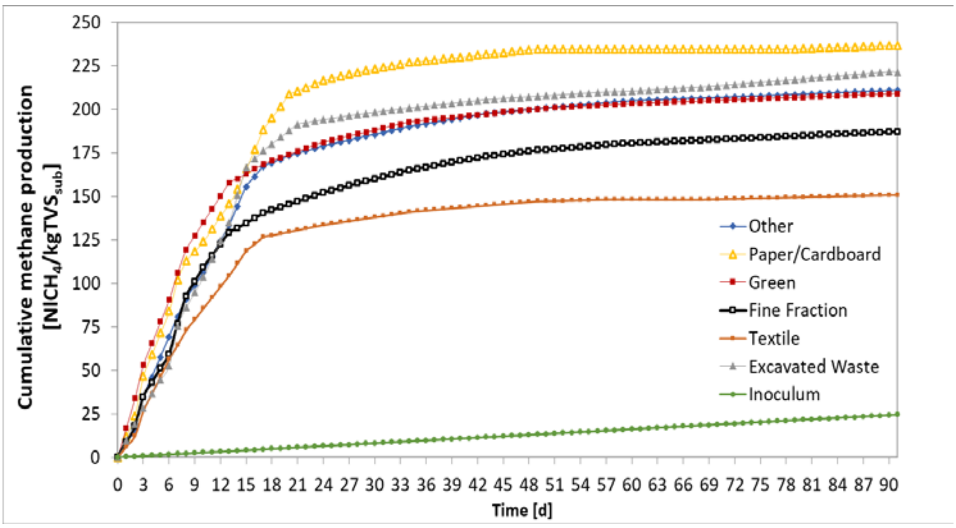

Fig. 1. Comparison of different BMP of waste categories (2001 sample)

Fig. 2 illustrates the differences between the results in terms of GS of all fraction which compose the 2001 sample separately and the global contribution of mixed sample (with the percentual composition report in Table 1).

Figures show as the highest specific production of methane and biogas was detected in paper biodegradability assays. The green waste and wood present a significant production of biogas while the textiles present a low contribution.

The BMP_f and the GS of whole 2001 samples of excavated waste result similar to the weighted average obtained with the single contribution per percentage composition.

As a point of reference, the German landfill ordinance (AbfAblV, 2001) requires that waste in MBT should be stabilised to a level such that its gas production potential as measured by a standardised method (GB21) should be <20 Nl/kg TS over a period of 21 days. On the basis of the present BMP assays (the method has some differences compared to GB21 test) and the assumption that 50% of biogas production would have been carbon dioxide (data not shown), no samples would have attained the maximum permissible value (<20 Nl/kg TS), indicating that waste had not yet been stabilised to this standard in either landfill. The production obtained for the 2001 sample was comparable to a biogas production of an organic fraction of MSW (Pecorini et al., 2012).

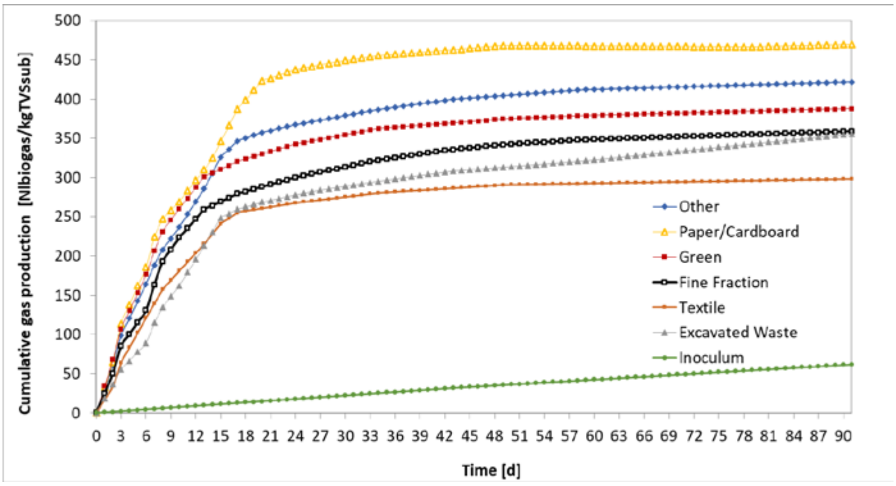

Fig. 2. Comparison of different GS of waste categories (2001 sample)

6. Concluding remarks

The methodology applied to sample and characterize the wastes from an MSW landfill used in this study can be used in other possible landfill mining sites.

On the basis of the biochemical methane potential assays, it resulted that waste had not yet been stabilised in the landfill, which was probably due to low moisture content of excavated waste (data not shown). In conclusion, waste sampling is a feasible way of characterising the landfill body, despite of the high variation observed and the fact that the minimum number and size of samples cannot easily be generalized to other landfills, due to different methods of waste management and different landfilling histories.

Based on the characteristics of the individual fractions separated from the waste, the valorisation options were assessed. During full scale excavation of the landfill, a specific treatment plant will be designed to treat and separate the waste which could result in different characteristics. For industrial waste, a detailed mechanical sorting can be convenient in “an end of waste” recovery approach to improve the calorific value.

Future studies on the stabilization of the excavated fine fraction (with high values of biodegradability) could be carried out in order to ensure eligibility for landfilling (refilling) or material recovery.

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DIGESTATE STABILITY: COMPARISON BETWEEN ONE-STAGE AND TWO-STAGE ANAEROBIC DIGESTION PROCESS *

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Abstract

The Bio2Energy project aims at improving the efficiency of public utility facilities using anaerobic digestion process. This purpose is carried out through the production of bio-fuels and bio-products such as digestate. The use of digestate as agricultural fertilizer and soil conditioner is one of the objectives of the project that position it within the Circular Economy concept.

The aim of this work is to compare the performance of the traditional one-stage anaerobic digestion process with its implementation in a two-stage process in terms of outgoing digestate stability. The stability index is assessed using SOUR test. This respirometric technique allows to determine anaerobic digestion process efficiency and which configuration between one-stage and the two-stage process has better results referring to digestate biostabilization.

The configuration with the dark fermentation used as preliminary treatment of anaerobic digestion process results to be the most efficient in terms of stability index. This configuration allows 79.42% of SOUR reduction for the out coming digestate in particular with a typical co-digestion substrate.

Keywords: dark fermentation, food waste, oxygen uptake, SOUR

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1. Introduction

The EU action plan for Circular Economy (European Commission, 2015) considers that the products at the end of their service life are turned into resources for new purposes. According to the Circular Economy concept, waste production should be minimized through maintaining for as long as possible the value of products, materials and resources (Webster, 2013). In this respect, bio-refineries represent an important possibility for residues valorization due to their aim to convert biomass in bioenergy, biofuels and bio-products. The increase of renewable energy obtained from anaerobic digestion (AD) of biodegradable substrates and the use of its effluent (digestate) as agricultural fertilizer, recognize AD process such as a proven biological-based technology in terms of biofuels and bio-products production (Iacovidou et al., 2012; Pecorini et al.,2016; Tambone et al., 2010). For this reason, the increasing interest in AD of bio-waste drives the scientific community on improving process efficiency, in particular by biohydrogen production in a two-stage AD process through dark fermentation (DF), the acidogenic phase of AD (Cavinato et al., 2012; Chinellato et al., 2013; Micolucci et al., 2014; Pecorini et al., 2017a, b).

The characterization of the digestate coming from AD process could be used for evaluating its properties as fertilizer and soil conditioner and to estimate the economic and environmental sustainability of AD technology according to Circular Economy perspective (Pecorini et al., 2017a). The analysis of waste treatment efficiency in AD plants requires a reliable measure of the biodegradable organic matter content of the outgoing digestate. The evaluation of digestate stability is defined based on readily biodegradable organic matter has decomposed (Lasaridi and Stentiford, 1998). For this purpose, in the past different methods to determine biological stability have been tested (US Compost Council, 1997). Amongst them, the Specific Oxygen Uptake Rate (SOUR) is considered to be a reliable and simple static method for the assessment of stability index (Adani et al., 2001; Scaglia et al., 2007). This method estimates the oxygen consumption in an aqueous suspension containing solid sample and nutrients during a limited period of time and consequently it allows to calculate the oxygen uptake rate. During this respirometric test oxygen dispersion is guaranteed by continuous stirring and intermittent aeration. Respect to respirometric methods performed in the solid state, the liquid state analysis can remove limitations related to structure, moisture content and especially oxygen availability (Lasaridi and Stentiford, 1998). The oxygen transfer in organic matrices is indeed profoundly conditioned by material characteristics in particular by water content (Giraldi and Iannelli, 2009).

In this study, we compare the performance of a single-stage AD classic reactor with that of a two-stage system in terms of digestate stability at reactor exit. For this purpose, two sets of experiments were performed, associated with two scenarios: in the first scenario (Run 1) the digestion process was performed in AD, in a single step; in the second scenario (Run 2) two working reactors were considered connected in series, evaluating the process considering the two steps associated with the AD and DT reactors, respectively. Scenarios were carried out in semi-continuous mode using two different substrates: FW and FW mixed with wastewater sludge (WS) in order to simulate anaerobic co-digestion of sludge and bio-waste. Performances of the two scenarios were compared referring to digestate stability index evaluated through SOUR test.

2. Materials and methods

The sets of experimental test were performed. In the first set (Run1), we have evaluated the digestate resulted from the traditional one-stage AD process. In the second set

(Run2), a two-stage process was analyzed using two reactors connected in series, which also aimed at evaluating the digestates coming from DF and AD reactors.

2.1. Substrate and digestate characterization

For the anaerobic fermentation, FM was used as substrate, manually sorted from the organic fraction of municipal waste, as it has been shown to have high biodegradability, is available and has a well-balanced carbon content and nutrients (Micolucci et al., 2014, Chinellato et al. Cavinato et al., 2012). The municipal waste used was collected in a municipality in Tuscany (Italy) via a waste collection system. Two different substrates were used during the test: the first substrate was represented by FW only (S1); the second one was characterized by FW mixed with WS (S2-COD) to simulate co-digestion process. The sample was treated in a food processor and then sieved (3 mm diameter) to obtain a slurry with a solid content suitable for wet fermentation. The sample was then mixed with water (S1) and WS (S2-COD) (Pecorini et al., 2016). Suspension analyzes aimed at determining total solids (TS) and total volatile solids (TVS). TS and TVS were determined in order to characterize each substrate according to standard methods (APHA, 2006). Ashes and moisture contents were then obtained in accordance with TS and TVS measurements. According to Angelidaki et al. (2006), due to the acidic condition of each substrate, TS determination was performed at 90°C instead of 105°C until constant weight in order to avoid the volatilization of VFA. Moreover, outgoing digesate coming out from each reactor was analyzed in terms of TS and TVS. The characteristics of substrate and digestate are shown in Table 1.

Table 1. Substrates and digestates characterization
(values are expressed by averages and standard deviations)

Sample	*TS (%)*	*TVS (%)*
S1	19.59 ± 0.21	67.38 ± 0.16
Run1-AD (S1)	13.61 ± 0.04	75.63 ± 0.32
Run2-DF (S1)	18.82 ± 0.08	87.50 ± 0.53
Run2-AD (S1)	17.94 ± 0.31	76.06 ± 0.21
S2	27.93 ± 0.13	82.47 ± 1.72
Run1-AD (S2)	15.88 ± 0.07	74.25 ± 0.21
Run2-DF (S2)	23.16 ± 0.17	69.19 ± 0.33
Run2-AD (S2)	16.60 ± 0.05	85.33 ± 6.47

4.2. Experimental set-up: respirometric procedure

The specific oxygen uptake rate (SOUR) was measured for each substrate and digestate obtained during the experimental test. SOUR was determined according to the method described by Lasaridi and Stentiford, 1998 and modified by Adani et al., 2003. A sample of 5 g (wet weight) was mixed with 1 L distilled water in a food blender and then placed in a Duran bottle. Phosphate buffer, ATU (allylthiourea) and nutrient solutions ($CaCl_2$, $FeCl_3$ and $MgSO_4$), made up according to the standard methods BOD test procedures (APHA, 2006), were added to the aqueous suspension of sample. The test was run for about 20 hours with a water bath heated at 30° C. The suspension was continuously stirred by a magnetic stirrer (Velp Scientifica, AREX Digital PRO) and periodically aerated by a fish-tank air pump.

Dissolved Oxygen (DO) concentration was measured in reading cycles by a DO probe (Mettler Toledo, InPro6000, Optical O_2 Sensors) connected to an automatic data acquisition system (LabView, National Instruments Corporation, Italy). The control system provided a repeating sequence of 15 min aeration, followed by 15 min measurement of the DO concentration in the bottle.

For each reading cycle, SOUR ($mgO_2*gTVS^{-1}*h^{-1}$) that represents the maximum oxygen consumption rate was calculated by Eq. (1):

$$SOUR = \frac{|S\max|*V}{m*TS*TVS} \quad (1)$$

where: |Smax| is the maximum absolute slope (oxygen consumption $mgO_2*L^{-1}*h^{-1}$); V is the volume of the aqueous suspension (L); m is the mass of the sample (g, wet weight); TS and TVS are the decimal fraction of dry solids and total volatile solids.

Only one test for each sample was performed for the analysis showed in this study.

2. Results and discussion

During Run1 was evaluated the traditional one-stage AD process efficiency. The two substrates (S1 and S2) were fed to AD reactor and the out coming digestate was analyzed in terms of stability index (Run1_AD (S1) and Run1_AD (S2)).

Reffering to Run2, the stabilization efficiency was estimate considering the two-stage process. Indeed, AD reactor was implemented with the preliminary stage of DF. In this case, the bio-stabilization of both the digestates coming from the two reactors were studied (Run2_DF and AD (S1) and Run2_DF and AD (S2)). These two Runs allowed to compare the efficiency of different configuration of the AD process.

Table 1 shows the stability index results measured through SOUR test referring to the different substrates and the two configuration considered for the experimental tests. Fig.1 and Fig.2 represents the trends of SOUR values during Run1 and Run2 respectively for S1 and S2.

Table 1. Stability index of substrates and digestates.
(results are expressed in terms of SOUR [$mgO_2*gTVS^{-1}*h^{-1}$])

Sample	*SOUR ($mgO_2*gTVS^{-1}*h^{-1}$)*
S1	88
Run1-AD (S1)	29
Run2-DF (S1)	51
Run2-AD (S1)	33
S2	83
Run1-AD (S2)	36
Run2-DF (S2)	42
Run2-AD (S2)	17

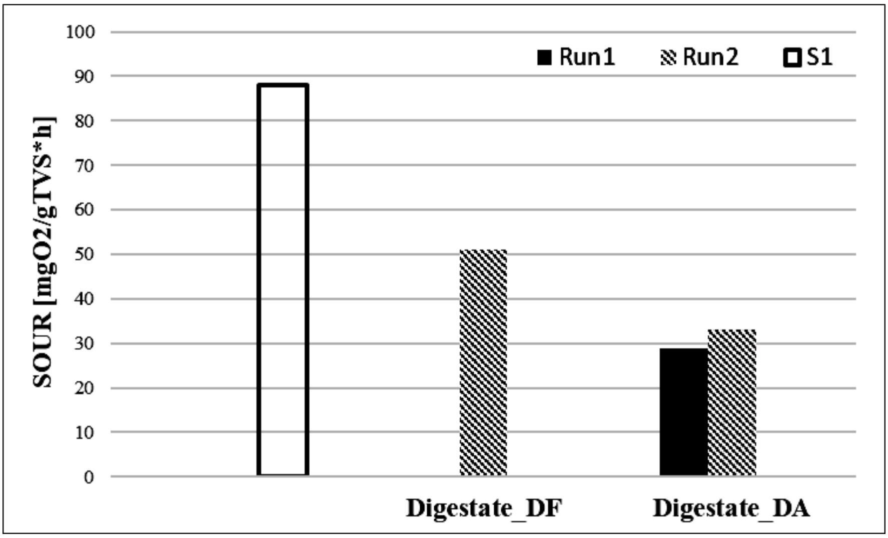

Fig. 1. SOUR trend in Run1 and Run2 for S1

The results obtained for S1 shown that Run1 is more efficient that Run2 in terms of biostabilization of the outcoming digestate. Indeed, the stability index reduction is equal to 67.05% and 62.50% respectively for the traditional AD process and for the two-stage configuration. These results are not confirmed from the test carried out with the co-digestion substrate. In that case, SOUR reduction is evaluated 56.63% for Run1 and 79.52% for Run2.

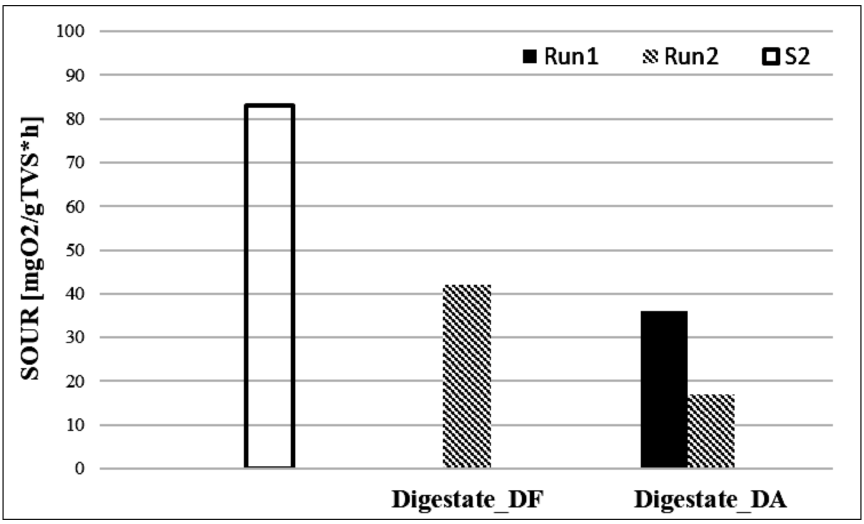

Fig. 2. SOUR trend in Run1 and Run2 for S2

The experimental test performed for the evaluation of digestate stability are not sufficient for identify which process is more efficient in terms of biostabiliazation of the outcoming bio-products. The number of SOUR tests could be improved for each configuration and substrate. Moreover, respirometric procedure could be implemented and optimized with the aim to guarantee the repeatability and reproducibility of the test.

6. Concluding remarks

The analysis conducted in this work shown that the best performance in terms of stability index are carried out with S2. This substrate would simulate a co-digestion process, in fact it is obtained mixing FW and WS. The configutration with DF (Run2), as preliminarly treatment of AD, guarantees 79.42% of SOUR reduction for the outcoming digestate. Indeed, the digestate obtained from two-stage AD process results to be the most stable referring to SOUR index (SOUR equal to 17 $mgO_2*gTVS^{-1}*h^{-1}$). Based on these results, the configuration concerning co-digestion with the two-stage AD process results the most efficient.

Future studies on stability index determination of digestate could be carried out in order to confirm the results obtained from this work and for a better evaluation of the efficiency of one-stage and two-stage AD process in terms of biostabilization.

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