ACTIONS FOR A SUSTAINABLE WORLD

FROM THEORY TO PRACTICE

BOOK OF PAPERS

THE 24th INTERNATIONAL SUSTAINABLE DEVELOPMENT RESEARCH SOCIETY CONFERENCE

MESSINA · ITALY JUNE 13/15 2018

The 24th International Sustainable Development Research Society Conference (ISDRS 2018)

ACTIONS FOR A SUSTAINABLE WORLD: FROM THEORY TO PRACTICE

13-15 June 2018, Messina (Italy)

BOOK OF PAPERS

Edited by: The Organizing Committee of the ISDRS 2018 Conference

ISBN 978-88-943228-6-6

Department of Economics
Piazza Pugliatti, 1 – Messina (Italy)

Table of Contents

UNIVERSITY OF MESSINA
Department of Economics
P.zza Pugliatti, 1 · 98122 Messina (Italy) +39 090.6767113
www.unime.it/it/dipartimenti/economia

International Sustainable Development Research Society
www.isdrs.org

Designing a circular economy model from the olive mill waste

Annalisa Romani[1], Annarita Paiano[2], Manuela Ciani Scarnicci[3], Arianna Scardigli[4], Giovanni Lagioia[5]

[1] *PHYTOLAB (Pharmaceutical, Cosmetic, Food Supplement, Technology and Analysis)-DiSIA, University of Florence, Florence, Italy, annalisa.romani@unifi.it*

[2] *Department of Economics, Management and Business Law, University of Bari Aldo Moro, Bari, Italy, annarita.paiano@uniba.it*

[3] *eCampus University, Novedrate, Como, Italy, manuela.cianiscarnicci@uniecampus.it*

[4] *PHYTOLAB (Pharmaceutical, Cosmetic, Food Supplement, Technology and Analysis)-DiSIA, University of Florence, Florence. Italy, arianna.scardigli@unifi.it*

[5] *Department of Economics, Management and Business Law, University of Bari Aldo Moro, Bari, Italy, giovanni.lagioia@uniba.it*

Abstract

A sustainable system is characterized, inter alia, by a much reduced use of inputs and by the reuse and recycling of material outputs (waste is considered a resource and resources have to be maximised within the system). Hence, a circular economy model that moves towards the closing loop also suggests a drastic reduction or elimination of waste and dissipative loss. The present paper focuses on an useful concept of waste and by-products within the agro industrial system, based on the perspective of circular economy.

This approach can be achieved through efficient small and industrial scale bioenergy plants, biorefineries and environmentally friendly processes for the production of biomolecules to be employed as active principles in many sectors. In particular, the case study of this paper concerns the exploitation of an olive-oil by-product (wet-pomace) as a new source of energy and polyphenol compounds on an industrial scale.

The paper aims to design a technical and economic model of a platform which produces bioactive compounds from the Olea by products, in particular from wet pomace, an olive-oil mill waste, which usually represent a disposal problem. By the application of the MFA methodology (Material Flow Analysis) to the production process, the authors provide a case study about the implementation of this kind of multifunctional platform in a region in southern Italy, where the cultivation of *Olea europaea L*. and the production of virgin olive oil are widespread. The regional level has been chosen, because the local approach allows for avoiding and/or reducing the economic and environmental cost of the waste transport.

The recovery of chemicals and the production of energy should be a continuous process of interaction between high technology and environmental and economic sustainability, making this kind of platform highly innovative and consistent with the principles of the circular economy, as well as with the development of a new business. The results have highlighted that this platform can produce up to 6000 kg of enriched polyphenol fractions, generating an approximate income of over 155,000 Euros; moreover, each residue of the process (water, olive stones, destoned pulp) comes into a new use in the same and/or external processes according to the circular economy. The conclusion underlines the main positive features of this sustainable model, in particular the eco-innovation of the process and the economic and environmental advantages consisting in reducing waste, water and energy consumption.

Keywords: Circular Economy; Biorefinery; Agroindustrial Residues; Polyphenols; Olive oil mill waste

1. Introduction

A sustainable system is characterized, inter alia, by a much reduced use of inputs (both renewable and non-renewable) and by the reuse and recycling of material outputs (waste is considered a resource and resources have to be maximised within the system). Hence, this circular economy model that moves towards the closing loop also suggests a drastic reduction or elimination of waste and dissipative loss (Ayres, 1996; Ayres and Simonis, 1994; Stahel, 2016).

In this perspective, a new concept of waste and by-products within the agroindustrial system could be appropriately developed, based on the agrifood chain and a lifestyle based on a "zero waste" model.

This approach can be achieved through efficient small and industrial scale biorefineries (Garcia-Nunez et al., 2016), bioenergy plants and environmentally friendly processes for the production of biomolecules (polyphenols) to be employed as active principles in agronomy, cosmetics, food, feed and pharmaceutical applications (Brunelleschi et al., 2007). Polyphenols are compounds considered to be excellent antioxidants (Owen et al., 2000; EMA, 2017) and cancer prevention biocomponents (Owen et al., 2004; Pampaloni et al., 2014); furthermore they have antimicrobial properties (Medina et al., 2013), hence polyphenols are used in dietary, pharmaceutical and cosmetic products. Among the polyphenols, hydroxytyrosol has useful antioxidant properties and may become important in the search for ‘natural’ replacements for ‘synthetic’ antioxidant food additives; in particular it could be employed to stabilize or enhance products, such as bakery products and meat (Tafesh et al., 2011; Romani et al., 2017).

Globally, the polyphenols market has grown rapidly over recent years and it is expected to reach 900 million Euros by 2020 (Hexa Research, 2015; Grand View Research, 2016). The three main geographical areas of consumption are Asia-Pacific, North America and Europe. As a consequence, an increasing production of these biomolecules can be forthcoming.

In this direction the present paper aims to elaborate a technical and economic model of a platform which produces bioactive compounds from the Olea by products, in particular from wet pomace, an olive-oil mill waste, which usually represent a disposal problem. A sustainable extractive technology followed by membrane separation methods has been applied to the olive oil by-product in order to obtain different commercial extracts, which are useful for different applications.

It is noteworthy because this plant is on industrial scale, instead of on laboratory or pilot scale trials (Garcia-Castello et al., 2010; Cassano et al., 2013) that are the most widespread plant types of the recovery of bioactive molecules from different plant tissues in Europe.

The industrial plant just aims at the development of a coherent industrial-scale production process, taking into account the quantities of raw material available on the local territory. Each membrane is modular and thus easily scalable for any size of production (Romani et al, 2017). It has to be underlined that it promotes a new agribusiness model, where regional actors (economic, social, environmental) use waste as a resource (Tello et al., 2016; Cardoen et al., 2015). Moreover, the planning of sustainable and profitable districts, based on the industrial symbiosis, is reported in the Action Plan on the Circular Economy developed by the European Commission in 2015 (European Commission, 2015) and in its revision of 14 March 2017.

In the light of these considerations, a case study of estimating the feasibility of this multifunctional platform in Apulia, a region in southern Italy, is provided. So, in order to evaluate the availability of the wet pomace supply, its potential in the regional territory was assessed.

After the introduction, which summarises the aim and structure of the paper, the materials and methods section identifies material, energy and economics data of the production process described. The methodology of MFA (Material Flow Analysis) was applied to identify and quantify the material and energy flows of the production process. Results have highlighted that this platform can produce up to 6000 kg of enriched polyphenol fractions, and each residue of the process (water, olive stones, destoned pulp) comes into a new use in the same and/or external processes according to the circular economy concept. Finally an economic evaluation of the process was made. The feasibility of this plant in Apulia follows. Discussion shows the potentialities and the main drawbacks of this industrial platform; lastly, conclusion underlined the positive features of this sustainable model, in particular the eco-innovation of the process and the economic and environmental advantages consisting in reducing waste, water and energy consumption, demonstrating how the closing loop approach is also highly profitable.

2. Material and methods

The technical, economic and environmental evaluation of the platform requires a material and energy flow analysis of the production cycle. The methodology used is the MFA, which allows to evaluate the energy and material flows in an well identified system, that is the production process of the polyphenols from Olea, accounting the inputs (material and energy resources consumption) and the outputs (waste products) of the process (Brunner and Rechberger, 2004).

Within this context, initially, a brief description of the production process was made and the input and output data identified (sub-section 2.2) and quantified (sub-section 3.1). Finally the evaluation of the availability of the wet pomace supply and its potential in the regional territory was assessed in order to adequately plan the scale of platform, also according to the regional district level identified.

2.1 Production process

Data and methods concern the extraction of polyphenols from olive oil by-products based on new sustainable technologies, with a water extraction and membrane separation system. Previously, scientific reports considered the same procedure for olive-oil waste-water polyphenol purification at a laboratory scale (Garcia-Castello et al., 2010) (Cassano et al., 2013). This innovative industrial process instead has been used at an industrial level by using physical technologies (PCT/IT/2009/09425529 "Process for producing concentrated and refined active substances from tissues and by-products of *Olea europaea* with membrane technologies") defined as BAT (Best Available Technology) and recognized by the EPA (Environmental Protection Agency) (Pizzichini et al., 2011; Romani et al., 2015; Romani et al., 2016a; Romani et al., 2016b).

The process is based on membrane technologies applied to aqueous extracts obtained in a pneumatic extractor and then purified by filtration. In particular, the process proposed comprises the following operations in sequence:

a) the provision of a starting material consisting of wet pomace produced by two-phase oil extraction processes;

b) electrical destoning of the pomace;

c) acidifying the destoned pulps to a pH between 2.5 and 4 in order to favour the extraction of the bio-components and stabilize the chemical environmental conditions;

d) extraction at room temperature, with an aqueous solvent, of active components from the matrix, using an electrical pneumatic extractor;

e) treating of the liquid phase resulting from the previous operation with an integrated system of several filtration stages, in particular microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO).

The membrane technology, characterised by different molecular weights with cut-off and filtration degrees is used to obtain concentrates enriched in polyphenol active principles.

f) the last step is concentration under vacuum using a scraper evaporator series (C&G Depurazione Industriale company) provided with a heat pump (fuelled by olive-stones) in order to increase the concentration of the bioactive components of the materials (coming from MF or UF and RO) of commercial interest, and to obtain purified active principles belonging to different phenolic subclasses.

The chromatographic, spectrophotometric and spectrometric (HPLC/DAD/ESI-MS) analyses were performed for each extract obtained from the industrial plant just to identify and quantify polyphenolic classes, highlighting a content of over 90% of hydroxytyrosol and derivates among them.

The products thus obtained can be marketed either as concentrated solutions and powders with a standardized content in polyphenols. In particular the liquid products are dried or spray-dried to obtain stable powders rich in antioxidants of biomedical interest.

As a result, three commercial products are obtained through this process: a liquid fraction, a concentrate paste, and a powder (Fig.1), each with different hydroxytyrosol concentrations.

***Fig. 1**. Powder from olive pulp.*

2.2 Material and energy data

2.2.1 Material inputs and main outputs

In this paper the attention was focussed on the process to be carried out on the platform: from wet pomace to concentrate-enriched products. The first phase of the olive-oil production, from olives to oil and wet pomace has been only considered in the material data (as figure 2 shows) and it emerges that from the processed olives, by the use of two-phases system, the wet-pomace can be extracted in the rate of 80% (Roig et al., 2006). The remaining share represents the olive oil (20%). As regards the process, from wet pomace to the main output, the yield is very low, equal to approximately 4.4%. The by-products coming from the process include: *demineralised water*, obtained from RO, phase (e) and by condensation in the concentration phase (f); *olive stones* from the destoning of the wet pomace (phase b); *destoned pulp* from the phase (d). It must be noted that they are suitable for being used again.

2.2.2 Energy inputs and outputs

The energy consumption of the production cycle is concentrated in the main three phases of the process and it can be allocated as follows: 20.8% from the olive stones separation phase (b), 31.2% from the extraction phase (d) and 48% from the concentration phase (f). It must be noted that the last phase, which is the highest, is also the cheapest in both environmental and economic terms, due to the use of olive stones as the energy input. The Lower Heating Value (LHV) of olive stones is equal to about 20.5 MJ/kg (ECN, 2016). As regards the destoned pulp, its LHV is about 16 MJ/kg, however its energy use has not been considered in this paper.

2.3 Economic data

The capital cost of this platform is around 730,000 Euros, of which over 73% concerns the extraction plant. To this cost it could be added the one of biomass gasification plant in the range between 150,000 and 350,000 Euros, according to it is only heating plant or heat and power microgeneration plant.

As regards the production costs of the main outputs (including process, maintenance, personnel and distribution costs) they differ according to the form and content of hydroxytyrosol as follows: liquid fraction (concentration 3%) 11 €/kg, concentrate paste (concentration 5%) 14 €/kg and powder (concentration 10%) 16 €/kg. To the production costs would be added the ones of the wet-pomace supply which are variable and linked to the regional market (i.e. in Apulia they are 0.015€/kg, which is the lowest in Italy). Since the olive-oil mills usually should pay to dispose of this residue, however they could prefer to deliver it free; so the cost of wet-pomace supply has not been included in our hypothesis.

The market prices of the enriched products strictly depend on their hydroxytyrosol content, rising as its concentration increases. They are as follows: liquid fraction (concentration 3%) 30€/kg, concentrate paste (concentration 5%) 50€/kg and powder (concentration 10%) 100€/kg.

Finally, the market prices of the by-products, olive stones and destoned pulp, are about 0.18 €/kg and 0.12 €/kg respectively (Unaprol, 2018).

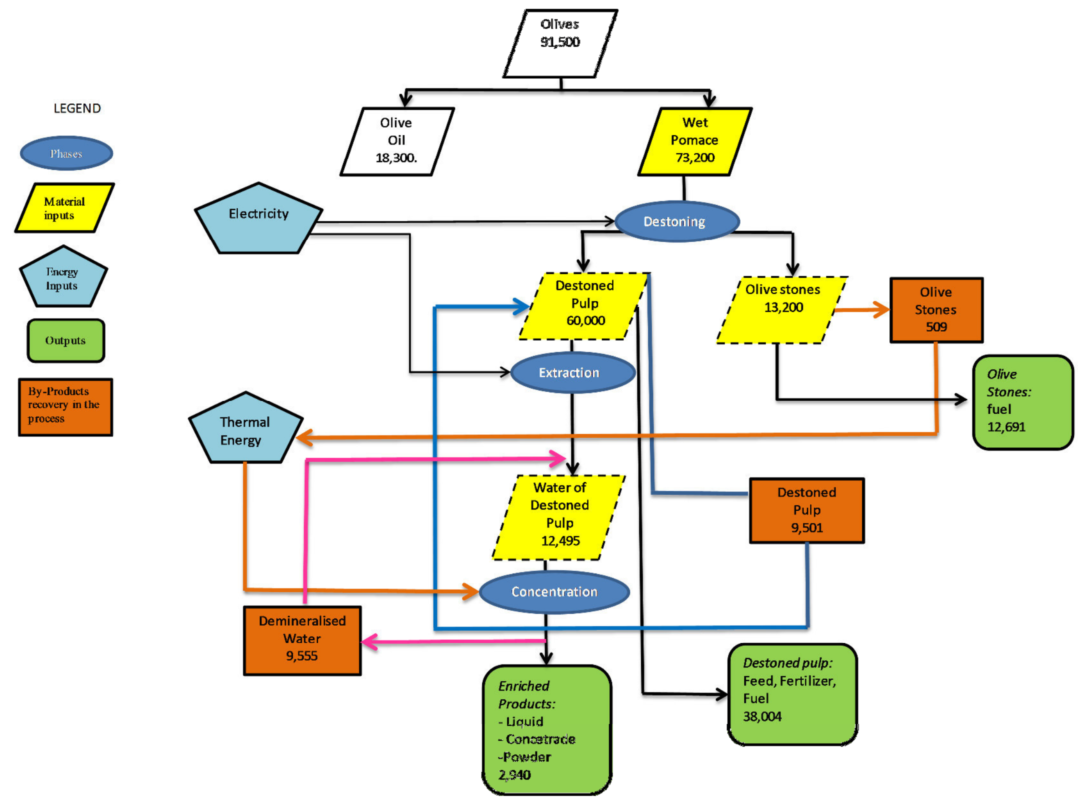

Fig. 2. *Flowchart of the process (kg).*

2.4 Case study. Input and output parameters for the estimate of the olive-oil mill waste in Apulia

In Apulia the cultivation of *Olea europaea L*. and the production of virgin olive oil are widespread: in particular, this region is the first producer of olive oil in Italy and consequently the first producer of the wet pomace, which has to be considered likewise waste of the olive oil production and main input for the enriched fractions production. Hence, a brief assessment of residual biomass potential from an olive-oil mill (in particular, wet pomace from two-phase extraction system[1]) in the Apulia region allows, as already mentioned, for gaining knowledge about the availability of the regional supply.

In order to quantify an average amount of olive-oil mill waste available in Apulia per year, it is necessary to first assess the residues per crop (Olea) and region. A methodology based on a linear correlation among the main outputs per year (P), calculated according to statistical data, and the reproducibility factor of agro-industrial residues (R/P), was used as follows:

eq. a) agro-industrial residues R per year (t/y) = P(R/P)(1-WR/100).

[1] The need to improve the oil quality while reducing the environmental impact of the waste has generated further studies on the possibility of modifying the widespread "three-phase" centrifugal extraction system so as to reduce the addition of process water. For the above reason the so-called "two-phase" extraction systems have been introduced, where no water is added to the decanter and the by-product obtained consists of one phase only, made up of a mixture of husks and waste-waters. This improvement, however, has no effect on the reduction of the environmental impact and fails to provide a total solution to the problem, consequently further research and experimental applications have been conducted aiming towards innovative solutions for the purification and disposal of these residues, such as membrane separation processes (e.g. ultrafiltration and reverse osmosis).

It must be pointed out that: P, the olive production, greatly affected by several factors, above all weather conditions and some diseases of the olive trees[2], is an average value of five years (2011–2015) (ISTAT, 2016); R/P is the ratio between the residue and the production of the main output (wet pomace/olives), it is especially relevant and very variable depending on the type of crop, harvesting technique and olive oil production, and as well as on other factors (Paiano et al, 2016); WR represents the moisture content of the residue. Hence, the following parameters are identified: (P) 990,242 tons, (R/P) 0.84, (WR) 60 (Riva, Carrafù, 2013; Motola et al., 2009).

However, it should be highlighted that the share of two-phase extraction processes, used in Apulia and here considered, is equal to about 50% of the total (Regione Puglia, 2012), so this rate has been considered in our estimate. As a consequence, P became 495,121 tons and will be considered as the parameter in the equation a), the results of which are illustrated in Sub-section 3.3.

3. Results and discussion

3.1 Material and energy results

The material balance of the process, illustrated in Table 1, is equal to a total of 73,200 kg as input and output, of which 2,940 kg are the main outputs. It must be stressed that all residues found another use, according to the circular economy, as illustrated in the flowchart in Figure 2. In particular, 9,555 kg of demineralised water, obtained by condensation from the evaporator, is reused in the subsequent cycle, preferably for the preparation of the extraction bath; 13,200 kg of olive stones from the destoning are separated and used as energy input of the process for only about 8% and the remaining main part are sold as a fuel outside; 47,505 kg of destoned pulp was filtered: in our hypothesis, a part (20%) is reused in the process to be further refined or added to the extraction water, and the rest (80%) can be allocated and sold outside as animal feed or input in the production of fertilizers or energy.

As regards the main output (2,940 kg) it is divided among the following products: 80% (2,352 kg) liquid fraction (concentration 3%), 16.5% (485 kg) concentrate past (concentration 5%) and 3.5% (103 kg) powder (concentration 10%). They are commercially available and generally suitable to be sold to other stakeholders.

The full scale plant could increase the production of these outputs twofold in a few years: hence, almost 6,000 kg of enriched polyphenol fractions will be produced yearly.

Table 1. *Material balance of the production cycle of enriched polyphenol products.*

Input	kg	Outputs	kg
Wet pomace	73,200	Enriched product	2,940
		Residues:	
		-Olive stones	13,200
		-Destoned pulp	47,505
		-Demineralised water	9,555
Total	73,200	Total	73,200

The energy consumption of the three main production phases is quantified as follows: the concentration phase only uses heat produced by the waste biomass of the process, olive stones, for about 8,876 MJ; the destoning phase and the extraction one use electricity respectively for 1,066 kWh (equal to 3836 MJ) and 1,600 kWh (equal to 5,761 MJ). Bearing in mind the conversion efficiency of 40% for electricity and 85% for thermal energy production, it is possible to calculate the total primary energy consumption for the process considered, which is almost 35,000 MJ. It must be pointed out that the use of

[2] Over the last four years a particular disease caused by the bacterium *Xylella fastidiosa* has infected a great number olive trees of Apulia, in particular of the provinces of Brindisi and Lecce, often causing their death.

by-products enhances the energy efficiency of this process, as well as the economics: the total primary energy consumption indeed can be reduced of about 30%, if the energy consumption of the concentration phase, dealt with the use of olive stones, has been taken away.

3.2 Economic results

An economic estimate of the described production has been made, as you can see from Table 2. To the revenues illustrated have to be added ones coming from the share of destoned pulp sold in the agricultural, zootechnical and energy sectors (4,560 €) and from the olive stones sold as fuel in several sectors (2,284 €). They have been calculated according to the material data shown in Figure 2 and based on the market prices of these by-products indicated in sub-section 2.3.

So the income amount to over 77,600 Euros and it can be increased to 155,200 Euros, if the production doubles, based on the potential full capacity of the plant which could be achieved in a few years, as already mentioned.

It has to be underlined that a framework of financial and economic indices of the platform will be elaborated in a further analysis.

Table 2. *Economic estimate of the production process*

Enriched products		Production costs		Revenues	
	kg	€/kg	Total €	€/kg	Total €
liquid 3%	2,352	11	25,872	30	70,560
concentrate paste 5%	485	14	6,790	50	24,250
powder 10%	103	16	1,648	100	10,300
Total	2,940		*34,310*		*105,110*

Furthermore, the savings of thermal energy and water, here not quantified, allow for further enhancement, in both environmental and economic terms.

3.3 Case study. Potential production of the enriched products in Apulia

On the basis of the parameters and by using the conversion equation a), illustrated in sub-section 2.4, it is possible to calculate the olive oil pomace per year and region, in particular in Apulia, which is about 420,850 tons as wet substance (w.s.) and almost 168,342 tons as dry substance (d.s.). These data concern the two-phase extraction method, but as aforementioned, there are other methods that can affect the quantity and quality of pomace produced.

Taking into account the quantitative data of the process and the assessment of the wet-pomace supply in the Apulia region, we can calculate how many enriched products (almost 17,000 t per year) could be obtained if, in a simplified hypothesis, all the wet pomace coming from two phases extraction system, was to be used for these kinds of platforms. The yearly income could achieve roughly 450,000 euros.

3.5 Discussion

It must be noted how the continuous interaction between high technology and environmental and economic sustainability makes this kind of multifunctional platform highly innovative and consistent with the principles of the circular economy. Each residue of the process (water, olive stones, destoned pulp) would come into new use in the same and/or external processes, according to the "zero waste" model. As already mentioned, after the extraction of bioactive fractions, residues of olive oil mill can be used as animal feed, compost or other agricultural or agro industrial products and/or be exploited as energy sources (as Figure 2 shows).

Bearing in mind that the olive cultivation and olive oil production are among the main economic activities of the region Apulia and that this platform is a sustainable example of a closed loop, it would be appropriate for these kinds of activities to be implemented in this territory in order to address numerous issues: reducing waste disposal, resource consumption, and revitalising the rural areas with the start-up of new firms. Moreover, innovative production chains could focus not only on agroindustrial waste, but also on the Olea agricultural residues, according to the assessment of the residues in Apulia which have been estimated in the following figures: agricultural residues (leafy and bunch prunings, wood from uprooting) are approximately 695,000 t/y (dry substance, d.s.), or 1,200,000 t/y as wet substance (Ispra, 2010; Paiano and Lagioia, 2016). They are quantitatively remarkable, equal to over 37% of the Italian total, as well as the agro-industrial residues (e.g. the wet-pomace which is the feedstock used in this paper). These residues could be suitable for use in energy production, cogeneration and/or anaerobic digestion, depending on their characteristics, but mainly their lower heating value and moisture content. In particular, lignocellulosic residues from Olea, which have a high LHV of 18 GJ/t and an average energy potential for Apulia of 12,500 TJ/year, are suitable for the thermochemical process for heat and/or electricity generation, and, according to a more innovative production cycle, they could also be used to produce second-generation biofuels (Paiano et al., 2011).

Another implementation could entail the gasification plant for producing syngas from the destoned pulp, and electricity through cogeneration (IGCC), in order to achieve the closing loop, supplying the electricity for the destoning and extraction phases, besides to sell the surplus of this energy. This further implementation, whose cost is mentioned in the paper, will be analysed in the next research.

As a result, the start-up of sustainable and innovative activities could find the best dimension for growth in the regional or/ provincial districts according to the circular economy model (Hubeau et al., 2017). Furthermore, the local approach allows for avoiding and/or reducing the economic and environmental cost of waste transport.

It must be highlighted how the use of the wet pomace as the input in a new production chain allow for addressing several problems, due to the chemical and physical characteristics of this residue, which make its disposal very difficult and extremely environmentally dangerous. It has a high moisture content (at least 60%), and that is why the mills for the extraction of residual olive oil from pomace will not use it, preferring the pomace from other extraction methods with a much lower moisture content. For the same reason, the thermal plants which use the exhausted pomace as fuel would dry it before the energy production, with a rise in costs. Moreover, the high moisture, oil and polyphenol content of the wet-pomace make its scattering in the fields difficult. In particular, the polyphenols increase the antimicrobial activity and reduce the biodegradability of this residue. Therefore, the extraction of polyphenols, as here illustrated, also allows to reduce phytotoxicity of the wet-pomace so as to be used in the fields.

In addition, the process repeatability must be taken into consideration, compatibly with the fact that the composition of a vegetable matrix in any case maintains a natural variability over time. Indeed, several matrices can be used in the same platform to produce the purified fractions having different active principle compositions with a high biological value. Such matrices comprise the olive tree pruning waste (e.g. leaves, twigs), solid or semisolid olive oil mill residues (e.g. wet pomace as in the paper) and other residual biomasses, e.g. from Cynara, the cultivation of which is widespread in the same region. This could be useful in overcoming the seasonality of some crops and/or agro-industrial products[3], allowing for full operability of the platform throughout the year, also in order to increase the economic result.

Further added value is given by the ecological and economical sustainability of the process that uses agro industrial waste as a raw material, and only water as a solvent. This is especially important if we consider that most of the industrial processes for obtaining purified extracts currently involve the use of solvents and chemicals.

This has opened up interesting agronomic, environmental and economic opportunities due to the fact that Italy produces approximately three million tons of waste from the-olive-oil industry per year. It is noteworthy that the valorisation of these waste products can create a parallel market to that of the olive oil one. In this sense, virtuous olive oil mills which invest in innovation could transform waste into a very profitable resource. Nonetheless, one of the main issues, that constitute a

[3] For example wet pomace is available from October to February, Cynara from February to June and others in different period.

drawback for developing the membrane technologies to large-scale applications, is just mainly due to the olive oil industry, which is often composed of little and dispersed factories, that cannot bear the high costs of extract production and the maintenance of industrial plants, even considering the savings, coming from the reduction of disposal costs of olive mill waste and other agroindustrial by-products.

4. Conclusion

The use of residual biomass as a source of bioactive compounds can also be considered a preliminary stage of a closed cycle for the production of energy from waste and exhausted raw materials, according to the circular economy concept. Indeed, the results suggest the possibility of implementing a multifunctional platform, from which the agro industrial chain and a lifestyle targeting a "zero waste" model could be suitably developed. In particular, the extraction of the new biomolecules from the olive-oil milling can be considered an integrated step of the circular economy process applied to olive processing.

In addition, the use of water alone as a solvent makes the extraction and purification method described ecologically and economically sustainable, since the industrial processes are usually based on methods of purification via extraction with organic solvents. Moreover, the use of a by-product for obtaining differentiated and refined marketable fractions overcomes many of the ecological and economic problems associated with the disposal of production waste.

Eco-innovation of the process, economic advantages with a reduction of waste, and water and energy consumption are the main positive features of this circular economy model. Market analyses have highlighted how polyphenols will be much more in demand, especially these types of products extracted by means of mild and sustainable processing from traceable natural sources.

The optimisation of the productive process that uses sustainable technologies to obtain standardized and stabilized fractions with higher concentrations of biologically active molecules, will allow for gaining new and increasing market shares, since these biomolecules are suitable for innovative uses in many sectors, such as agronomy, textile/dyeing, cosmetics, foods and phytotherapy. In addition they all demand increasingly higher value added products, which also are environmentally friendly. In this sense it should be stressed that bioenergy, especially from residues, is expected to play a significant role in the medium term according to the Impact Assessment of the 2030 Climate and Energy Framework. In addition, it could provide a feasible option for economic growth and higher land productivity, particularly in rural areas, which have been left behind. Hence, planning the implementation of agro-energy districts in the Italian territory, in accordance with the size of the provincial or regional areas, as designed in this paper, could enhance the collection and transport phases, reducing the biomass costs and revitalising the rural areas as well. Many similar platforms could also be planned and located in the regional territory in order to address the issue of the disposal of these by-products as one of the most important agroindustrial productions, as well as developing many small and medium-sized integrated systems to convert agricultural activities into agro-energy districts based on a circular economy model.

In this sense, it should be highlighted that systemic change and innovation have to be developed in technology, organisations, society, economic and financial methods, as well as policies involving all levels of governance (business, consumer organisations, non-governmental organisations, trade unions, research institutions and other stakeholders). The circular economy may thus create new markets responding to the shift in consumption patterns away from traditional ownership towards using, reusing and sharing products, and contributing to more and better employment. These changing social attitudes directed towards sustainable waste management are among the main reasons underlying the implementation of policies based on the circular economy model.

Acknowledgements

This paper is the result of the authors’ commitment. Particularly: sections 2, 2.1 and 4 are ascribed to Romani; sections 1, 2.2, 3 and the References collection to A. Paiano; section 1 to Ciani Scarnicci; section 2.1 to Scardigli; section 4 to Lagioia.

The Authors are grateful to VITA SAFER S.R.L. (Montecatini Terme, PT, Italy) for providing plant and commercial fractions. The present study was funded with the EU Project LIFE13 ENV/IT/000461 - EnVironmEntally fRiendly biomolecules from aGRicultural wastEs as substitutes of pesticides for plant disEases control (EVERGREEN), and the Project Eccellenze TOSCANE tracciate NATura BENessere (Tuscany NATURBEN) - PRAF 2012-2015 Misura 1.2.e by Regione Toscana.

References

Ayres, R.U., 1996. Creating industrial ecosystems: a viable management strategy. Int. J. Technol. Manag., 12, 608–624.

Ayres, R.U., Simonis, U. E. (Eds.). 1994. Industrial Metabolism: Restructuring for Sustainable Development. United Nations University Press, Tokyo.

Brunelleschi, S., Bardelli, C., Amoruso, A., Gunella, G., Ieri, F., Romani, A., Malorni, W., Franconi, F., 2007. Minor polar compounds extra-virgin olive oil extract (MPC-OOE) inhibits NF-kB translocation in human monocyte/macrophages. Pharmacol. Res., 56, 542-549.

Brunner, P.H. Rechberger, H. 2004. Practical handbook of material flow analysis. Lewis Publishers, CRC Press LLC, Boca Raton, USA.

Cardoen, D., Joshi, P., Diels, L., Sarma, P., M., Pant, D., 2015. Agriculture biomass in India: Part 1. Estimation and characterization. Resour. Conserv. Recycl., 102, 39-48.

Cassano, A., Conidi, C., Giorno, L., Drioli, E., 2013. Fractionation of olive mill wastewaters by membrane separation techniques. J. Haz. Mat., 248-249, 185-193.

ECN (Energy research Centre of the Netherlands), 2016. Database for biomass and waste. https://www.ecn.nl/phyllis2/ (accessed 03.05.2016).

EMA (European Medicines Agency), 2017. Assessment report on Olea europaea L., folium. http://www.ema.europa.eu/docs/en_GB/document_library/Herbal_-_HMPC_assessment_report/2018/01/WC500240952.pdf (accessed 01.03.2018).

European Commission, 2015. Communication From the Commission to the European Parliament. The Council, the European Economic and Social Committee and the Committee of the Regions. Closing the Loop - An EU Action Plan for the Circular Economy COM (2015) 614 final. https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF (accessed 15.03.2018).

Garcia-Castello, E., Cassano, A., Criscuoli, A., Conidi, C., Drioli, E., 2010. Recovery and concentration of polyphenols from olive mill wastewaters by integrated membrane system. Water Res., 44, 3883-3892.

Garcia-Nunez, J.A., Ramirez-Contreras, N.E., Rodriguez, D.T., Silva-Lora, E., Frear, C.S., Stockle, C., Garcia-Perez, M., 2016. Evolution of palm oil mills into bio-refineries: Literature review on current and potential uses of residual biomass and effluents. Resour. Conserv. Recycl., 110, 98-114.

Grand View Research, 2016. Polyphenols Market Projected to Reach $1.33 Billion By 2024. https://www.grandviewresearch.com/press-release/global-polyphenols-market (accessed 01.08.2016).

Hexa Research, 2015. Polyphenols Market Analysis, Market Size, Application Analysis, Regional Outlook, Competitive Strategies and Forecasts, 2012 To 2020. https://www.hexaresearch.com/research-report/polyphenols-industry/ (accessed 08.01.2015).

Hubeau, M., Marchand, F., Coteur, I., Mondelaers, K., Debruyne, L., Van Huylenbroeck, G., 2017. A new agri-food systems sustainability approach to identify shared transformation pathways towards sustainability. Ecol. Econ., 131, 52–63.

Ispra (Institute for Environmental Protection and Research), 2010. Studio sull'utilizzo di biomasse combustibili e biomasse rifiuto per la produzione di energia. ISPRA, Rome.

ISTAT (Italian Institute of Statistics), 2011-2015. Dati annuali sulle coltivazioni. http://agri.istat.it/jsp/Introduzione.jsp?id=15A|18A|18C (accessed 06.05.2016).

Medina E., de Castro A., Romero C., Ramírez E., Brenes M., 2013. Effect of antimicrobial compounds from olive products on microorganisms related to health, food and agriculture. Microbial pathogens and strategies for combating them: science, technology and education, Méndez-Vilas A. Ed., Spain, pp. 1087-1094.

Motola, V., Colonna, N., Alfano, V., Gaeta, M., Sasso, S., De Luca, V., De Angelis, C., Soda, A., Braccio, G., 2009. Censimento potenziale energetico biomasse, metodo indagine, atlante Biomasse su WEB-GIS. RSE/2009/167. ENEA (National Agency for New Technologies, Energy and Environment), Rome. http://old.enea.it/attivita_ricerca/energia/sistema_elettrico/Censimento_biomasse/RSE167. pdf (accessed 21.03.2016).

Owen, R.W., Giacosa, A., Hull, WE, Haubner, R., Würtele, G., Spiegelhalder, B., Bartsch, H., 2000. Olive-oil consumption and health: the possible role of antioxidants. Review, Lancet Oncol., 1, 107–112.

Owen, R.W., Haubner, R., Würtele, G., Hull, WE, Spiegelhalder, B., Bartsch, H., 2004. Olives and olive oil in cancer prevention. Eur. J. Cancer Prev., 13, 319-326.

Paiano, A., Camaggio, G., Lagioia, G., 2011. Territorial level for biofuel production - Case study of an Italian region. Renew. Sust. Energy Rev., 15, 2222–2231.

Paiano, A., Lagioia, G., 2016. Energy potential from residual biomass towards meeting the EU renewable energy and climate targets. the Italian case. Energy Policy, 91, 161-173.

Pampaloni, B., Mavilia, C., Fabbri, S., Romani, A., Ieri, F., Tanini, A., Tonelli, F., Brandi, M.L., 2014. In vitro effects of extracts of Extra Virgin Olive Oil on Human Colon Cancer Cells. Nutrition and Cancer: An International Journal, 66, 1228-1236.

Pizzichini, D., Russo, C., Vitagliano, M., Pizzichini, M., Romani, A., Ieri, F., Pinelli, P., Vignolini, P., Phenofarm S.R.L. (Roma), Process for producing concentrated and refined actives from tissues and by-products of Olea europaea with membrane technologies. EP 2338500 A1, June 29, 2011.

Regione Puglia, 2012. Banca Dati Regionale del potenziale di biomasse in Puglia. Metodologia e Risultati. Progetto Probio.

Riva, G., Carrafù, L., Laboratorio Biomasse UNVPM, SIBE S.r.l., 2013. Stima della disponibilità nazionale di residui idonei per le applicazioni previste dal D.M. 6.7.2013 e del relativo contributo energetico, 16-38. Energia e dintorni. Supplement of October 2013 http://www.energiaedintorni.it/newsletter/2013_12_dicembre /Dossier_07bis.pdf (accessed 03.11.2015).

Roig A., Cayuela M.L. and Sánchez-Monedero M.A., 2006. An overview on olive mill wastes and their valorisation methods. Waste Management, 26, 960-969.

Romani, A., Scardigli, A., Pinelli, P., 2017. An environmentally friendly process for the production of extracts rich in phenolic antioxidants from Olea europaea L. and Cynara scolymus L. matrices. Eur. Food Res. Technol., 243, 1229–1238.

Romani, A., Ciani Scarnicci, M., Scardigli, A., Paiano, A., 2016a. Circular Economy as a New Model for the Exploitation of the Agroindustrial Biomass. Proceedings of the 20th IGWT Symposium "Commodity Science in a changing world", Varna (Bulgaria), 12-16 September 2016.

Romani, A., Pinelli, P., Ieri, F., Bernini, R., 2016b. Sustainability, innovation and green chemistry in the production and valorization of phenolic extracts from Olea europaea L. Sustainability, 8, 1-10.

Romani, A., Scardigli, A., Campo, M., Romani, M., Pinelli, P., 2015. Sustainable productive processes of polyphenol standardized fractions. 9th ISANH Congress Polyphenols Applications, St Julian's (Malta), June 3-5 2015, p. 175.

Stahel, W.R. The circular economy. Nature 2016, 531, 435–438.

Tafesh A, Najami N, Jadoun J, Halahlih F, Riepl H, Azaizeh H (2011) Synergistic antibacterial effects of polyphenolic compounds from olive mill wastewater. Evid Based Complement Altern Med 2011,1-9. Art ID 431021, doi:10.1155/2011/431021.

Tello, E., Galán, E., Sacristán, V., Cunfer, G., Guzmán, G.I., González de Molina, M., Krausmann, F., Gingrich, S., Padró, R., Marco, I., Moreno-Delgado, D., 2016. Opening the black box of energy throughputs in farm systems: A decomposition analysis between the energy returns to external inputs, internal biomass reuses and total inputs consumed (the Vallès County, Catalonia, c.1860 and 1999). Ecol. Econ., 121, 160-174.

Unaprol (Consorzio Olivicolo Italiano), 2018. Market Press. http://www.unaprol.it/index.php/osservatorio-economico/bollettino-dei-prezzi.html. (accessed 05.03.2018).